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Cognitive Abilities in Hearing Loss: Perceived and Performance Abilities of Adults Related to Attention, Memory, and Social Cognition

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COGNITIVE ABILITIES IN HEARING LOSS: PERCEIVED AND PERFORMANCE ABILITIES OF ADULTS RELATED TO ATTENTION, MEMORY, AND SOCIAL COGNITION

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in
the College of Public Health
at the University of Kentucky

By

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ABSTRACT OF DISSERTATION

COGNITIVE ABILITIES IN HEARING LOSS: PERCEIVED AND PERFORMANCE ABILITIES OF ADULTS RELATED TO ATTENTION, MEMORY, AND SOCIAL COGNITION

Hearing loss is the most common sensory deficit noted in aging adults. It is commonly known to reduce an individual's ability to detect, identify, and localize sounds and speech and to cause issues in communication. However, there are other less commonly discussed impacts that hearing loss has beyond the auditory system. Literature suggests a correlation between hearing loss and cognition in aging adults. Similar to hearing loss, the domains of cognition experience performance and functional changes across the life span. In an aging adult, changes related to cognition are also suggested to be associated with hearing loss. This study aimed to add to the corpus of literature surrounding the relationship between hearing loss and cognition, specifically memory, attention, executive functioning, and social cognition in adults with and without hearing loss.

The purpose of this multi-methods study was to describe if group differences in adults with and without hearing loss existed between perceived and performance-related cognitive abilities. The study focused on twenty-eight adults between the ages of 50-69 years; fourteen adults had normal hearing, while fourteen adults had hearing loss which ranged in the mild to moderate sensorineural range. Based on age and hearing loss, adults were separated into four distinct groups: normal hearing between the ages of 50-59 years, hearing loss between the ages of 50-59 years, normal hearing between the ages of 60-69 years, and hearing loss between the ages of 60-69 years. Performance-related cognitive abilities were assessed through five different cognitive assessments: the Weschler Memory Scale, Weschler Adult Intelligence Scale, Faux Pas stories, Advanced Clinical Solutions, and Bluegrass Short-Term Memory task. Perceived abilities were addressed through structured, open-ended questions that centered around the impacts of hearing and hearing loss and an individual's communication abilities.

The first aim examined how adults described the impacts of hearing loss and their communicative abilities. Individual responses highlighted what impacts adults thought hearing loss had beyond communication and their communicative abilities. The majority of adults expressed that they did not have any communication errors and could accurately express their own thoughts/viewpoints/emotions and understand others' thoughts/viewpoints/emotions. The second aim determined that group differences were present on memory subtests from the Weschler Memory Scale and a subtest from the Weschler Adult Intelligence Scale. While there was no significant difference between responses on the Bluegrass Short-Term Memory task, there was a group interaction on left frontal theta oscillation (memory & decision-making related), and right frontal beta frequency (attention-related) during data collection on EEG resting state eyes open. The final aim determined that there were group differences on the social cognitive assessment.

Auditory and cognitive processing have previously been viewed as separate and distinct factors that are crucial for communication, yet the growing body of literature suggests that these elements are actually intimately coupled. This research yielded evidence that even a mild HL in adults between the ages of 50-69 is associated with changes in cognitive functioning, specifically on memory, attention, and social cognition. Singularly, the auditory system and cognitive domains are each complex, yet these must be assessed as factors that have the potential to influence each other. The open-ended questions revealed that researchers and clinicians need to continue to address the wide-ranging impacts of hearing loss among adults. While adults did recognize impacts of hearing loss beyond communication, some participants also reported no thoughts on the impact beyond communication. This is a strong suggestion that adults need to be further educated about hearing loss as a critically prevalent public health matter.

KEYWORDS: Hearing Loss, Cognition, Memory, Attention, Social Cognition

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CHAPTER 1: INTRODUCTION

Hearing loss (HL) currently represents the most common sensory deficit in aging adults. In addition to being a chronic health issue, it entails a host of social implications as well (Mathers et al., 2006). Although age-related HL predominantly occurs in older adults, a decline in hearing can begin as early as an individual's third or fourth decade of life (NIDCD, 2018). It is widely known that HL causes issues with everyday communication, including interference not only with the ability to recognize speech in noisy environments but also with the ability to detect, identify, and localize sounds both reliably and quickly (Arlinger, 2003). Untreated HL is associated with declines in both well-being and quality of life, especially in the domains of depression and social engagement (Arlinger, 2003; Mick et al., 2014).

Research has revealed a correlation between HL and loss of cognitive function and performance (Uhlmann et al., 1986; Arlinger, 2003; Mathers et al., 2006; Lin et al., 2011; Surprenant & DiDonato, 2014). According to Frith & Frith (2008), cognition includes many different domains, such as memory, attention, and social cognition, by which humans understand and make sense of the world. Cognition also changes across the life span, and cognitive performance levels in general can start declining as early as the third decade in life and continue throughout the remaining life span (Salthouse et al., 1995). The current corpus of research has indicated an association between hearing loss and at least some of the six key domains of cognitive function, which are as follows: attention, executive function, memory, language, perceptual motor function, and social cognition (Arlinger, 2003; Mathers, Lopez, & Murray, 2006; Lin et al., 2011; Surprenant & DiDonato, 2014). Memory is the ability to encode, store, and retrieve information (Lezak et al., 2012) or

alternatively, is the capacity to retain information and utilize it for certain purposes (Fuster, 1999). Attention is a broad term that applies to the cognitive process that allows one to selectively concentrate on certain parts of available information and focus on a certain task (Anderson, 2008; Lezak et al., 2012). Social cognition comprises the various psychological processes that are necessary for individuals to engage in human interaction (Frith, 2008), a hallmark of which is the ability to process social cues in social contexts (Henry et al., 2015). This is of particular interest given that quality of life for aging adults is highly correlated with the quality of social interactions (Arlinger, 2003). Executive function enables a person to engage in appropriate, independent, purposive, and self-serving behavior. Executive functioning includes the ability to self-monitor, organize, plan, reason, and problem-solve (Harada et al., 2013; Lezak et al., 2012). While each domain has its own function, they are not independent from each other and a negative impact on one domain can create deficits in other domains. Due to the complicated nature of the interaction between these domains, a greater understanding of the impacts that HL has on all cognitive domains is warranted. Additionally, while the domains of memory and attention have attracted significant research consideration, there has been minimal exploration of social cognition and executive functioning in adults with hearing loss.

Research on HL and cognition in aging adults has tended to emphasize only the aggregated 65+ age group. This emphasis neglects the presence and potential impacts of precursor declines that start in the third and fourth decades of life (Salthouse et al., 1995; Arlinger, 2003; Mathers et al., 2006; Lin et al., 2011; Lin et al., 2013). This dissertation research was developed to fill some of the current gaps in knowledge regarding the

impacts that hearing loss may have on attention, memory, executive functioning, and social cognition in middle-aged adults.

1.1 Dissertation Research

A multi-methods study design was developed for this research to examine quantitative relationships between hearing loss and performance-related abilities in the cognition domains of attention, memory, executive functioning, and social cognition in adults between the ages of 50-69 years. Additionally, qualitative questions were posed which allowed for the layering-in of participant perceptions of HL and communicative abilities. Four overarching questions guided the research.

1.2 Central Questions, Specific Aims, and Hypotheses

This research involved a contemporary age group of adults between 50 and 69 years of age. There were two goals: first to explore the perception of the impact of HL and communicative abilities, and second to describe if group differences were present in adults with and without HL on performance-related abilities of attention, memory, and social cognition. A central hypothesis was that group differences would be present based on age and HL. Within the two primary goals and central hypothesis, three specific aims were identified.

Aim 1: To understand how adults (aged 50-69), with and without hearing loss, describe the impact of HL and their communicative abilities.

Question: How do adults between the ages of 50-69, including both those with and without hearing loss, describe the impact of HL and their communicative abilities?

Rationale: When describing the impacts of HL, previous literature often discusses the implications that HL has on communication. Besides communication issues, literature suggests that those with HL often experience social isolation, reduced quality of life and self-esteem, and shame or frustration (Strawbridge et al., 2000; Kramer et al., 2002; Dalton et al., 2003; Monzani et al., 2008; Lotfi et al., 2009; Pronk et al., 2013). Those with HL often exhibit issues in conversational fluency, defined in this context as communication with minimal struggle (Cassie & Rockwell, 1993; Cassie, 2000; Erber, 2002).

The most common method to report and describe the extent of hearing loss is with an audiogram, but research has found that perceptions of function vary widely despite similar audiogram results (Newman et al., 1997). Furthermore, even when the audiogram findings are similar, adults with hearing loss differ greatly in how a hearing loss impacts their health. As such, qualitative research and interviews have become critical in understanding the perspectives of adults with and without hearing loss (Laplante-Lévesque et al., 2012). While there has been numerous studies on the impact that hearing loss has on such things as memory and attention, none have assessed if adults perceive that their cognitive abilities have been impacted by HL (Uhlmann et al., 1986; Arlinger, 2003; Mathers et al., 2006; Lin et al., 2011; Surprenant & DiDonato, 2014). Additionally, research has lacked focus on understanding if aging adults with normal hearing are actively thinking about the implications that hearing loss may have beyond communication difficulties.

Hypothesis: No hypothesis is stated due to the qualitative nature of this question.

Aim 2: Describe group differences on social cognitive ability in adults 50-69 years old with and without hearing loss using performance-based social cognition/executive functioning assessments while controlling for health and lifestyle covariates.

Question: Are group differences present on social cognitive abilities in adults between the ages of 50-69 years with and without hearing loss while controlling for health and lifestyle covariates?

Rationale: An increase in age has been found to negatively impact an individual's social cognition (Moran et al., 2012). When compared to younger individuals (mean age of 23 years), older individuals (mean age of 71.8 years) responded less accurately to false belief stories and were unable to use actors' intentions when judging moral permissibility of behavior (Moran et al., 2012). Social cognition is crucial for daily human interactions and deficits could have an impact on social interactions which are affected by hearing loss. Parts of social cognition that were assessed include affect labeling, affect recognition from both faces and prosody, ability to identify sarcasm, the ability to verbalize intent of a speaker, facial memory (including face recognition), the recall of names, and the recall of pertinent information about a person from facial images. A clear relationship between age-related hearing loss and social cognition has yet to be identified. Social cognition is typically assessed using performance-based assessments since neurologically-based assessments of this domain remain inconclusive (McCleery et al., 2011).

Many variables are thought to influence an individual's cognitive health, both positively or negatively. These influences on cognitive health include genetic, environmental, and lifestyle factors (NIA, 2017). Genetic factors, such as age and sex, cannot be controlled by an individual; there is ample evidence that these factors have an impact on all aspects of cognition (Adenzato et al., 2017). With advancing age there is evidence that attention, memory, executive functioning, and social cognition experience negative impacts (Li-Korotky, 2012; Moran et al., 2012; Adenzato et al., 2017; Loughrey et al., 2018). Sex can also have an impact on cognition, particularly social cognition. Other factors, such as environmental and lifestyle factors, can be controlled by an individual. These factors can include overall health, education, physical activity, diet, brain injuries, smoking and alcohol, depression, leisure activities, and social isolation and loneliness (Holland & Rabbitt, 1991; Brayne et al., 2007; Salthouse, 2009; Kim & Park, 2017). These factors have been found to have an impact on cognitive functioning in older adults and thus should be considered covariates (Kim & Park, 2017). A covariate is any variable that may be measurable and is considered to have a statistical relationship with a dependent, or response, variable (Salkind, 2010). Covariates can be an explanatory or predictive variable of the dependent variable. Covariates are crucial to control within a research study since they may interact with the independent variable(s) within a study and may obscure the actual relationship between the independent and dependent variable(s), thus causing a misinterpretation of the study results. The effect of covariates can be eliminated, minimized, or manipulated through effective experimental design

(Salkind, 2010). Typically, such experimental control can eliminate certain common covariates, such as age, sex, and ethnicity of participants. While not all covariates are knowable prior to conducting a study, it is important to attempt to control the effect of covariates when they are known since they can cause biased results and experimental errors (Salkind, 2010).

Hypothesis: Group differences will be present on social cognitive performance-based assessments even when covariates are controlled.

Aim 3: Describe group differences on cognitive function (specifically attention and memory) in adults 50-69 years old with and without hearing loss using cognitive performance assessments and neurologically-based tests while controlling for health and lifestyle covariates.

Question: Are group differences present on cognitive function (attention and memory) in adults between the ages of 50-69 years with and without hearing loss as indicated by cognitive performance assessments and neurologically-based tests while controlling for health and lifestyle covariates?

Rationale: When assessing the effects of hearing loss on cognitive load, previous research determined that in conditions where hearing loss is present, greater cognitive resources are dedicated to the auditory system and auditory processing (Pichora-Fuller et al.,1995; Wingfield & Grossman, 2006; Tun et al., 2009; Li-Korotky, 2012; Loughrey et al., 2018). When this occurred, other cognitive resources were affected negatively and resulted in declines in working memory, overall attention, processing speed, and a decline in semantic, immediate, and

episodic memory (Pichora-Fuller et al.,1995; Wingfield & Grossman, 2006; Tun et al., 2009; Li-Korotky, 2012; Loughrey et al., 2018). Cognitive abilities are often evaluated utilizing performance-based assessments (Harvey, 2012). These performance-based assessments require an individual to exercise certain skills in the presence of an examiner; however, the end product of these assessments can be greatly impacted by a research participant's behavior (Harvey, 2012; Gevins et al., 2012). For instance, a non-impaired individual who is not motivated to do well on these assessments may have poor performance-based assessments scores, but not have an issue with their cognitive abilities (Gevins et al., 2012). As such, performance-based assessments can have limited sensitivity and specificity if alertness or motivation is affected. Research has suggested that performance-based assessments can be impacted by confounding variables, whereas neurologically-based tests may not be (Harvey, 2012; Gevins et al., 2012). Such neurologically-based tests include computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and electroencephalography (EEG). Neurologically-based tests allow researchers to factor physiological brain activity in analyses of data on cognitive performance. Previous research to track changes in memory favored functional magnetic resonance imaging (fMRI). Task-controlled EEG testing, as used in this dissertation research, offers a less expensive approach to imaging while providing more information within a smaller time-frame than is possible with fMRI. (Gevins et al., 2011). As stated in Aim 2, the interaction that covariates may have on this relationship will be assessed and controlled.

Hypothesis 1: Group differences will be noted on attention and memory assessments even when covariates are controlled.

Hypothesis 2: Short-term memory abilities on EEGs will show group differences even when covariates are controlled.

1.3 Innovation

The current research supports ongoing scholarship examining the relationship between hearing loss and all cognitive domains. While research is currently assessing memory and attention in those with and without hearing loss, this dissertation research is the first to examine the relationship of HL and social cognition. This is crucial since successful social interactions form a cornerstone of the quality of life in an individual. Additionally, a more thorough understanding about the extent of the relationship between hearing loss and cognitive abilities in middle-aged adults could help identify interventions that may offset or delay such deficits. Current research on HL and cognition often assesses adults who are over the age of 65, while neglecting adults who, though earlier in life, are already experiencing age-related changes to the brain and ear. Additionally, by applying a short-term memory task paired with EEG testing, this research also incorporates an objective method of quantifying cognitive processes.

1.4 Outline of Dissertation

The remaining chapters follow the development of this dissertation research from initial conception, based on the extant literatures dominantly within audiology and psychology, through research design strategies and completion of data analyses and presentation of findings. Chapter Two discusses the background and significance of the

study. This chapter provides background information on neural anatomy, cognition, hearing and hearing loss, and the relationship between hearing loss and cognition. Furthermore, the second chapter provides information needed to understand the reasoning of this research and sets up the basis of knowledge behind the theoretical and conceptual framework. The third chapter focuses on the aforementioned theoretical and conceptual framework which underpins the research. This chapter provides the reasoning and thought processes that the researcher had in creating this research, specifically the aims and hypotheses. Chapter Four includes the design of the study, including study sites, participants, and assessments used. This chapter details the steps, assessments, and subtests that comprise this research, and the cognitive domains that the assessments examined. Chapters Five outlines the findings from each survey, assessment, and subtest as well as the statistical analyses performed. Chapter Six outlines the discussion, reviews the limitations of the study, details potential future research, and summarizes the study. As a whole, this dissertation seeks to fill in the gaps in the corpus of research that surrounds the intricate relationship between HL and cognition in adults.

CHAPTER 2: BACKGROUND AND SIGNIFICANCE

This research centers around the relationship between HL and cognition, specifically the domains of attention, memory, and social cognition. This chapter covers a varied range of related topics in an effort to provide a holistic foundation for exploring the aforementioned relationship. Background information is provided on the anatomy of the brain, specifically the parts necessary for the aspects of cognition listed above, as well as brain structure and function and the tests used to assess these elements. After the structure and function are discussed, background is provided on cognition and the cognitive domains, as well as sensory issues related to hearing and HL. Ultimately, subsequent discussion addresses how these factors may indeed be linked.

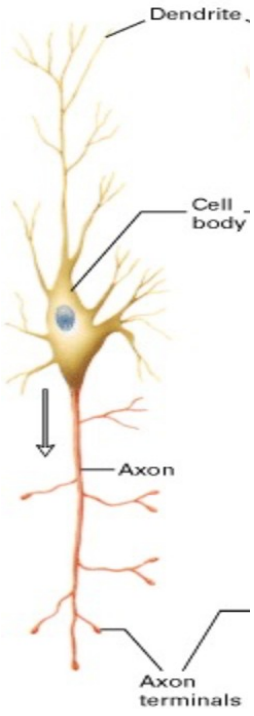
2.1 Neural and Brain Structure and Function

The brain is a three-pound organ that is the control center for a human's body functions. In a full-grown male, the brain, on average, weighs 1336 grams; a female brain averages 1198 grams. This weight difference between the two sexes has no effect on function (Jawabri & Sharma, 2019). The brain is a complex and dynamic organ: each individual structure is associated with a specific function, yet all of the structures must work together in order to work properly and efficiently. These functions are managed by the nervous system, which is divided into two primary aspects: the central nervous system (CNS) and the peripheral nervous system (PNS). The dominant elements of the CNS are the brain and spinal cord. The PNS contains nerves that connect the CNS to all parts of the body (Mendoza & Foundas, 2008).

The CNS

The CNS is comprised of two different types of cells: neurons and glia. Neurons are the cells responsible for the brain's activity; there are billions of them arranged in circuits and sub-circuits. There are three main elements that make up neurons: dendrites, axons, and soma. Dendrites are tree-like filaments that allow neurons to receive input/ information from other cells. Axons can be described like tree roots and are responsible for the transmission of information between neurons. The soma, or cell body, is where the nucleus is located. Through nerve impulses, neurons transmit information throughout the nervous system to the brain; the number of these neurons present is purported to range from ten billion to one trillion neurons (Kandel, et al., 2000; Herculano-Houzel, 2009; Lezak, 2012). Figure 2.1 below provides a visualization of the structure of a neuron.

Figure 2.1: Structure of a Human Neuron (Lodish et al., 2000)



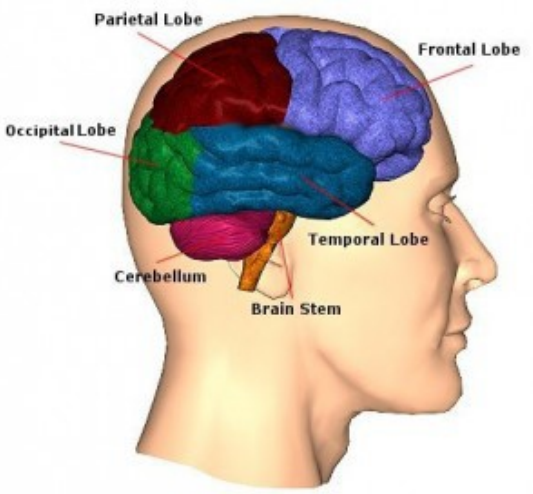
Glia perform multiple functions, such as modulating the rate of nerve signal propagation, providing a scaffold for neural development, aiding in recovery when neural injury is present, maintaining the ionic milieu of nerve cells, and controlling the uptake of neurotransmitters (Purves et al., 2001). These cells maintain homeostasis/equilibrium, lay down myelin, and aid in removing cellular debris from cell death (Purves et al., 2001). All are essential to maintain healthy neural function. It is estimated that glial cells are 10 to 50 times more prevalent than neurons (Levitan & Kaczmarek, 2002; Jäkel & Dimou, 2017). Without glial cells, neurons and synapses would fail to function properly (Jäkel & Dimou, 2017).

The CNS is composed of two types of tissues: gray and white matter. Gray matter consists of neuronal cell bodies, dendrites, unmyelinated axons, glial cells, synapses, and capillaries (Mercadante & Tadi, 2020). Gray matter is present on the surface area of the brain and inside the spinal cord and is responsible for processing information. Gray matter is fully developed in the second decade of an individual's life. In contrast, white matter is found in the deeper tissues of the brain and contains nerve fibers (axons). White matter derives its name from the electrical insulation, or myelin, which coats the axons and is critical for high-speed transmission of electrical impulses. Damage to the myelin can impair the conduction of these impulses and consequently impact sensory, motor and cognitive functions (Fields, 2010)

Myelination of the brain continues until approximately the third or fourth decade of age. The frontal region of the cerebral cortex is the last area of the brain to become myelinated (Raz et al., 2005; Fields, 2010). Neural development is a complex, dynamic, and adaptive process. These developmental stages result in the brain splitting into three

main divisions: cerebrum, cerebellum, and brain stem (Muller, 2005; Jawabri & Sharma, 2019). The cerebrum represents the largest part of the brain and is comprised of two cerebral hemispheres and their cortices (Lezak, Howeison, Loring, 2004). The cerebrum as a whole processes sensory information, controls movement, and allows for the formation of conscious and unconscious actions. The longitudinal fissure separates the cerebrum into right and left hemispheres. The two hemispheres are connected by the corpus callosum (a thick bundle of nerve fibers), which allows for communication between the hemispheres. In simplistic terms, the right hemisphere is responsible for spatial thinking, while the left is responsible for speech, language, and abstract thoughts. Each hemisphere controls the contralateral side of the body, meaning that the left hemisphere controls the right side of the body while the right hemisphere controls the left. Two further prominent fissures separate the cerebral hemispheres into four lobes: the frontal lobe, parietal lobe, occipital lobe, and temporal lobe (Lezak, Howeison, Loring, 2004). Figure 2.2 provides a visual of the structure of the brain.

Figure 2.2: Structure of the Brain (Northeastern University, 2010)



The frontal lobe is the largest portion of the cerebral hemispheres. Behind the frontal lobe is the parietal lobe, which can be separated into two functional regions: anterior and posterior. The anterior parietal lobe contains the primary sensory cortex (SI) while the posterior parietal contains the somatosensory association cortex and secondary somatosensory cortex (SII). The second largest region of the cerebral hemispheres is the temporal lobe, which can be separated into the lateral and medial surfaces. The lateral surface contains the superior temporal sulcus and lateral temporal sulcus. It is divided into three gyri: the superior temporal gyrus (STG), middle temporal gyrus (MTG), and inferior temporal gyrus. The smallest and most posterior portion of the brain is the occipital lobe (Lezak, Howeison, Loring, 2004). The general functions of each lobe are explained in Table 2.1 below (Huff, Mahabadi, & Tadi, 2019).

Table 2.1 Functioning of the Lobes of the Brain

Lobe	Function	
Frontal	-Prospective memory	-Social skills
	-Speech and language	-Movement functions
	-Personality	
	-Decision making (planning/reasoning/problem solving)	
	-Recognizing and regulating emotions	
Parietal	-Interpreting somatosensory signals	
	-Learning	-Spatial recognition
	-Language	-Reading
	-Sensorimotor planning	-Stereognosis

Table 2.1 (continued)

	-Phonological representation	-Semantic retrieval
Temporal	-Sound recognition and control	-Semantic memory
	-Visual perception	-Facial perception
	-Declarative memory	-Recognition
	-Episodic memory	-Recollection
	-Familiarity	
	-Translating and processing all sounds and tone	
Occipital	-Visual Processing	-Interpretation

While the research questions addressed in this study are mainly focused on information processed within the frontal and temporal lobes, the parietal and occipital lobes are equally important. For example, although the occipital lobe processes and interprets visual information, this information is also sent to the temporal lobe for further analysis (Huff, Mahabadi, & Tadi, 2019). So, while each lobe has its primary functions, other lobes do assist in receiving, processing, and interpreting all information. While research has determined primary functions of lobes, more research is still needed to enhance understanding of how the different lobes operate as integrated units.

The fully formed hindbrain, located within the lower part of the brainstem, contains the medulla oblongata, the pons, and the cerebellum. The hindbrain contains the centers for control of respiration, digestion, blood pressure, and heartbeat. The medulla contains nuclei that are necessary for speech, swallowing, and other functions related to the pharynx and oral cavities. The pons sits higher in the hindbrain and contains the major pathways for fibers that connect the cerebral cortex and the cerebellum. The pons is responsible for control of sleep, respiration, equilibrium, and eye movement. Motor

impulses relayed from the cerebrum are sent to the pons and cerebellum to regulate these motor impulses. The cerebellum has multiple connections throughout the brain, with linkages to the hypothalamus, spinal cord, and brain stem nuclei. The midbrain includes the reticular activating system, whose primary function is to coordinate sleep-wake cycles and wakefulness (Garcia-Rill et al., 2013). It is ultimately within the midbrain where auditory and visual processing occurs, allowing for reflexes and autonomic responses in the presence of both types of stimuli. The forebrain includes the thalamus, hypothalamus, and cerebrum. The thalamus is known to have a significant role in relaying both sensory and motor signals to the cerebral cortex and therefore has a key role in auditory function. The thalamus also receives afferent input from the amygdala, temporal cortex, hypothalamus, and other thalamic nuclei. The hypothalamus is important in regulating body functions and coordinating autonomic and endocrine function. Certain behavior patterns are associated with the hypothalamus, such as rage and fear.

The PNS

The PNS consists of the nerves and ganglia that are found outside of the brain and spinal cord; this includes the cranial nerves from the brain and the nerves that branch from the spinal cord, spinal nerves, and peripheral nerves. The structure and function of the PNS is an essential transmission link between the peripheral end organs of the body (ear, eye, nose) and the CNS. While the PNS is separated into the autonomic nervous system and the somatic system, the questions in this study focus on the latter.

The somatic nervous system consists of 12 pairs of cranial nerves (CN) and 31 pairs of spinal nerves (Watson et al., 2010). CNs emerge directly from the brain and brainstem, while the spinal nerves emerge from the spinal cord. CNs are generally named

according to their function and/or structure. The main function of the CNs is to relay information between different parts of the body and the brain. CNs can be sensory, motor, or both, and they are numbered based on their rostral-caudal position. A breakdown of the cranial nerves can be seen in Table 2.2.

Table 2.2 Cranial Nerves, Functions, and Type

Nerve	Function	Type
CN I- Olfactory	Sense of smell	Sensory
CN II- Optic	Relay visual information from retina to brain	Sensory
CN III- Occulomotor	Eye movement and the ability to keep the eyelid open.	Motor
CN IV- Trochlear	Innervates the superior oblique muscle in the eye.	Motor
CN V- Trigeminal	Sensation and motor function in the face and mouth	Both
CN VI-Abducens	Lateral eye movement	Motor
CN VII- Facial	Controls muscles of the face and conveys taste from the anterior 2/3 of the tongue	Both
CN VIII- Vestibulocochlear	Hearing and balance information	Sensory
CN IX- Glossopharyngeal	Receives sensory information from the remaining 1/3 of the tongue, ear canal, pharynx, and tonsils	Both
CN X- Vagus	Gastrointestinal peristalsis, muscle movements in mouth and larynx, and heart rate	Both
CN XI- Accessory	Nerve controls of muscles that are in the shoulders and neck	Motor
CN XII- Hypoglossal	Tongue movements	Motor

2.1.1 Techniques to Study Brain Function

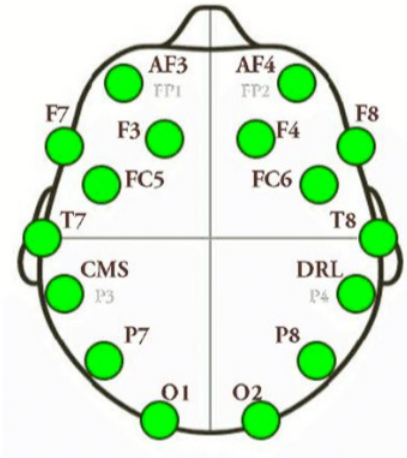
Researchers have developed multiple non-invasive techniques to study the complexities of the brain (Yuste & Church, 2014). Invasive techniques include microscopy, staining brain sections, histochemical staining, immunohistochemistry, common immunohistochemical markers, lectin stains, and cell culture (Watson et al., 2010). Non-invasive techniques include computed tomography (CT) scans, Functional magnetic resonance imaging (fMRIs), Positron Emission Tomography (PET), and Electroencephalography (EEG).

A CT scan is a collection of different X-ray measurements from a plethora of angles to create a three-dimensional image. These scans can show outlines of structures within the nervous system and can detect density variations. Using similar technology to MRIs, fMRIs detect differences in the flow of oxygenated blood levels in response to neural activity. During an fMRI, individuals are asked to perform a specific task (such as answering questions on a screen) which stimulates certain parts of the brain. In performing this task, the brain requires more blood volume to transport glucose to the active areas. This increase in blood flow creates an image which can be used to examine functional anatomy of the brain. PET scans yield a three-dimensional map, produced as a result of scanning the brain with a gamma ray detector over relatively long periods of time; to obtain this map, individuals are intravenously administered radioactive substances. EEGs represent electrical activity of the brain as recorded by placing multiple electrodes at different points on the scalp. EEGs can provide information about amplitude, timing, spatial distribution, and frequency composition of electrical potentials (Watson et al., 2010). These noninvasive techniques have been extremely important for

understanding the maturation of emotional, cognitive, and social functions of the brain structures, and therefore are of considerable interest to this research from a wider perspective; EEGs in particular were employed in this research.

Typically, EEG data is recorded from metal electrodes coated with conductive paste that are applied to the scalp and held in place by a cap, adhesive, or suction (Aminoff, 2012). The placement of the recording electrodes is based on the international 10-20 system, which describes four standard positions on the head: the nasion, inion, and right and left preauricular points (Figure 2.3). Odd number electrodes are located on the left side of the head while even numbers refer to the right side of the head.

Figure 2.3: International Electrode System (Li et al., 2017)



Note. AF= Anterior Frontal; CMS/DRI= Reference points; F=Frontal; FC= Frontal Central; O= Occipital Lobe; P= Parietal Lobe; T= Temporal Lobe

This system requires electrodes to be approximately 5-7cm apart. When neurons are activated, an electro-chemical current is produced; an EEG test measures this

electrical activity. These currents typically involve sodium, potassium, calcium, and chloride ions that are sent through channels in the neurons. Resulting electrical activity is measured by the scalp electrodes to produce graphic signatures based on specific energy characteristics, including frequency, amplitude, and distribution of electrical activity in resting state or external stimulation. Frequency is used to characterize electrical activity, which is often rhythmic. Frequency ranges of the EEG occur from 0.1-100 Hz. These frequencies are typically grouped into five brain wave classifications or rhythms: delta, theta, alpha, beta, and gamma (Teplan, 2002; Aminoff, 2012). Each different wave is associated with a certain brain function, all of which are discussed in the table below.

Table 2.3 Brain Wave Classification and Function (Teplan, 2002; Aminoff, 2012)

Brain Wave Classifications/Rhythm	Hertz	Brain Function
Delta	0.1-4	Sleep
Theta	4-7	Attentional Processing/ Working Memory
Alpha	7-13	Attentional Processing
Beta	14-30	Sensory Feedback
Gamma	32-100	Memory and Motor

Delta activity is mostly noted in infants or in deep sleep stages in older adults. This activity is often associated with subjects with cortical plasticity and is prominent in cognitive processing during event-related studies such as P300. Delta waves are the primary contributor to P300, which is an indicator of cognitive processing (Malik & Amin, 2017). Theta activity is noted in a drowsy state and is more common in children. Age has an impact on theta activity, with older adults showing lower amplitude theta

activity than younger adults and children (Teplan, 2002). This activity is noted during attentional processing and working memory. Depression in adults can have an impact on theta activity (Malik & Amin, 2017). Alpha activity may occur between 8-13 Hz but is most often noted to occur between 9-11 Hz in adults (Teplan, 2002). Alpha waves are noted during wakefulness and in relaxed states in adults (Malik & Amin, 2017). When eyes are closed with no mental activity, these waves are observed primarily in the parietal region. Cognitive tasks and attentional processing attenuate these waves. The peak frequency of these alpha waves is often an indicator of general intelligence (Grandy et al., 2013). Beta waves are observed in the frontal and central brain regions during anxious thinking, activeness, problem solving, and deep concentration (Gola et al., 2013). In individuals with high mental performance, these waves can be seen to increase in the occipital region during visual attention and spatial discrimination tasks. The activity of beta waves may be involved with cognitive processing and the motor system (Engel & Fries, 2010). Gamma waves are observed during conscious perception; unlike the earlier waves, gamma waves are not widely studied but are reported to be involved in attention, long-term memory, and working memory (Jensen et al., 2007). Gamma activity is seen in psychiatric disorders such as schizophrenia, hallucinations, Alzheimer's disease, and epilepsy (Herrmann & Demiralp, 2005).

2.1.2 Structural Age-Related Changes

There are normative (and expected) changes that occur in the brain as the individual advances in age (Peters, 2006). Changes in the brain due to aging have been found to occur both structurally and functionally. For example, multiple research studies have determined that the volume and weight of the brain decrease with age (Giedd et al.,

1999; Uttara et al., 2009; Terry & Katzman, 2001). After the age of 40, there is a decrease in brain volume of 5% per decade (Svennerholm et al., 1997). While the entire brain decreases in volume, certain brain regions are impacted more by age-related changes, as discussed below (Peters, 2006).

MRI and postmortem studies have provided evidence that gray matter volume begins to decrease around adolescence (Giedd et al., 1999; Sowell et al., 2003; Marsh et al., 2008; Uttara et al., 2009). Several researchers have proposed that reductions in gray matter are correlated with a reduction in number of neuronal cells, neuron size, and the number of neuron connections (Anderton, 2002; Uttara et al., 2009). MRI and cortical matching determined that there is a nonlinear decline in gray matter density (GMD) as age progresses (Sowell et al., 2003). The greatest nonlinear decline was seen between the ages of 7 and 60 years in most dorsal aspects of the frontal and parietal regions on both the lateral and inter-hemispheric surfaces. After the age of 60, there appears to be minimal to no decline in the GMD in these regions. However, in the temporal region, gains in GMD were noticed until the age of 30, with rapid declines occurring thereafter. These non-linear changes in GMD in different brain regions contribute to where age effects are noted in certain regions more so than others. A linear pattern has been revealed in which areas that myelinate early (the auditory, limbic, and visual cortices) are the first to lose myelination with increasing age. The posterior temporal cortices in the left hemisphere were found to have the most prolonged course of maturation than any other cortical region (Sowell et al., 2003).

After the age of 40, white matter volume begins to decrease (Bartzokis et al., 2001). Not only is there a decrease in the structure of white matter, but a decrease in the

function as well. Using diffusion tensor imaging, the integrity of white matter function declines as a result of the normal aging process. Due to the loss of white matter function, deficits in executive function can be noted on assessments (O'Sullivan et al., 2001). Greater decreases in brain volume were found to occur more in the frontal lobe than in the temporal lobe (Cowell et al., 1994; Marner et al., 2003).

Structurally, changes to both gray and white matter occur. Typically, the loss in both white and gray matter is noted in the prefrontal cortex. Gray matter loss in both the frontal and temporal lobes are linearly correlated with age, while white matter volume was found to increase in the frontal and temporal lobe until the ages of 44 and 47 respectively, after which a decline was seen (Bartzokis et al., 2001). Brain imaging research has suggested a greater loss in white matter than gray matter (Salat et al., 1999; Marner et al., 2003). Estimates suggest that there is an approximately 30% decrease of white matter over the course of aging (Marner et al., 2003). Furthermore, white matter shrinkage has been found in the precentral gyrus, gyrus rectus, corpus callosum, and the parahippocampal region (Meier-Ruge et al., 1992).

The degree of change due to age differs across the brain regions, with the frontal and prefrontal cortex experiencing the most loss of volume (Trollor & Valenzuela, 2001). Of all other brain structures, the occipital lobe is impacted the least with age. Although studies have found the majority of changes occur in the frontal lobe, research has not concluded if there are changes in the hippocampal region. Research states that hippocampal declines are not typically seen in the normal aging process but are seen in those with pathological cognitive aging (Hedden & Gabrieli, 2004), while other studies

suggest that the hippocampus is the brain region most impacted (Terry & Katzman, 2001; Anderton, 2002; Peters, 2006).

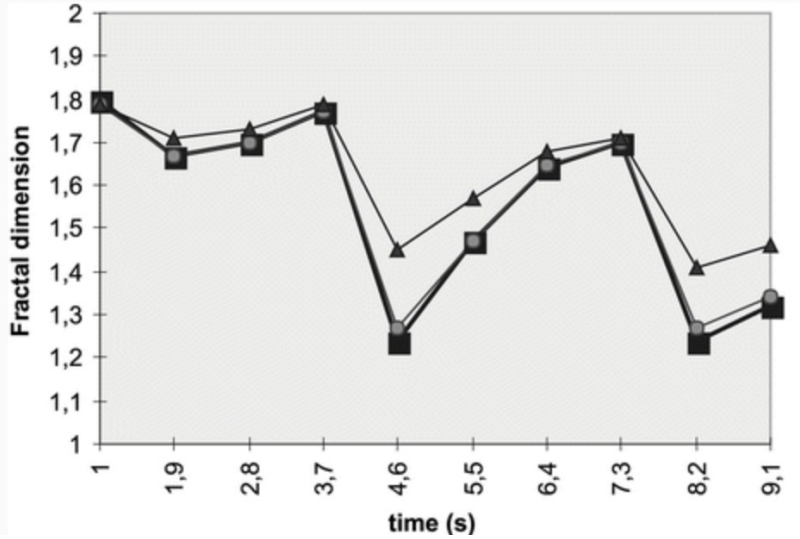
Research also suggests that there are sex differences in age-related brain changes. Specifically, males experience more change in the frontal and temporal lobes while females experience increased hippocampal and parietal lobe changes (Murphy et al., 1996). Regardless of sex, age has a major impact on volume loss. While volume loss begins after the age of 40, there is an acceleration of volume loss after the age of 70 (Svennerholm et al., 1997; Scahill et al., 2003). Using MRIs, researchers aimed to investigate the brain changes in healthy adults (n=76) (Coffey et al., 1992). From these MRIs, researchers determined that as a person ages, three main themes arise. The MRIs revealed a decrease in the volumes of the cerebral hemispheres (0.23% per year), the frontal lobes (0.55% per year), the temporal lobes (0.28% per year), and the amygdala-hippocampal complex (0.30% per year). Secondly, MRIs revealed an increase in volumes of the third ventricle (2.8% per year) and the lateral ventricles (3.2% per year). Imaging also revealed an increase in the odds of cortical atrophy (8.9% per year), lateral ventricular enlargement (7.7% per year), and subcortical hyperintensity in the deep white matter (6.3% per year) and the pons (8.1% per year) (Coffey et al., 1992). These findings reinforced the idea that the frontal cortex experiences the most change in volume as a person ages (Peters, 2006). Those who underwent the MRI studies were healthy individuals between the ages of 31-84 (N=39). Researchers determined that there were significant decreases in the temporal lobe and hippocampal volumes, but an increase in ventricular volume. The most marked changes occurred after the age of 70, during which

the increase in ventricular volume and decrease in hippocampal volume were seen to be most aggressive (Scahill et al., 2003).

A further study used MRIs to study the brains of 142 subjects between the ages of 21-80 years (Christiansen et al., 1994). Researchers assessed the number and size of the white matter hyperintensity lesions (WMHL) in the cerebral hemispheres as well as the volume of the cerebral hemispheres and lateral ventricles. WMHL appears to increase with increasing age, no matter the sex of the individual. A significant decrease in the volume of the cerebral hemispheres was found for older males, and a significant increase in the volume of the lateral ventricles was seen for both older males and females. Together these results suggest that with aging, central atrophy increases more than cortical atrophy. No correlation was found between the decreasing volume of the cerebral hemispheres and the increasing number and size of WMHL. Furthermore, no correlation was seen between the increasing volume of the lateral ventricles and the increasing number and size of WMHL.

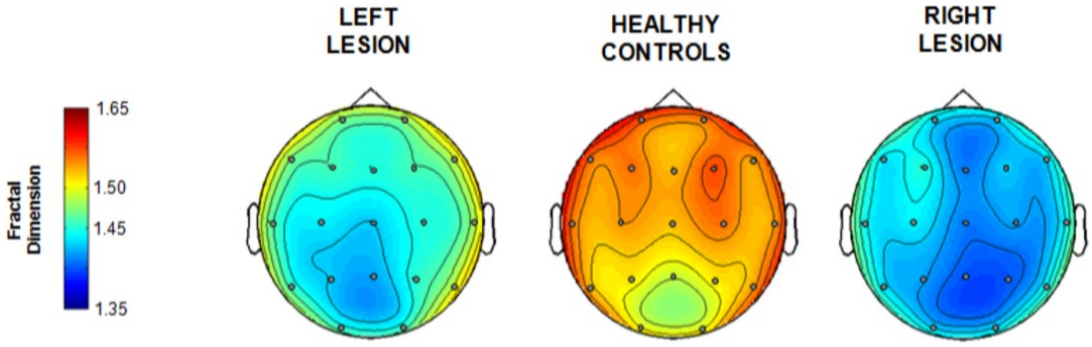
As expected, with the loss of synaptic connections and neuronal apoptosis due to the normal aging process, there are changes in brain functioning (Zappasodi et al., 2015). To highlight the functionality changes due to the aging process, EEG fractal dimensions have been assessed. The brain, due to its complexity and nonlinearity, cannot be measured by linear methods. Nonlinear methods, such as fractal analysis, are superior for these studies. From these measures, results can be shown visually based on changes of fractal dimension over time (Klonowski, 2016). Fractal dimensions allow for the processing and functioning of the brain to be captured and measured in a pattern. These fractal dimensions are displayed in Figure 2.4.

Figure 2.4: Fractal Dimension of EEG (Klonowski, 2002)



The EEG has one of the highest temporal resolutions of any of the neuroimaging techniques, which allows for localizations of electrical behavior in the brain. This localization allows researchers and clinicians to visualize specific areas electrical behavior in the brain. Based on the electrical behavior, a scalp topographic map can be created, which can be seen in Figure 2.5. These maps allow for visualization of electrical sources in the brain at certain depths (Duru et al., 2009).

Figure 2.5: Topographic Scalp Map in Stroke Patients and Healthy Adults (Zappasodi et al., 2015)



The differences in fractal dimensions noted in aging adults could be the result of reduced neural efficiency due to a decline in neurotransmitters, reduction of neural

networks, and loss of white and gray matter (Bäckman et al., 2006; Zappasodi et al., 2015). During visual perception and multisensory tasks, age-related changes caused a decrease in cross-hemispheric communication and a reduction of fractal dimensions across the entire scalp. An inter-hemispheric imbalance between the primary motor/premotor areas was also noted. The reduction of fractal dimensions was noted more in the left primary motor and premotor areas than in the right, which could point to potential compensation occurring. This inter-hemispheric imbalance is noted in theta, beta, and gamma bands.

2.2 Cognition

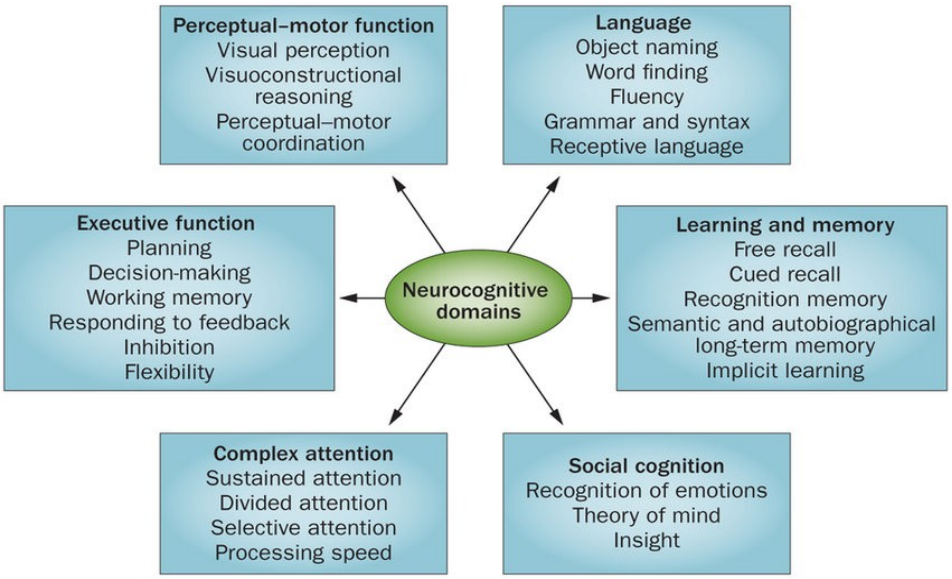
The earliest discussions on cognition began with Plato and Aristotle and continue to be researched today. In its simplest terms, cognition is any mental action or process of understanding and acquiring knowledge through experience, thought, and senses (Oxford, 2020). There are different processes that enable humans to function on many levels on a daily basis (e.g., learning, solving problems, and reasoning), forming a considerable indication of the complexity of cognition.

2.2.1 Neurocognitive Domains

The Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-V) determined that cognitive functioning can be separated into six key domains (American Psychiatric Association, 2015). Such separation allows clinicians and researchers to establish the etiology and severity of each neurocognitive disorder. The domains include executive functioning, complex attention, learning and memory, language, perceptual motor function, and social cognition. Each domain contains many different sub-themes, as illustrated in Figure 2.6 (American Psychiatric Association, 2015). The domains that

are particularly poignant to this research include memory, executive functioning, complex attention, and social cognition.

Figure 2.6: Neurocognitive Domains (APA, 2015)



2.2.1.1 Memory

Memory is the ability to encode, store, and retrieve information (Lezak et al., 2012). It is defined as the capacity to retain information and utilize it for certain purposes (Fuster, 1995). Memory involves a processing system that is made up of working/short-term memory and long-term memory. The short-term store, also known as working memory, receives selected inputs from both the sensory register and long-term store (Atkinson & Shiffrin, 1968). Long-term memory is responsible for the storage, management, and retrieval of information. Long-term memory is comprised of declarative (explicit) and procedural (implicit) memory, such as the memory of facts, events, and unconscious memory. Procedural memories are typically non-conscious, meaning that no thought is given to them (i.e., riding a bike or tying shoes). Declarative memories are memories that are consciously available. Declarative memory is considered

to have two subdivisions: episodic (memory for events) and semantic memory episodic (memory for facts) (Atkinson & Shiffrin, 1968; Baddeley, 1966; Riedel & Blokland, 2015). Memory as a whole is an ongoing process that changes continuously in an individual's everyday life based on new information being encoded, stored, and retrieved.

2.2.1.2 Executive Functioning

Executive functioning enables a person to engage in appropriate, independent, purposive, and self-serving behavior. Executive functioning includes the ability to self-monitor, organize, plan, reason, and problem-solve (Harada et al., 2013; Lezak et al., 2012). While there are six sub-themes under executive functioning in the DSM-V, the sub-theme of working memory is the focus of this research. Working memory is a blurred line between attention and memory. It is the temporary storage and workplace of the brain and is considered "the blackboard of the mind," which allows for one to process moment-to-moment information as well as archived information. Therefore, working memory represents the link which facilitates the storing of information into long-term memory (Just & Carpenter, 1992). Working memory is important in learning, higher-order thinking, and cognitive flexibility. It is linked to arithmetic skill, reading, verbal fluency, and problem-solving and adapting. Working memory is considered to have three parts: phonological loop, visuospatial sketchpad, and the central executive. The phonological loop stores verbal information with a rehearsal mechanism. The visuospatial sketchpad processes and analyzes visual information for manipulation in short-term memory. The central executive, in turn, controls both the phonological loop and visuospatial sketchpad. The central executive delegates work to both systems in order to facilitate coordinated reasoning, comprehension, learning, and decision-making

(Baddeley et al., 1974). Baddeley (2000) included the episodic buffer into the components needed for working memory. This element is thought to link information across domains to integrate visual, spatial, and auditory information.

2.2.1.3 Complex Attention

Attention is a broad term that applies to the cognitive process that allows one to selectively concentrate on certain parts of available information (Anderson, 2004). Attention is the ability to concentrate and focus on a certain task (Lezak et al., 2012). Per the DSM-V, attention can be categorized into four different types: sustained, selective, divided, and processing speed. Sustained attention is the ability to focus on one specific task for a long period of time. Selective attention is the ability to ignore irrelevant information while focusing on specific information. Divided attention is the ability to focus on multiple different stimuli or tasks simultaneously (Lezak et al., 2012). Processing speed refers to the rate at which cognitive processes can be carried out, including the rate at which individuals can complete basic cognitive functions with reasonable accuracy, such as item identification or discrimination (Fry & Hale, 2000; Salthouse, 2012). Both working memory and processing speed develop over time and are considered elements of intelligence. Current research suggests that both constructs are fully developed in the later teenage years (Daneman & Carpenter, 1980; Just & Carpenter, 1992).

2.2.1.4 Social Cognition

Social cognition refers to the brain's processing of social information, such as the ability to determine others' emotions and how to respond to those emotions appropriately (Henry et al., 2015). Frith (2008) stated that social cognition is the various processes that

enable people to be a part of a social group. Harvey and Penn (2010) described social cognition as a set of processes that allow one to recognize, understand, use, and process social cues that are present in real-world situations, while Penn et al., (2008) described social cognition as the array of abilities that are involved in social situations. Social cognition allows individuals to recognize social signals which permit us to interact and learn about the world. Social cognition skills are critical for mental health and successful communication (Henry et al., 2015). Declines in social cognition present themselves as poor theory of mind, impaired social perception, and poor emotion recognition. As seen above, the definitions of social cognition are often vague and rarely all-encompassing since there are many domains of social cognition. The DSM-V states that there are three sub-themes of social cognition: recognition of emotions, theory of mind, and insight. Other research suggests that there are five areas of social cognition: theory of mind, social perception, social knowledge, attributional bias, and emotional processing (Green & Leitman, 2008; Harvey & Penn, 2010).

Each of the aforementioned areas defines a particular facet of social cognition. Theory of Mind (ToM) is the ability to attribute beliefs, desires, emotions, intents, and knowledge onto oneself and others. It is also the ability to understand that others' beliefs, desires, emotions, intents, and knowledge may be different from one's own (Frith, 1992). Social perception is the ability for a person to identify social roles, social context, and societal rules. Humans identify these aspects by gathering information based on physical appearance, in addition to non-verbal and verbal cues. These cues may include gestures, body movement and positioning, facial expression, and tone of voice (Toomey et al., 2002; Sergi & Green, 2003). Social knowledge, otherwise known as social schema, is the

awareness of the goals, rules, and roles that govern social interactions and social situations (Corrigan & Green, 1993; Subotnik et al., 2006). Social knowledge is thought to overlap with social perception, since social knowledge requires awareness of which cues occur in specific social situations and how one is expected to respond to such cues. Social knowledge is considered an integral first step for adequate social competence (Bellack et al., 1994). Attributional bias is the ability to infer the causes of negative or positive events. Attributions are causal statements that are a type of verbal behavior found commonly in speech. Attributional bias is typically measured by using questionnaires, transcripts, or interactions (Kinderman & Bentall, 1996). Emotional processing is the ability to perceive and understand emotions and is thought to have four components: identifying emotions, understanding emotions, facilitating emotions, and managing emotions (Mayer et al., 2003). When any of the aforementioned domains are affected, a reduction in social functioning can be observed (Couture et al., 2006).

2.2.2 Age-Related Changes to Neurocognitive Domains

Normal age-related brain changes can have an impact on an individual's quality of life and day-to-day functioning; as a result, it is becoming far more important to understand these changes. Since the changes discussed above are normal and expected changes, there is no prevalence data on normative cognitive changes (Harada et al., 2013). This area of research on normative cognitive decline and determining the prevalence of such declines may assist in the growing body of research to distinguish normal from disease states (Harada et al., 2013).

Similar to the structural changes in the brain, there are normative and abnormal age-related changes to the neurocognitive domains. While every adult will not develop

mild cognitive impairment (MCI) or dementing conditions of various types, most if not all will experience subtle cognitive changes. Even these subtle cognitive changes can have impacts on a person's quality of life and everyday function. Numerous studies show a correlation between age and cognitive decline, but the age at which a cognitive decline becomes evident is a subject of considerable debate (Brayne et al., 2007; Holland & Rabbitt, 1991; Salthouse, 2009).

There are normal cognitive changes that accompany aging (Harada et al., 2013). These are important to understand due to the impact that they can have on an aging person's daily function. It is crucial to note that not all cognitive changes result in a decline, since some cognitive functions improve with age or are resilient to the aging brain. Sub-themes such as vocabulary and general knowledge tend to remain stable or even improve until the sixth to seventh decade of a person's life (Lezak et al., 2012; Salthouse, 2012). On the other hand, fluid intelligence, which refers to the ability to problem-solve and to reason novel problems independent of previous knowledge, tends to experience declines with age (Lezak et al., 2012). The domains of executive function, processing speed, and psychomotor ability, tend to peak in the third decade of life and then steadily decline. The decline is mostly seen in processing speed and psychomotor ability at a rate of -0.02 standard deviations per year (Salthouse, 2012).

Processing speed typically starts declining around the age of 30. This decline continues to decline throughout one's life (Salthouse et al., 1995). Given that processing speed includes the rate at which cognitive abilities are executed as well as motor responses, a decline in this domain can impact performance on other domains (Salthouse, 2012; Harada et al., 2013). Attentional decline is observed in selective

attention and divided attention. In terms of executive functioning, certain sub-themes decline while others remain stable. After the age of 70, a decline in concept formation, abstraction and mental flexibility, response inhibition, speed motor components, and reasoning with unfamiliar material is noted (Salthouse, 2012; Hayden & Welsh-Bohmer, 2011). Around the age of 45, deficits can be seen in verbal and mathematical reasoning. In contrast, some skills are stable: the ability to describe the meaning of proverbs, reason about familiar material, and appreciate similarities remain stable as one ages (Singh-Manoux et al., 2012).

In terms of memory, longitudinal studies have determined that declines typically begin around the age of 60. Certain functions remain preserved throughout the lifespan, up until the latter stages in life: specific examples of these functions include semantic memory and short-term memory. There are also some functions that are relatively untouched during the aging process, such as emotional memory, autobiographical memory, and implicit memory (Hedden & Gabrieli, 2004). Memory is often the most common cognitive complaint among aging adults. Episodic memory declines are seen throughout life, while semantic memory typically experiences declines that begin in late life (Ronnlund et al., 2005). Delayed free recall, source memory, and prospective memory also decline with age. Delayed free recall is the ability to spontaneously (after a delay period) retrieve information from memory (the "free" descriptor is used because the recalled items do not need to be recounted in any particular order).

These changes may be due to the slower processing speed, decreased use of ways to improve memory, and a reduced ability in selective attention (Luszcz & Bryan, 1999; Isingrini & Taconnat, 2008). The rate at which we acquire new information and retrieve

information declines throughout the lifespan as well (Haaland, Price, Larue, 2003). However, as briefly noted above, not all aspects of memory decline with age. Non-declarative memory remains unchanged throughout a person's lifespan. Recognition memory, temporal order, and procedural memory remain stable throughout the lifespan. Recognition memory is the ability to retrieve information when given a cue. Temporal order memory is the ability to remember the correct time or sequence of past events. Procedural memory is the ability to remember how to do things (Harada et al., 2013). In a longitudinal study of British civil servants (n=7,390) between the ages of 45-70, two key findings were determined from cognitive assessments (Singh-Manoux et al., 2012). First, a decline in all cognitive domains, except vocabulary, was noted for all age groups. The second finding suggests that cross-sectional data may not provide the most reliable estimates of age-related decline. Cross-sectional data can conflate the effects of age with differences in birth cohorts as a result of a variety of factors. This particular study determined that the data overestimated decline in women but not in men, which they suggest was due to cohort differences in education (Singh-Manoux et al., 2012).

Social cognition also reveals a decline in the ability to determine intentions and accurately identify false beliefs (Moran et al., 2012). Research on social cognition suggests that impairments may occur more in tasks that require mentalizing, or the process used to determine and understand what others are thinking or feeling (Moran et al., 2012). Compared to the other cognitive domains, the effects of aging on social cognition has not been researched in any particular depth. Further research is needed to understand the changes that occur in this cognitive domain. Table 2.4 provides a quick summary of normative age-related changes in each cognitive domain.

Table 2.4 Age-Related Changes to Cognitive Domains

Domain	Age-Related Changes
Executive Functioning	Subthemes start declining around the third or fourth decade of life
Memory	Subthemes that remain stable include non-declarative memory, recognition memory, temporal order, and procedural memory. All other subthemes decline.
Attention	All subthemes note a change
Social Cognition	Impairments in understanding false belief stories and determine intention

2.3 Hearing and Hearing Loss

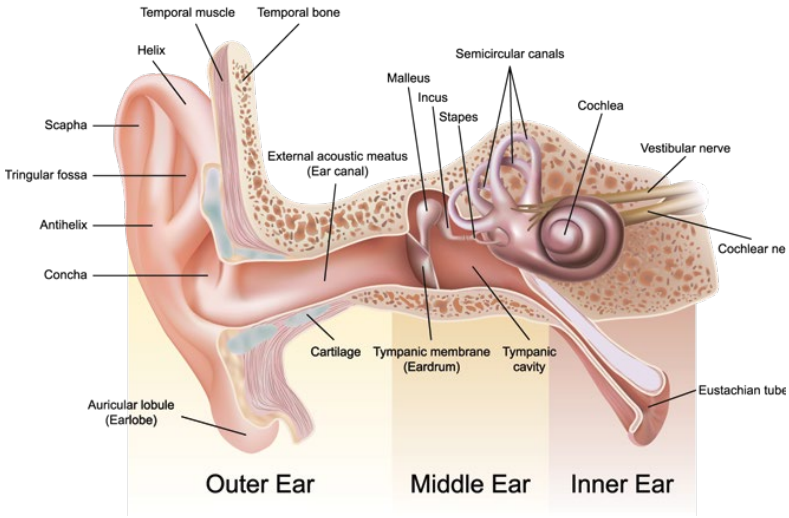
The brain has yet another function: to process sensory information. Sensory information is obtained from the five basic senses: hearing, sight, smell, taste, and touch. This information allows for the brain to make sense of the world. The sensory information most important to this research is obviously hearing. Information from this sense is sent from the ears, paired organs located on and within the temporal bones of the head. The main function of the ears is to convert sound waves to encoded nerve impulses, the result of which allows humans to perceive sounds (Alberti, 2001). The process of hearing is intricate; the basics, however, are discussed below.

2.3.1 Ear Anatomy

The ear can be separated into three parts: the outer ear, middle ear, and inner ear. Figure 2.7 provides a visualization of the anatomy of the ear. The outer ear is comprised of the pinna and ear canal. The pinna is attached and protrudes from the side of the skull in such a way that it collects sound vibration from the environment. Vibrations are then channeled into the ear canal, which is approximately four centimeters long. The ear canal

has a slight bend once the outer cartilaginous part becomes thin-skinned and bony. The bend in the canal is a protective mechanism that hinders objects from reaching the tympanic membrane (TM), which marks the start of the middle ear (Alberti, 2001).

Figure 2.7: Anatomy of the Ear (NIDCD, 2016)



The TM is a membrane comprised of a stiff fibrous middle layer. It is approximately 1/10th of a millimeter thick and covers an opening that is approximately one centimeter in diameter. Beyond the membrane, the middle ear is an air-filled space that is connected to the back of the nose via the Eustachian tube. Three bones (malleus, incus, and stapes) are located in the middle ear. The handle of the malleus is embedded within the center of the TM, while the head of the malleus is suspended by a ligament. The head of the malleus articulates with the incus. In turn, the tip of the incus is connected to the stapes. Part of the stapes, called the foot plate, covers the oval window that functions as the opening into the vestibule of the cochlea; this represents the beginning of the inner ear (Alberti, 2001).

The cochlea is a bony, snail-like structure that houses a membranous labyrinth containing approximately 30,000 hair cells; this structure transduces vibrations into

neural impulses to 19,000 nerve fibers which transmit signals to the brain. The labyrinth is separated into two outer sections (scala vestibuli and tympani) and an inner section (scala media). Both outer sections are filled with perilymph, while the inner section is filled with endolymph. The scala vestibuli is connected to the oval window while the scala tympani is connected to the round window (the oval window is positioned above the round window). Both windows are covered by a fibrous membrane that moves in an opposite yet synchronous phase with each other. Two membranes, Reisnner's and basilar, separate these two outer sections from the endolymph-filled scala media, or cochlear duct. While the basilar membrane is a continuous, single structure, the width, stiffness, and mass changes along its length. The different properties along the basilar membrane determine its characteristic frequencies, with high frequency sounds being localized near the base of the cochlea and low frequency sounds localizing at the apex. Thus, human pitch discrimination ability is attainable because of these physical property differences; this will be discussed further. Along the base of the basilar membrane there are four rows of hair cells. These hair cells assist in taking impulses from the brain to the cochlea (efferent pathways) and from the cochlea to the brain (afferent pathways) (Alberti, 2001).

2.3.2 Physiology of Hearing

A human's auditory system can detect frequencies from approximately 20 to 20,000 hertz (Hz) with an amplitude between -10 to 130 decibels. The pinna functions as a funnel for sound waves to be sent through the ear canal, a stimulus which forces the TM, malleus, incus, and stapes to vibrate. As the stapes vibrates, the foot plate of the stapes moves back and forth from the oval window. This disturbance at the oval window causes a disruption in the perilymph, creating traveling waves along the basilar membrane that create peaks in different regions depending of the pitch of the sound.

Specifically, high pitched sounds produce peaks near the base of the basilar membrane, while low pitched sounds create peaks nearer the apex. When the basilar membrane is rocked by the traveling wave, the cilia of hairs cells are bent corresponding to their place along basilar membrane with lower pitches bending cilia near the apex and higher pitches near the base. Consequently, when a particular hair cell is stimulated, afferent fibers are triggered, and neural impulses correlated with the pitch of the sound that is present are transmitted to the brain via the VIIth cranial nerve (Hallowell & Silverman, 1970; Alberti, 2001). Impulses are sent along a chain beginning at the cochlear nuclei, continuing along the superior olivary complex, lateral lemniscus, inferior colliculus, medial geniculate nucleus, and finally terminating at the auditory cortex. This terminus, the auditory cortex, is located in the superior temporal gyrus under the lateral fissure (Alberti, 2001).

2.3.3 Age-Related Changes to the Auditory System

There are also age-related changes to the entire auditory system. In the outer ear, the cartilaginous portion of the external auditory canal may collapse due to age (Chandler, 1964). In the middle ear, the tympanic membrane and ossicular chain both stiffen, which can cause a decrease to the vibrations which reach the basilar membrane in the cochlea (Belal, 1975). Within the cochlea there can be metabolic and vascular changes as well as a loss of sensory cells and cochlear neurons (Johnson & Hawkins, 1972; Hawkins, 1973; Belal & Glorig, 1987; Schuknecht & Gacek, 1993; Howarth & Shone, 2006). The number of neurons present in the cochlear nuclei and auditory centers of the brain also decrease with age (Johnson & Hawkins, 1972; Chisolm et al., 1972). MRI studies have determined that those with HL have a smaller amount of gray matter

volume in the auditory cortex (Peelle et al., 2011), and the function of the spiral ganglion neurons (Bao & Ohlemiller, 2010), cochlear nuclei (Gray et al., 2008), superior olivary complex, and inferior colliculus all demonstrate some degree of change (Caspary et al.,2014). These changes will not only affect the perception of sound but also the discrimination ability of an individual.

There are six distinct types of HL associated with age (when combined, the following types are often grouped under the term 'presbycusis'): sensory, neural, strial, cochlear conductive, mixed, and intermediate (Chisolm et al., 2003; Howarth & Shone, 2006). While each of the six types presents with six different clinical presentations, these often combine in the aging ear, which results in sensorineural HL (SNHL). SNHL occurs when there is damage or dysfunction to the cochlea or VIIth nerve. SNHL is the most common type of loss in adults and is permanent. SNHL can be due to any number of factors including illnesses, ototoxic drugs, genetic hearing loss, aging, head trauma, malformation of the inner ear, and exposure to loud noise (ASHA, 2015; Cunningham & Tucci, 2017).

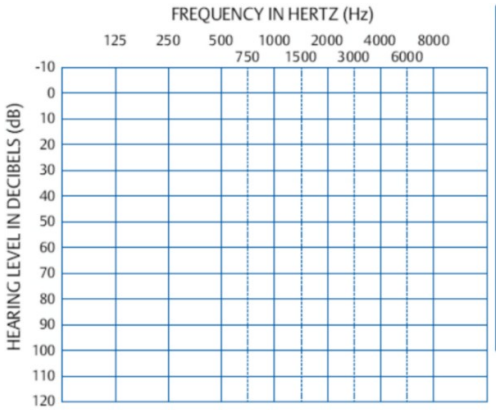
When assessing hearing audiometrically, HL is typically described in terms of type and degree. There are three different types of HL, with the focus of this research being on SNHL. SNHL is categorized based on degree. Degree of loss is measured in terms of decibels (dB) across different frequencies (typically 250-8000 Hz). The degree and type of hearing loss is determined during an audiological assessment. This assessment includes both air and bone pure tone testing, which is discussed more in the fourth chapter. Audiological standards state that there are five main degrees of HL based on dB range, which are noted in the table below (ASHA, 2015).

Table 2.5 Degrees of HL (ASHA, 2015)

Degree of HL	HL range (dB HL)
Normal	-10 dB to 25 dB
Mild	26 dB to 40 dB
Moderate	41 dB to 70 dB
Severe	71 dB to 90 dB
Profound	91 dB and above

The degree of HL is typically plotted on an audiogram as seen in Figure 2.8 (ASHA, 2015). As the degree of HL increases, an individual is expected to have more issues understanding speech and being alert to environmental sounds.

Figure 2.8: Sample Audiogram (ASHA, 2015)



2.3.4 Prevalence of Hearing Loss

After hypertension and arthritis, the third most prevalent chronic condition affecting older adults is Age-Related Hearing Loss (ARHL) (Lethbridge-Çejku & Vickerie, 2004; Lin & Albert, 2014). An epidemiological study of hearing loss conducted from 1993-1995 revealed that almost 46% of adults between the ages of 48-92 years of age had at least a mild unilateral hearing loss. Prior to this study, no study utilized standard audiometric testing to describe the prevalence of hearing loss in adults.

Participants in this study were from Beaver Dam, Wisconsin (n= 3,753); 57.7% were female, and the average age was 65.8 years. Pure tone air and bone conduction testing was completed on every adult, which determined that 45.9% of these adults had hearing loss. The odds of hearing loss increased with age (1.88 for 5 years, 95% confidence interval (CI) 1.80-1.97). Men were found to be more at risk for hearing loss than women even after adjusting for age, education, noise exposure, and occupation (OR = 4.42, 95% CI 3.73-5.24) (Cruickshanks et al., 1998). More recent estimates using National Health and Nutritional Examination Surveys (NHANES) data state that 30 million Americans age 12 and older (12.7%) have bilateral hearing loss (Lin et al., 2011). Using the same NHANES dataset, prevalence of hearing loss was found to double with every 10-year age increase. Approximately half of US adults between 60-69 years of age and 80% of US adults over the age of 85 have a HL which affects daily communication (Agrawal et al., 2008; Lin et al., 2011). It is suggested that this prevalence is expected to increase. Research estimated that in 2020, 44.11 million adults over the age of 20 are expected to have at least a mild hearing loss, while it was estimated that by 2060 that number is expected to reach 73.50 million adults (Goman et al., 2017).

2.3.5 Impact of Hearing Loss

It is widely known that HL causes issues with everyday communication, including recognizing speech in noisy environments and the ability to detect, identify, and localize sounds both reliably and quickly (Arlinger, 2003). The most common impact that HL has on an individual is impaired communication (Cunningham & Tucci, 2017). Impaired communication can cause adverse effects on relationships, cause difficulty in the workplace, and can cause individuals to withdraw from social settings. This withdrawal

can lead to feelings of isolation, anxiety, headaches, increased stress, anger, fatigue, tension, depression, and an overall poorer quality of life (QoL) (Mulrow et al., 1990; Fortunato et al., 2016). Although the most common impact is on communication, research has determined that HL is the fourth leading cause of disability globally (Vos et al., 2016). HL is known as an "invisible disease" that has wide-ranging impacts on an individual. Beyond communication difficulties, HL also has indirect health, psychosocial, and economic impacts which can lead to a reduced QoL and social isolation (Cunningham & Tucci, 2017). Individuals with HL have higher rates of hospitalization (Genther et al., 2013), are more at risk for falls and frailty (Lin & Ferrucci, 2012), and demonstrate increased incidence of depression (Li et al., 2014). Adults with HL also have higher annual health care costs than their normal hearing peers (Allen & Eddins, 2010).

2.4 The Relationship between Hearing Loss and Cognition

Multiple studies have revealed a correlation between hearing loss and loss of cognitive function and performance (Uhlmann et al., 1986; Arlinger, 2003; Mathers et al., 2006; Lin et al., 2011; Surprenant & DiDonato, 2014). Individuals with HL are at a greater risk for cognitive decline and dementia (Lin et al., 2013). This relationship remains present even if sex, age, race, diabetes, smoking history, education, and cardiovascular issues are controlled. When compared to normal hearing individuals, individuals with a mild, moderate, and severe hearing impairment, respectively, had a two-, three-, and fivefold increased risk of incident all-cause dementia over >10 years of follow-up (Lin et al., 2011). Lin et al., (2013) completed a six-year prospective observational study intended to determine whether hearing loss can independently accelerate cognitive decline. Older individuals (n=1,984) underwent cognitive

assessments in the Health ABC Study. Individuals were given the Modified Mini-Mental State Exam (3MS) and Digit substitution test at four different times throughout the six-year period while pure-tone audiometry from 0.5-4 kHz was completed once at baseline. Baseline measures indicated that 1,162 individuals had a pure-tone average of >25 dB. These individuals also had a greater decline on both cognitive assessments compared to normal hearing participants. When individuals with hearing loss were compared to those without hearing loss, researchers found a 24% increased risk for incident cognitive impairment. The severity of the subjects' baseline hearing loss, the rates of cognitive decline, and the risk for incident cognitive impairment were all linearly associated (Lin et al., 2013).

Studies that examined the effects of hearing loss on cognitive load determined that, in conditions where hearing loss is present, greater cognitive resources are dedicated to the auditory system and auditory processing (Pichora-Fuller et al., 1995; Wingfield & Grossman, 2006; Tun et al., 2009; Li-Korotky, 2012; Loughrey et al., 2017). When cognitive load was reached, cognitive resources were affected negatively and resulted in a decline in working memory, decline in overall attention, decline in processing speed, and finally a decline in semantic, immediate, and episodic memory. Therefore, the cognitive load induced by hearing loss could result in a smaller pool of resources being available for other cognitive domains (Lin et al., 2011).

Despite the statistical correlation reported between HL and cognition, a sufficient explanation of the underlying relationship remains lacking. It is unknown whether hearing loss takes a cumulative toll on cognitive reserve (Wingfield & Peelle, 2012), which is discussed in Chapter Three. Another explanation could be that cognitive reserve

is being stressed in the presence of HL while individuals must process and make meaning of auditory information instead of memorizing information or paying attention. Another unanswered question about this relationship is if HL causes cognitive decline due to social isolation and depression (Wingfield & Peelle, 2012). It is documented that HL causes social isolation, which in turn can cause depression; both are associated with cognitive decline (Strawbridge et al., 2000; Barnes et al., 2004). HL is the third most common chronic health condition in older adults and research has suggested that HL is a potential modifiable risk factor for dementia and neurocognitive impairment later in life (Loughrey et al., 2019; Uchida et al., 2019; Ortega et al., 2019). The Lancet International Commission on Dementia, Prevention, Intervention, and Care has estimated that if mid-life HL is eliminated, an individual's risk for dementia may decrease by nine percent, which was the highest percentage of any of the modifiable risk factors studied (Livingston et al., 2017; Kivimäki, & Singh-Manoux, 2018; Ortega et al., 2019).

Previous research is in agreement that HL is a potential modifiable risk factor of neurocognitive impairments and dementia, despite the fact that the reasons behind this link are yet to be determined. Not only is it important to understand that HL is a modifiable risk factor for dementia; researchers must also assess prevention or treatment options for HL and cognitive decline (Livingston et al., 2017; Kivimäki, & Singh-Manoux, 2018; Ortega et al., 2019). Public health initiatives are focused on understanding the impacts that HL may have on cognitive decline, yet there are gaps in research. While there is no treatment for HL, research has revealed that there are management options (aural rehabilitation and assistive listening devices) which may provide patients with perceived benefit. Unfortunately, current initiatives and research

lack focus on understanding if aural rehabilitation or assistive listening devices, such as hearing aids, may have mitigating effects on cognitive decline (Loughrey et al., 2018).

Together, this body of literature displays that there are cognitive, hearing, and brain-related changes that occur due to age (Livingston et al., 2017; Uchida et al., 2019). However, many gaps remain in the literature, and their absence highlights the incomplete knowledge of this relationship. While research insinuates that cognitive decline and HL are related, there are yet to be definitive studies truly linking the concepts. For example, it is uncertain if all cognitive domains (such as social cognition,) or even cognitive resources, are impacted by HL. Furthermore, gaps are also present with regard to the degree of HL at which these cognitive issues arise.

2.5 Comorbidities of Hearing Loss and Cognition

NIH (2012) defines a comorbidity as two or more illnesses which occur in the same person. Comorbid illness or disease may occur at the same time or one after another. When a comorbidity occurs, it is implied that either illness could worsen the course of the other. Comorbidities are important to assess, since they are associated with increased health care costs, worse health outcomes, and a possible increase in the complexity of clinical management of an illness (Valderas et al., 2009). Hearing loss has been found to be independently associated with dementia (Lin, 2011). Specifically, dementia is more prevalent in people with hearing loss than in counterparts without hearing loss (Uhlman et al., 1986; Harrison et al., 2015; Suprenant & DiDonato, 2017; Lin, 2011; Lin et al., 2011; Lin et al., 2013; Schubert et al., 2017; Quaranta et al., 2014; Deal et al, 2017). When compared to those with normal hearing, those with HL are at 1.73 times the risk of developing dementia (Hsu et al., 2016).

HL and cognitive issues share many of the same comorbidities. Similar comorbidities include cardiovascular issues, cerebrospinal disease, obesity, diabetes, thyroid issues, head trauma/injury, depression, stress, cancer, and vision issues (Bainbridge et al., 2011; Nachtegaal et al., 2011; Mener et al., 2013; Hsu et al., 2016; Li et al., 2014). A large prospective study in the Netherlands assessed hearing ability in adults age 18-70 years using a digits-in-noise test with a self-report of comorbidity in those with hearing (Nachtegaal et al., 2011). Of the participants who scored poorly on the digits-in-noise test (a speech-in-noise test), 78.5% of those suffered from at least one other chronic condition. In participants who had normal hearing, only 68.6% reported one or more chronic conditions. Once age and sex were adjusted in this study and others, it was determined that the following comorbidities were most prevalent: diabetes, arthritis, and dizziness which resulted in falls (Bainbridge et al., 2011; Nachtegaal et al., 2011). Multiple studies have determined that HL and cognitive decline are independently associated with depression (Mener et al., 2013; Hsu et al., 2016; Li et al., 2014). Individuals from the NHANES study revealed that a person was 1.5 times more likely to report depression per every 25dB of hearing loss (Mener et al., 2013). Many similar comorbidities are shared between HL and cognitive decline, which can lead to worse outcomes. As such, researchers and clinicians should be aware of these combined comorbidities.

2.6 Synopsis

This chapter sought to provide a holistic background on the brain, specifically its structure and function. It is important to understand the structure and function of the brain since it is directly related to cognition, hearing and HL, and the interconnections that

these concepts may have amongst one another. Age-related changes in these systems have the ability to impact many parts of an individual's life. While this chapter sought to provide a holistic background, it also noted the gaps in the literature that remain. There is a lack of understanding on the underlying mechanisms of cognitive decline and HL. Gaps also exist in how exactly HL impacts cognition and its domains, since research has focused on memory and attention domains. Additionally, research is lacking as far as what degree of HL may impact cognition as well as if aural rehabilitation or assistive listening devices may assist in mitigating cognitive decline due to HL. Due to the wide-ranging effects that these systems may have on individuals, in addition to the gaps in the literature, this relationship is crucial to further explore, necessitating the stated aims of this particular study.

CHAPTER 3: CONCEPTUAL AND THEORETICAL FRAMEWORK

Research has focused on the multitude of age-related changes that occur to both the structural and functional aspects of the brain, and yet no definitive conclusions have been found. As such, many theories have arisen in an attempt to understand the structural and functional age-related changes to the brain. Previous research has noted even in normative changes to an older adult's brain, there are marked differences between individuals. The potential reasons for these differences in the aging brain may be life-course factors, such as education, leisure activities, and hearing loss. One approach to explore in more depth is the life course connection between the auditory system and cognitive/brain system. It is often stated that "we hear with our ears, but we listen with our brains" (Pichora-Fuller et al., 2016). Theories include not only elements such as age-related changes, but also societal and environmental factors that affect the aging process. In an attempt to understand the complex relationship between cognition and hearing, theories that apply to both audition and cognition should be considered as they serve to frame research in these areas. Some of the important theories that underpin the relationship between cognition and auditory function with age include: Capacity Theory, Cognitive Reserve (Kahneman, 1973; Pichora-Fuller et al., 2016), and the Scaffolding Theory of Aging and Cognition (STAC-r) (Park & Reuter-Lorenz, 2009; Park & Reuter-Lorenz, 2014).

3.1 Capacity Theory and Effortful Listening

One theoretical approach used to understand the impact that hearing loss may have on attention and working memory comprises critical integration of the Capacity Theory and the related Framework for Understanding Effortful Listening (FUEL)

(Kahneman, 1973; Pichora-Fuller et al., 2016). Capacity Theory was first published by Kahneman (1973) in a study that focused on attention demands and effort. Researchers determined that if a person was expending cognitive abilities towards simultaneous tasks that their attention towards other tasks may be limited based on how much cognitive capacity, or space, was available. Later, Just and Carpenter (1992) expanded on capacity theory by incorporating the concept of total capacity amount. This concept is defined as the maximum amount of activation (storage and processing) that is available in working memory to support other cognitive functions. Research on attention and working memory suggest that these functions have an apparent ceiling, or maximum amount, of resources that can be dedicated during highly demanding activities in complex environments. This means that when an individual is in complex listening or visual environments, their working memory and attention can be negatively impacted because both processes are competing for a fixed number of resources in the brain. Pichora-Fuller and colleagues (2016) then adapted the Capacity Model of attention to include effortful listening demands called the Framework for Understanding Effortful Listening (FUEL). FUEL incorporates the aspect of cognitive demand and the supply of cognitive capacity available to listening situations. When in the midst of a difficult auditory environment, individuals are required to concentrate on multiple sources of input. Similarly, in persons with hearing loss, individuals must allocate more resources to comprehend, remember, and respond to events and auditory information (Pichora-Fuller et al., 2016). Given the reduction in quality and intensity of an auditory signal, a person with hearing loss exerts significant effort to understand speech during listening condition. This notion is now referred to as "effortful listening."

Capacity theory and FUEL suggest that in order to achieve acceptable auditory perception, one must tap into both cognitive resources and auditory function. In situations where cognitive load is high and auditory streams are excessive (i.e. listening in a restaurant), an individual may not have the capacity to actively attend to all criteria necessary for auditory input that is crucial for spoken communication. Additionally, FUEL posits that individuals unconsciously assign a value on listening and then subconsciously conduct a 'cost-benefit analysis' to determine if benefit will occur from putting forth more effort to listening; if no benefit is determined, the listener will allocate their cognitive capacity elsewhere (Pichora-Fuller et al., 2016). This means that when an individual is in a multi-talker environment, an "auditory scene analysis" is conducted. During this analysis, auditory objects are grouped into different auditory streams (Bregman, 1990; Shinn-Cunningham & Best, 2008). These streams include acoustical cues and voice characteristics of each talker. This analysis and grouping of auditory information allow for the individual to either selectively attend to the talker of interest or redirect his or her attention to a different auditory stream (Meister et al., 2016). For example, when an individual is in a social setting listening attentively to a specific speaker (S1) while ignoring background noise, hearing their name from a different speaker (S2) will cause an attention shift away from S1 and to S2 until it is decided if the acoustical information is necessary/important.

In studies that examine the effects of HL on cognitive load, it was determined that in conditions where HL was present, more cognitive resources were dedicated to the listening, attending, and processing of auditory information (Pichora-Fuller et al., 1995; Wingfield & Grossman, 2006; Tun et al., 2009). When resources were dedicated towards

understanding and processing auditory information, cognitive abilities such as working memory were negatively impacted. For example, previous research illustrated that persons with HL had more difficulty than their normal hearing peers in recalling spoken word lists (Tun et al., 2009). Even a mild hearing loss was shown to have negative impacts on daily auditory communication. Communication problems are noted the most with environments in which speech must compete with background noise. In this difficult listening environment, an individual's cognitive load becomes focused on certain auditory information that is deemed important, while ignoring non-important background noise. A growing body of research suggests that cognitive factors, such as working memory capacity and attention, play an integral role in comprehension of speech beyond hearing ability alone (Akeroyd, 2008; Humes, 2013; Baddeley, 2010). In situations where cognitive load is high and auditory streams are excessive, an individual may not have the capacity to actively attend to all criteria necessary for daily communication. Therefore, the cognitive load induced by HL could result in a smaller pool of resources being available for other cognitive domains, such as memory, attention, and social cognition, which may well explain (in part) some of the declines observed in cognitive abilities (Tun et al., 2009). This theory suggests that for those with HL, an individual's capacity regarding working memory and attention may be reduced during conversations. In short, the wide-ranging effects of hearing loss on all domains of cognition may be partially explained through the Capacity Theory.

While the Capacity theory discusses the impacts that the environment may have on cognition, particularly related to hearing, it lacks life-span impacts that the environment may have in the long term on an individual. Thus, the next two theories,

Cognitive Reserve and STAC, assist in filling in these gaps.

3.2 Cognitive Reserve

As described in Capacity Theory, one's immediate environment can impact cognitive abilities in adults. If the complexity of an environment has an impact on cognition, perhaps one's environment throughout their lifespan may also have an influence on cognition later in life. While genetics are thought to account for 60-70% of cognitive ability variation observed in aging adults, 30-40% of this variance is unaccounted for (Neuner, Ding, & Kaczorowski, 2019). Research has suggested that the unaccounted variance may be due to brain reserve or cognitive reserve (CR) differences between individuals. The notion of reserve is that there are structural and functional variations among brains that impact cognitive abilities in adults throughout the life span. These variations could provide a sort of protective mechanism later in life. Unlike the Capacity Theory, where the immediate environment may tax the cognitive system beyond its capabilities, the concept of cognitive reserve is thought to provide a neural protective effect. Such a protective mechanism may dampen the severity of structural and functional changes in the brain due to age (Stern, 2012; Robertson, 2013).

Brain reserve refers to the brain's ability to function properly when exposed to increasing damage due to pathology or age. Individual brain differences, such as volume and the extent of neural connections, may allow the brain to either tolerate or mitigate disease (Valenzuela et al., 2011). The structural differences associated with brain reserve may lead to an increased tolerance of abnormal pathology and allow the individual's brain structure to remain intact with age. For example, a person with more neurons or an efficient neural network complexity could afford to lose more neurons/volume before an

impairment is noted. Brain reserve has gained support through studies that observed a relationship between larger brains and lower incidence of dementia (Katzman et al., 1988; Schofield et al., 1997). Brain reserve suggests that positive structural changes to the brain could potentially lead to positive functional outcomes, such as lower incidence of dementia, but other life experience may also be crucial to prevent or even minimize brain pathology (Stern, 2012). While brain reserve is an essential aspect which may affect cognitive performance, this study focused on CR due to the performance variations that can be highlighted in cognitive assessments in contrast to simple cognitive screening measures.

CR refers to the cognitive performance variations noted in adults, which may allow an individual to maintain normative cognitive functioning throughout their life span (Robertson, 2013). CR suggests that the brain actively adapts with structural changes by utilizing pre-existing cognitive processes or utilizing compensation mechanisms and strategies (Stern, 2012; Robertson, 2013). Factors that affect CR, such as education and occupation, have been shown to activate an individual's noradrenaline/ norepinephrine system. Norepinephrine is a neurotransmitter that is released by several brain nuclei. This neurotransmitter plays a number of roles related to forebrain function and is thought to be involved in sensory signal detection, arousal and alertness, attention, memory and learning, and behavioral flexibility (Berridge et al., 1993; Bouret & Sara, 2005; Devilbiss et al., 2006; Cain et al., 2011; Zhang et al., 2013).

In CR, the relevant variable is cognitive functioning instead of structural changes. Throughout the life course there are certain factors (discussed above) that research has hypothesized may enhance neural networks and provide a mechanism that results in

improved brain function in the presence of damage and/or disease. Researchers have hypothesized that the neurotransmitter noradrenaline mediates the protective effects of cognitive reserve (Traver et al., 2005; Veyrac et al., 2008; Robertson, 2013). Noradrenergic activity (NA) can have either a positive or negative impact on cognitive processes such as arousal, awareness, sustained attention, working memory, and response to novelty. An increased presence of NA results in more efficient cognitive processing and thus functioning, whereas a decreased presence of NA results in less efficient functioning (Robertson, 2013).

Genetics represent an important yet unmodifiable factor of an individual's cognitive abilities. However, an individual's life course may create conditions that could potentially mitigate genetically controlled cognitive declines. Research has proposed three underlying processes that combine to form CR: neural reserve, neural compensation, and the processes and associated neural circuits (Stern, 2009; Stern 2012). Neural reserve refers to the brain's capacity and efficiency of circuits to maintain an invulnerability to neuronal damage to skills and tasks that have been well-practiced. Neural compensation refers to the brain's abilities to allow for compensatory processes to occur after degradation of the original circuits needed for a specific task. Lastly, there are cognitive processes and the associated neural circuits which provide an individual with the ability to maintain their performance across a large range of tasks (Robertson, 2013).

Life course factors such as high levels of education, lifelong experiences, leisure activities, occupational complexity, and premorbid intelligence appear to be essential to mitigating major effects due to brain pathologies (Robertson, 2013; Stern, 2012). These protective factors have been cumulatively termed as CR and may reduce an individual's

risk of developing dementia (Robertson, 2013; Stern, 2012). In individuals with high CR, the assumption is that the onset of brain pathology may not immediately be expressed through clinical symptoms, such as MCI or certain dementias. Thus, individuals with a higher CR may have a higher tolerance for pathology than those with a low CR. Stern et al., (1994) completed a four-year study that analyzed data obtained from 593 non-demented individuals over the age of 60 years. Individuals with less than eight years of education had a higher risk of developing dementia during the study period than those having more than eight years of education. Those with low occupational levels (clerical/office worker, skilled trade or craft) were two times more likely to develop dementia than those with high occupational levels (professional, business, or government). Another study assessed leisure activities in older adults while controlling for age, ethnicity, education, and occupation (Scarmeas et al., 2001). Findings from this study determined that adults with high participation in leisure activities had a 38% lower risk of developing dementia. Together these findings suggest that certain life experiences may have the potential to mitigate cognitive declines (Scarmeas et al., 2001).

CR may provide an explanation for the differences that are noted between individuals who experience only normative cognitive changes based on age versus those with a greater susceptibility to mild cognitive impairment and dementia (Stern, 2012). Research in this domain included self-reported responses to questions addressing individual health status, levels of education, occupation, and physical activity. Since these factors can have an impact on cognitive decline, it is important to consider that they could potentially influence an individual's susceptibility to age-related brain changes: Therefore, including variables such as levels of education, lifelong experiences, leisure

activities, occupational complexity, and premorbid intelligence are important in any aging research. Furthermore, controlling for their effects in any research study may aid in understanding the effects of the life course on cognitive abilities. CR suggests that to fully examine cognitive abilities in late life, research needs to include assessing the life course of an individual to determine what factors have influence on cognitive abilities (Stern, 2012).

Nevertheless, there are some drawbacks to the CR theory. While CR does consider overall health status and multiple life course factors, it does not examine the impact that changes to the sensory systems or the immediate environment may have on the individual.

3.3 Scaffolding Theory of Aging and Cognition-Revised

Unlike younger adults, healthy older adults experience varying degrees of neural challenges and functional deterioration. Neural challenges include structural brain changes due to age, such as loss of white matter and cortical thinning (Park & Reuter-Lorenz, 2014). There are many functional changes that are related to an increase in age, such as decreased memory and attention. The Scaffolding Theory of Aging and Cognition (STAC) suggests that the brain builds "compensatory scaffolds" in response to age-related neural declines and cognitive challenges that present themselves throughout the lifespan of an individual (Park & Reuter-Lorenz, 2009; Park & Reuter-Lorenz, 2014). Using evidence from structural and functional neuroimaging, this model was constructed to explain how the effects from both compensatory and adverse neural processes impact cognitive functioning. Initially, the STAC model did not include life course influences (Park & Reuter-Lorenz, 2009). In reviewing research that included longitudinal data,

researchers determined that a revised theory was necessary (the STAC-r) which incorporated life course influences. Whereas CR suggests the presence of factors that may mitigate cognitive decline due to age or pathology, the STAC-r provides a more robust rationale for CR (Park & Reuter-Lorenz, 2009). Specifically, the STAC-r model suggests that the brain is a dynamically adaptive system that forms the aforementioned scaffolds. The function of these scaffolds is to engage supplementary neural circuity to provide support to the aging brain to preserve cognitive functioning (Park & Reuter-Lorenz, 2014). This suggests that even in the aging brain, neuroplasticity may occur to assist in cognitive decline noted with age.

Researchers suggest that individuals have the ability to enhance this scaffolding activity through lifespan and life course variables. The STAC-r suggests that if an individual engages in exercise, participates in cognitive training, and maintains high levels of engagement in novel activities, they can improve their ability to scaffold (Park & Reuter-Lorenz, 2014). Individuals with high levels of engagement in challenging tasks have the potential to have both higher reserve and scaffolding capabilities.

Concepts from both cognitive reserve and scaffolding explain the wide-ranging cognitive abilities that are seen in aging adults. However, a shortcoming of this model, as in CR, is that it lacks consideration of sensory changes and the effects of an individual's immediate environment.

3.4 International Classification of Functioning, Disability, and Health

While Capacity Theory suggests that cognitive abilities are impacted by an individual's current environment, CR and STAC theorize that cognitive abilities later in life can be impacted by exogenous factors throughout life. CR and STAC imply that

researchers need to assess life course factors and activities such as education, occupation, and leisure. The importance on these factors and activities in cognitive and hearing loss studies motivated inclusion of the International Classification of Functioning, Disability, and Health model (ICF) in this dissertation research (WHO, 2001). As a biopsychosocial model of disability, the ICF addresses the functioning and disability related to a health condition within the context of a person's activities and participation in their everyday life (WHO, 2001). The ICF links directly to and supports the aforementioned theories by including environmental and lifestyle factors.

The ICF views functioning and disability as multi-dimensional concepts that relate to body functions and structures, activities, participation, and environmental factors for each person (WHO, 2001). It proposes that three primary health outcomes exist: body functions/structure, activity, and participation. Body functions and structures are understandably described as the functioning at the level of the full body system. Activities and participation refer to those activities in which the individual engages and through which the individual functions as a member of society. Functioning is an umbrella term for the body's ability to engage in activities and participation, whereas disability is the umbrella term for all impairments, activity limitations, and participation restrictions (Danermark et al., 2010). The ICF includes two contextual factors: Environmental (exogenous) and Personal (endogenous). These factors can serve as either facilitators or barriers, affecting a person's experiences in either a positive or negative manner. Ultimately, what the ICF model does is conceptualize the interaction between a person's health conditions, environmental and personal factors, and their level of functioning. It shows the necessity of including a multidimensional approach when

attempting to assess a health condition and its effects. A visual model of the ICF can be found in Figure 1 (WHO, 2001).

The ICF model is particularly useful since it reinforces the idea that consequences of diseases will vary in how they manifest in different individuals. Even when individuals have the same disease, the response to the disease can be quite varied. Understanding the differences in how a disease affects an individual can be crucial in developing a wider understanding of the full range of impacts experienced; such an understanding is also central to their required level of care (McWhinney, 2001). The approach of looking at a disease on an individual level has been shown to improve health status and increase the efficiency of care (Stewart et al., 2000). To highlight the critical nature of its relevance, HL is projected to be one of the top 15 leading causes of burden of disease by the year 2030 (Mathers & Loncar, 2006; Goman et al., 2017). HL is a crucial issue in public health since it has consequences that can affect an individual's psychosocial functioning and quality of life (Danermark et al., 2010). HL is a multifactorial condition that is affected by both exogenous and endogenous factors throughout the life course of an individual, yet it is usually assessed using psycho-acoustic measurements. Therefore, incorporating HL into the ICF model provides a framework for how HL can be understood in a wider bio-psycho-social-environmental context (Gagné et al., 2009; Davis et al., 2016). When HL is viewed within the ICF model it shows how hearing loss can affect the body functions and structures (deterioration within the ear), activities (speech understanding and conversing), and participation (social interactions). The ICF also includes environmental (e.g., noisy environment) and personal factors (e.g.,

cognition) which can either facilitate or be a barrier to the success of functioning with HL.

An individual's health was once thought to be a unidimensional construct, but is now being regarded as a multi-dimensional one that is affected by a person's life course (Kuh et al., 2014). Incorporating the life course allows researchers to analyze changes, including biological, social, psychological, geographical, or historical issues, that arise in one's life. This is crucial because from birth to end of life, health is in constant flux (Hendricks, 2012; Ben-Shlomo et al., 2016). Using this lens helps explain why individuals have such variance in the aging process. Early aging research focused only on the latter stages of life; however, unexplained variations in age-related diseases drove aging research to focus on earlier life processes as well (Hanson et al., 2016). This was an important breakthrough, as previous research about diseases among older adults did not account for factors experienced early in life that had a major impact on health in later life (Kuh et al., 2012). To examine a disease or health issue, a life course perspective considers that aspects of an individual's life may influence the severity of a disease. For example, this approach could assist in determining why HL effects each individual differently. This approach recognizes the importance that time and individual factors may have on explaining the causal links between health and a disease (Lynch & Smith, 2005). Life course models are not meant to explain individual outcomes, but to explain group differences in aging (Ben-Shlomo et al., 2016). A conceptual model (Figure 3.1) was created based on models by Kuh et al., (2014) and Rutherford et al., (2018) to illustrate how the life course affects depression, cognition, and hearing loss.

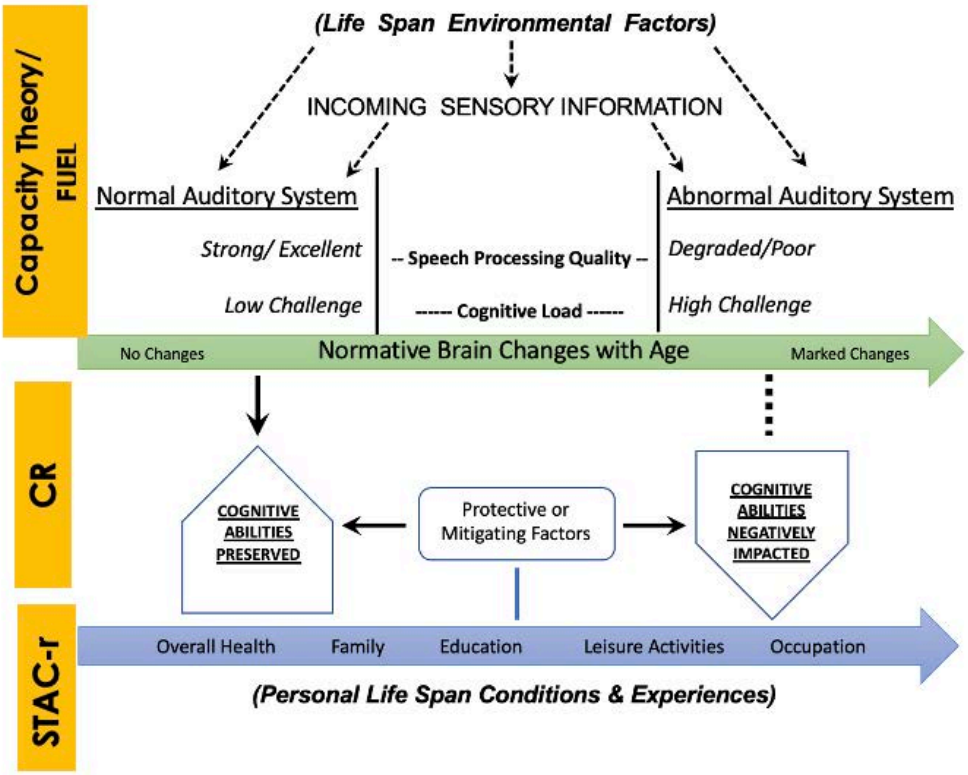
By viewing cognition and HL within the ICF model, one can see that these factors can have an impact on physical functioning and participation (Espmark et al., 2002; Scarinci et al., 2009). Cognitive domains to be assessed in this study included the ability to retain information (memory), the ability to process information selectively (attention), and the various processes that enable people to be a part of a social group (social cognition). The qualitative aspect of this study will assess participant perceptions of the impacts of HL and cognition. Finally, demographic, socioeconomic, and health factors that may influence both cognition and HL (such as sex, education level, socioeconomic status, family history of HL and dementia, tinnitus, job history, and medical history) will be collected (Gagné et al., 2009).

3.5 Integrating Theories and Research into Framework

Accumulating research and theories on HL and cognition suggest a complicated relationship, which remains largely unexplained as a consequence of the many and diverse factors that can affect both HL and cognition throughout the life span (Wayne & Johnsrude, 2015). Previous models and research were critically applied as a guide to create a framework specific to this research (Lin et al., 2011; Wayne & Johnsrude, 2015; Fortunato et al., 2016). Many models and theories, some of which have been presented here, have attempted to shed light on the intricate connections that exists between hearing ability and cognition. While these systems have an impact on each other, there are other factors at play that can further help or harm the functioning of the individual. The model, Life Span Factors and their Impact on Hearing Loss and Cognition Model (seen below in Figure 3.1), provides a visualization for the range of factors in play. This model addresses the shortcomings of the previous theories and models by including

lifespan factors, sensory changes, and immediate environment. Additionally, each of the aforementioned theories were placed into the model to provide visualization of how each theory fit.

Figure 3.1 Life Span Factors and their Impact on Hearing Loss and Cognition Model



Environmental conditions may either positively or negatively impact incoming sensory information. Negative conditions can include background noise, chemical contaminants, or visibility issues (Kelley et al., 2018). Positive conditions include close proximity to the speaker, well-lit environments, and little to no background noise. From there, the incoming auditory information can either be processed through a normal or abnormal auditory system. When information is processed through a normal auditory system, the speech processing quality is high while requiring low cognitive

load. In contrast, in an abnormal auditory system (i.e., hearing loss) poor speech processing capability and a high cognitive load is noted. This directly relates to Capacity Theory/FUEL, which states that environmental factors, such as background noise, can require more cognitive load to process auditory information. From the auditory system, information may then be processed through a brain that is either normal or experiencing age-related changes. Since a normal auditory system has excellent speech processing quality and cognitive load is low, an individual's cognitive abilities are preserved. When the auditory system is abnormal, the speech processing quality is negatively affected and the brain's cognitive load is high, which potentially causes cognitive abilities to be negatively impacted. The process of aging creates normative changes in the brain which may be negatively impacted by HL, but there are possible protective factors. These factors include overall health, education, lifelong experiences, leisure activities, and occupation. These factors are present over the life span, and have been shown in research to potentially mitigate these declines. This relates to the Cognitive Reserve (CR) theory and Scaffolding Theory of Aging and Cognition-revised (STAC-r) which has determined that certain factors may mitigate cognitive decline. Overall, this model sought to incorporate all of the theories into one cohesive model to visually show how lifespan factors impact both hearing loss and cognition.

3.6 Study Theoretical Lens

Although the brain is no longer considered static, the brain and its development, plasticity, and connections have yet to be fully explained as a result of its complex nature. The brain is not only affected by endogenous factors such as genetics, health, and disease, but exogenous factors as well that range from immediate living spaces through

encompassing social structures. Exogenous factors (elements of context) play an important role in plasticity throughout the life span. The environment can have major and immediate effects on the cognitive system, as the Capacity Theory states. These exogenous factors can also have lasting impacts on an aging adult's cognitive ability. A high level of activity throughout life may assist an individual in having a higher cognitive reserve and an increased ability to scaffold cognitive processes in late life. Developing a better understanding of neural plasticity and the hypotheses/ theories behind it will assist in understanding the wide-ranging cognitive abilities throughout the life span.

CHAPTER 4: STUDY DESIGN AND METHODS

This chapter describes the methodology employed to address the specific aims of this dissertation research. Chapter sections generally follow the study design, study sites, participant recruitment and management, and data collection instruments and procedures.

4.1 Study Design

This research was structured around a multi-methods study design with both quantitative and qualitative components. The main outcomes were centered on quantitative data to determine performance-based cognitive abilities in adults with and without hearing loss. A survey design was used to acquire additional self-reported demographic variables as well as information related to health history, socioeconomic status, education, and occupation. This allowed for numeric trends to be determined and compared with findings from the performance-related cognitive abilities and hearing loss. A phenomenological approach was used in the qualitative component to capture meanings of individual participant experiences with and without hearing loss. Perceived effects of HL and communication/communicative abilities were discussed with participants during structured, open-ended questions (Neubauer et al., 2019). The purpose of this multi-methods study was to determine the relationship between HL and the perceived and performance-related cognitive abilities.

4.2 Study Sites

All data collection occurred at the Charles T. Wethington building and the Medical Behavioral Science building, both of which are part of The University of Kentucky's campus in Fayette County, KY. These buildings, located a short distance from each other, housed such necessary resources as cognitive assessment tools, space to

complete testing, and a space that was conducive to minimizing distractions. Rooms in the Charles T. Wethington building were located in the clinical space of the Communication and Sciences Disorders clinic and included calibrated audiological equipment in sound-treated rooms for hearing assessments and paper-based cognitive assessments. Rooms from the Aging, Brain, and Cognition (ABC) Laboratory within the Medical Behavioral Science building were used for administration of the Bluegrass Short Term Memory Task and EEG data gathering. These rooms were quiet, relatively distraction-free, adequately lit, and well-ventilated, which are all characteristics necessary for cognitive assessments.

4.3 Recruitment and Participants

Recruitment

Participants were recruited using a ground-up community snowball sample approach (Carp, 1989). The recruitment strategy initially focused on leveraging existing ties with local participants who fit the study population criteria. Additional recruitment occurred through the posting of IRB-approved flyers (Appendix A) around the University of Kentucky's campus as well as community centers, such as libraries and senior centers. Participants were able to contact the primary investigator via email, text, or phone, and a Google voice number was created to act as a local number, which allowed participants to call and text. The study sought to recruit participants from different socioeconomic, racial, education, and sex groups.

Participant recruitment occurred from September 2019 to April 2020. Recruitment from March to April 2020 was, however, impacted by novel coronavirus (COVID-19). For example, 6 participants initially expressed interest in the study, yet ultimately decided to not complete testing based on the Centers for Disease Control (CDC)

recommendations on age vulnerability (CDC, 2020). In March 2020, all recruitment was suspended due to COVID-related restrictions on human subject research.

Participants

The research defined inclusion criteria based on age and hearing status. Individuals were first required to be between the ages of 50-69 years of age. Potential participants were then required to have either normal to minimal hearing loss through 4000 Hz (0-25 dBHL) or a mild to moderate bilateral untreated SNHL through 4000 Hz (30-65 dBHL) (Tharpe, 2007; ASHA, 2015). Untreated hearing loss was described as not currently utilizing hearing aids or assistive listening devices in the last 6 months. Based on these findings, individuals were separated into hearing loss (HL) and normal hearing (NH) groups. Individuals had to be able to read and write fluently in English for completion of cognitive assessments. Participants were screened for cognitive impairment prior to enrollment in the study. The Montreal Cognitive Assessment (MoCA; Nazreddine et al., 2005) was given during the first in-person meeting with the researcher (Appendix D). Individuals who scored within the range of Alzheimer's disease (AD) on the MoCA were labeled as ineligible for this study. These individuals were labeled as ineligible since they may not be able to give adequate consent to be a part of the research (Howe, 2012). Individuals with a diagnosis of Major Depressive Disorder (MDD) were also excluded due to the negative impact that depression has on cognitive abilities (NIMH, 2018; Kang et al., 2015). Similar to those with AD, individuals with psychiatric disorders, such as MDD, posed issues for obtaining consent, since their decision-making capacity (DMC) may be impaired (Hindmarch et al., 2013). An individual's depressive status was assessed using the Patient Health Questionnaire

(PHQ-9) via the Research Electronic Data Capture (REDCap) web-based data management system (Appendix C). Individuals located in nursing homes and other medically-focused long-term care facilities were excluded due to issues of access (Wysocki et al., 2015). Individuals who stated that they were unable to sit for long periods of time and/or wore hearing aids within the past six months were also excluded.

The age range of 50-69 years was selected for several reasons. First, this range encompassed a large segment of the Baby Boomers cohort (Colby & Ortman, 2014; Lin et al., 2011). The study's age inclusion intended to maintain comparability with extant studies having age/period/cohort-based findings. This study also wished to explore adults who were younger than the typical age range of 65 years for age-related research. Age-related hearing changes can be noted in adults as young as 30-40 years of age. Yet, even though these changes are noted sooner than the age of 65, previous research has mainly focused on adults over the age of 65 years. Finally, the study's age limits represent a life period of accelerating hearing loss. The age of 69 years was chosen as a cut-off for inclusion, since an age of 70 years and over is strongly associated with high prevalence rates of hearing loss, which may lead to difficulties in obtaining an adequate sample size of individuals with normal hearing. The hearing loss range of mild-to-moderate HL was chosen because persons with this degree of hearing loss do not typically utilize hearing aids on a regular basis (National Academy on an Aging Society, 1999). This was an important consideration based on research demonstrating that hearing aids may have a beneficial impact on cognition (Dawes et al., 2015).

As participants enrolled, Personal Identifying Information (PII) and Personal Health Information (PHI) was kept confidential with a cross walk table. Anonymity is

maintained by using codes that did not denote the participant's name or other potential identifying information (name, address, or date of birth). Codes were kept confidential with names and code identification kept in the locked file/office of the primary investigator and stored on an encrypted laptop. Each participant was assigned a participant number, which was used to identify the person following recruitment, during data collection, and when managing data. Subject codes were randomly assigned to participants to keep the participant's identity confidential. Subject codes were labeled based on hearing status, age, sex, and participant number. For example, the first participant was a 60-year-old male with hearing loss: his resulting subject code was HL60M-01.

4.4 Study Size

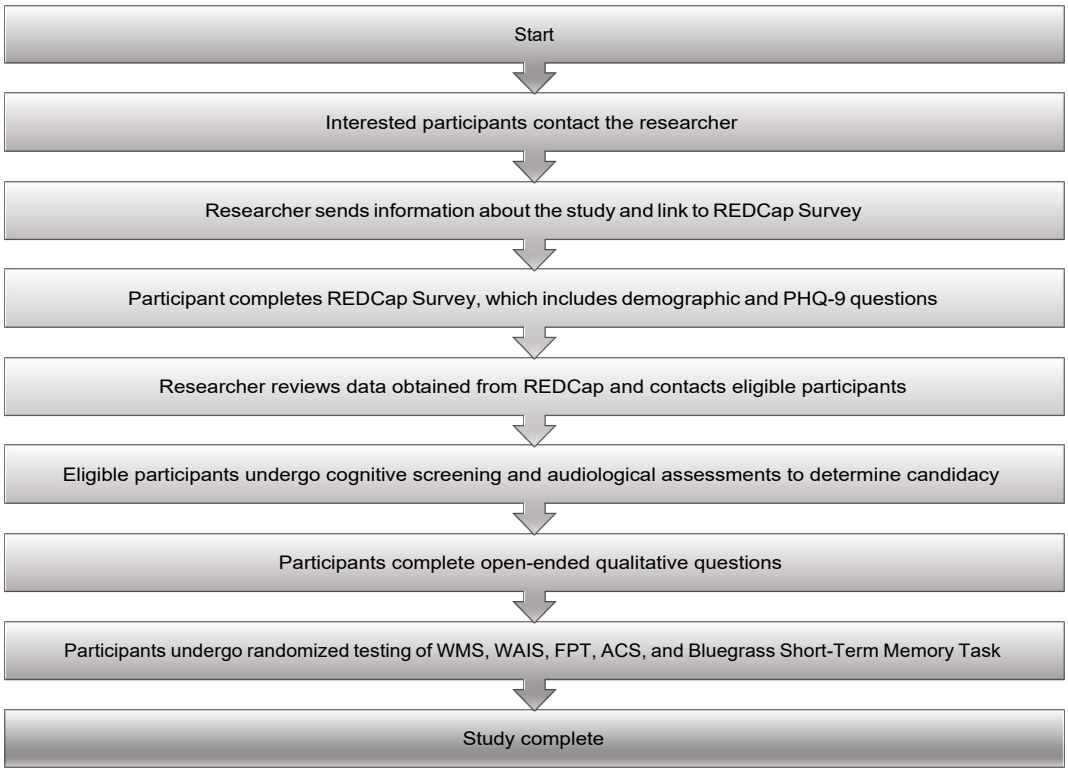
For quantitative data, the sample size was based on two groups: those with HL (A), and those with NH (B). The sample size was further stratified into two age groups: ages 50-59 (1) and 60-69 (2). This created a total of four groups based on HL and age. A power analysis was completed to determine necessary sample size. Given a test significance of .05, two factors in both A and B, a variance of 39.1 in means between AB, and power of .80 between groups (AB), 48 (n=48) participants were optimally necessary to conduct a two-way Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA). Analyses were completed in SPSS version 26. These analyses were used to determine relationships between cognitive assessments and hearing loss, and covariates that may have an impact on cognition and hearing loss.

For the qualitative data, all participants were asked structured open-ended questions with probing questions (Guess et al., 2006; Saunders et al., 2018). A list of probing questions used in this study is located in data collection instruments.

4.5 Data Instruments and Collection

Data collection included self-reported health history questionnaires, audiologic testing, cognitive screener, open-ended questions, performance assessments, and a neurologically based test (Creswell & Creswell, 2017). Initial self-reported questionnaires were completed over the Internet using a secured web application called REDCap to determine eligibility. After this, potential participants were contacted and an in-person meeting was scheduled. During the in-person meeting, consent to participate in the study was obtained. A copy of the consent form was provided to every participant (Appendix B). Data collection then commenced. A flowchart of the steps that each participant took can be found in Figure 4.1. All instruments and procedures used in this research are described in the following sections.

Figure 4.1 Flowchart of the Steps of Research



4.5.1 Self-Reported Questionnaires

Interested individuals contacted the researcher and were sent an email which contained further information about the study and a link to the REDCap survey (Appendix C). REDCap is a secure web application that allows for building and maintaining online surveys and databases (REDCap, 2019). Through the email link, the individual was prompted to complete a self-reported questionnaire. Within REDCap, demographic, socio-economic, and self-reported health data were collected using a modified version of the WHO Health Survey (WHO, 2002). The final part of the REDCap survey included the PHQ-9, which is a depression screener (see below). If an individual expressed concern in sharing information online through REDCap, they were given the questions in a printed format that was identical to that of the online survey.

4.5.2 Depression Screener

The PHQ-9 is a questionnaire and diagnostic tool for screening of both major and minor depression, since it reflects the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria for depression (Spitzer et al., 1999). This is a nine-item self-administered questionnaire about the participant's experience in the last two weeks. Questions target concentration, eating habits, energy levels, depression, interest in participation, sleep difficulties, self-perception, speed of functioning, and suicidal ideation. Each of the nine items are scored on a 0-to-3 scale, with 0 being not at all and 3 being nearly every day. Scores range from 0 to 27, with higher scores consistent with depression. Suggested cutoff points to identify depression are as follows: minimal (0-4), mild (5-9), moderate (10-14), moderately severe (15-19), and severe (≥20) depression. The PHQ-9 takes approximately five to ten minutes to complete (Kroenke et al., 1999).

4.5.3 Cognitive Screener

Cognitive screeners have become important tools that are often utilized in clinical and research settings to assist at the starting point in assessment of a person with possible cognitive impairment. These screeners typically take less than twenty minutes to complete and are graded based on normative data centered around age, sex, and education. The basic purpose of a cognitive screening tool is to indicate the likelihood of an actual cognitive impairment, based on the norms. The Montreal Cognitive Assessment (MoCA) was chosen for this research to determine if individuals met the inclusion criteria of having no cognitive impairment (Nasreddine et al., 1996).

The MoCA was designed to address the shortcomings of the Mini-Mental State Exam (MMSE) in detecting mild cognitive impairment (MCI) and to be a more challenging screening for executive functioning (Nasreddine et al., 1996). The MoCA is a one-page screening tool, administered online or on paper, that consists of 30 questions targeting short-term memory, visuospatial abilities, executive functioning, attention (concentration and working memory), and language (Nasreddine et al., 2005). The short-term memory recall required participants to learn five nouns and be able to recall these nouns after 5 minutes. Participants could score a maximum of five points on this task. Visuospatial abilities were assessed by having participants draw a clock and a three-dimensional cube. Participants could score three points for correctly drawing the clock and one point for drawing the cube. Executive functioning/visuospatial abilities were assessed by a task adapted from the Trail Making B task. The alternating trail making task required the participants to draw a line going from a number to a letter in ascending order. The maximum score for this task is one point. Attention was assessed using sustained attention tasks. Participants were asked to repeat digits either forwards or backwards. Participants were then instructed to listen to a sequence of letters and tap their hand when they heard the letter A. The last attention task required participants to start at 100 and subtract by 7 until they were told to stop. For all of the attentional tasks, participants could score a total of six points. Language was assessed via a three-item confrontation-naming task, with low-familiarity animals (lion, rhinoceros, and camel) and the repetition of two complex sentences. Participants could score three points on the language tasks. Finally, orientation to time and place was assessed by asking participants the date and city in which they were completing this assessment. Participants could score

six points on this task. A cumulative score of 26 or more out of a total of 30 was considered normal (Nasreddine et al., 2005). The MoCA also attempts to account for education by adding one point for those whose education level is less than 12th grade. Completion time for the MoCA is approximately 10 minutes (Nasreddine et al., 1996).

4.5.4 Standardized, Open-Ended Questions

After the MOCA and audiological testing were completed, all participants were interviewed using open-ended questions. Questions revolved around if participants perceived the impacts of HL beyond communication issues, communication with others, and their ability to determine other people's emotions in conversations. Table 4.1 is a summary of these open-ended questions and follow-up probing questions. All participant responses were recorded and transcribed. Qualitative analysis began with delineating units of meaning, clustering the units of meaning to form main themes, summarizing each interview, and validation (Groenwalkd, 2004). Participants had the ability to refuse recording of their responses, in which case detailed notes were taken by the researcher. These questions took less than 15 minutes to complete.

Table 4.1: Open-Ended Response Questions

Have you heard of ways that HL may affect you beyond communication difficulties? *Probe: What else have you heard about HL?*
Would you say your HL has affected you (or may affect you)? *Probe: What about in social situations?* *Probe: What about your relationships?*
During conversations, are you able to convey your own viewpoints/thoughts? *Probe: Do you feel that you can relay this if it does not align with another person's viewpoints?*
During conversations, are you able to understand another person's viewpoint? *Probe: Can you relate to another person's viewpoint if it does not align with your own?*

Table 4.1 (continued)

Can you understand both positive and negative emotions during conversations? *Probe: How?*
Do you think of getting your hearing checked annually as part of your annual health check? *Probe: Have you consider options for hearing loss-OTC devices or hearing aids?*
Is there anything else that you would like to add?

4.5.5 Audiological Assessments

Audiological assessments are a set of diagnostic procedures that allow for the health of the outer, middle, and inner ear to be checked (ASHA, 2018). In this study, audiological assessments included: otoscopy, tympanometry, acoustic reflexes, speech recognition, word discrimination, pure tone air and bone testing, and speech-in-noise testing.

4.5.5.1 Otoscopy

Otoscopy allows for visualization of the outer and middle ear (Katz et al., 2014). Utilizing an otoscope with a disposable tip, the pinna, ear canal, tympanic membrane (TM), and potentially the malleus and incus may be visualized. Video-otoscopy projects images onto a larger screen and allows participants to visualize their own ear canal and tympanic membrane. Participants were given the option of viewing the screen. Video-otoscopy was performed on every participant in this study using a Welch Allyn otoscope paired with the Welch Allyn viewer.

4.5.5.2 Tympanometry

After otoscopy was completed all participants underwent tympanometry. Tympanometry is an objective measure that assesses how sound energy and atmospheric pressure impact the middle ear system. If the pressure is impacted in the middle ear, it

can impact the tympanic membrane and ossicular chain function, which can impact audiometric findings. Tympanometry assesses the admittance of the middle ear by changing the air pressure in a sealed ear canal. For this study, a Maico easyTymp tympanometer with Maico eartips was used. A reusable eartip is placed on the end of the probe tip of the tympanometer and inserted in the outer portion of the ear canal. Participants were informed to sit quietly and were told that an eartip would be placed in their ear and they would feel a change of pressure and a tone in the air. The output of tympanometry is a tympanogram, which provides a graph and table view of admittance, ear canal air pressure, compliance of the TM, and volume of the ear canal. Based on the values obtained, the tympanometer displayed a graph with admittance on the y-axis and ear canal air pressure on the x-axis. From this graph the shape is used to describe and classify the tympanogram. There are five basic schemes for describing the tympanogram: Types A, As, Ad, B, and C (Lidén, 1969; Jerger, 1970). These schemes were used to describe the tympanograms obtained. Results were recorded on a table within an audiogram; this format was used for all participants. The purpose of completing tympanometry was to determine the health of the individual's middle ear system, as this system can impact findings on pure tone testing.

4.5.5.3 Audiometry

The audiogram is a graph of hearing sensitivity that is organized with frequency on the x-axis and decibels or amplitude (dB) on the y-axis. On this graph, an individual's pure tone threshold (PT), speech recognition, and discrimination thresholds were recorded. PT thresholds are described as the lowest level of response that an individual may have to a tonal stimulus (Katz et al., 2014). Speech audiometry refers to testing that uses speech stimuli to assess the auditory system.

Audiometry typically assesses the lowest threshold for frequencies most important to speech, which contains frequencies from 250 to 8,000 Hertz (Hz). PT testing was completed to quantify the hearing loss at each specific frequency. Speech testing was completed to determine how the individual's hearing may be impacting speech recognition and discriminability. Thresholds obtained from both speech and PT testing are expected to corroborate with each other. These tests, along with tympanometry, allowed for the researcher to double-check findings to determine the degree and type of hearing loss (Katz et al., 2014).

For this study, the Orbiter 922 version 2 clinical audiometer was used. All PT and speech testing were completed in a sound-treated chamber that met American National Standards Institute (ANSI) guidelines. The audiometer was calibrated by Gordon Stowe on January 2019 and January 2020. Prior to any testing and earphone placement, participants were given specific instructions. Sennheiser model HAD200 circum-aural earphones were used to obtain air conduction (AC) and speech thresholds. Due to the psychophysical nature of all audiological testing, instructions are a crucial component to data collection since results may be biased based on the willingness of the participant. This bias is controlled by informing all participants to respond 'yes' to any tone, no matter how faint the tone may be (Marshall & Jesteadt, 1986).

The first assessment performed in audiometry was the speech recognition threshold (SRT) ,which yielded the dB at which an individual perceives and can repeat a spondaic word (two-syllable words with equal stress on each syllable) 50% of the time (ASHA, 1988). Individuals were instructed that they would hear spondaic words (i.e., cowboy, baseball) at different loudness levels. If the participant could recognize

the word, they were asked to state what word they heard even if the word was soft. Participants were made aware that they could guess throughout the testing. Each participant was familiarized to the spondaic words before testing. If a better hearing ear was noted, then testing began in that ear. If a better hearing ear was not noted, then the right ear was tested first starting at 50 dBHL. If the participant responded correctly then there was a 10 dBHL drop until an incorrect response was recorded. Once an incorrect response was recorded, the level was raised by 5 dBHL until a correct response was recorded. The lowest level at which a person responded 50% of the time was recorded as the SRT level. After the SRT, Word Discrimination testing (WDS) was completed bilaterally. This test assessed how well an individual understands speech in a quiet environment, specifically when speech is loud but comfortable. The Northwestern University Auditory Test word list (NU No. 6; Tillman & Carhart, 1966) was used for discrimination testing. The NU-6 contains phonemically balanced monosyllabic words, such as pick or room. The word lists were presented at 40 dB above the SRT level obtained in each ear. Participants were instructed that they would hear 'say the word' and then the target monosyllabic word, and to repeat the monosyllabic or last word only. Each participant was given 50 words, with 25 words in each ear (Katz et al., 2014).

After SRTs and WDSs were obtained, the participant was directed over the audiometer microphone that AC testing was about to begin. In AC testing, PT thresholds were obtained using a modified Hughson-Westlake down-up procedure (Hughson & Westlake, 1944). Threshold-finding started at 50 dBHL at 1000 Hz in the right ear, unless the participant reported that the left ear was the better hearing ear. After a threshold was obtained at 1000 Hz in the right ear, the remaining frequencies were tested

in this order: 2000, 4000, 8000, 250, and 500 Hz. The same sequence was then repeated in the left ear. Pulsed tones were presented for a duration of one to two seconds. All participants were instructed to respond with 'yes' if they heard a tone. A response was considered a threshold if the participant responded twice to ascending runs at a particular level and frequency (Hughson & Westlake, 1944; ASHA, 2005). Thresholds were marked on the audiogram based on ASHA (2005) recommendations. If there was more than a 20 dBHL difference between these octave frequencies, the intra-octave frequencies were tested. If there was more than a 40 dBHL difference at a particular frequency between the two ears then masking noise was introduced into the better hearing ear to rule out participation from this ear (Katz et al., 2014).

After completion of AC testing, bone conduction (BC) testing was completed. BC thresholds were obtained utilizing a bone oscillator placed on the most prominent part of the mastoid process. Visual inspection confirmed accurate placement of the bone conductor. Responses were obtained in the same manner as AC testing. The oscillator was placed either on the left ear or on the worst hearing ear. For this study, BC was assessed at 500, 1000, 2000, and 4000 Hz. If there was more than a 10 dBHL difference between the AC and BC thresholds, then masking was implemented in the better hearing ear.

After completion of all PT testing, speech-in-noise testing in the sound field was administered. The purpose of speech-in-noise testing is to assess a person's ability to understand speech in background noise, which attempts to make testing more realistic to an individual's everyday communication environment (Carhart & Tillman, 1970). Speech-in-noise testing also allows for a better estimate of the impact that hearing loss

may have on an individual. Participants all underwent the Hearing in Noise Test (HINT) (Nilsson et al., 1994). The HINT contains 10 sentences that contain straightforward vocabulary and syntax, which were presented at 60 dBHL from the left speaker. At the same time, constant speech-spectrum noise was presented at 55 dBHL from the right speaker. This allowed for a 5 dBHL difference between speech and noise (SNR +5). All participants were seated facing the left speaker and were directed to repeat the entire sentence that is heard and ignore the noise. Only one score was obtained due to sound field testing providing binaural responses.

After completion of all audiometric testing, the researcher utilized the audiogram and ASHA (2005) guidelines to determine the individual's degree and type of hearing loss. Individuals consequently identified with normal to moderate hearing loss were included in this study. The researcher labeled an individual to have normal hearing if thresholds were better or equal to 25 dBHL from 250-4000 Hz bilaterally, while those with thresholds from 30 dBHL to 65 dBHL were placed within the hearing loss group.

4.5.6 Performance-Based Cognitive Assessments

Cognitive abilities are often quantified using performance-based assessments (Harvey, 2012). These performance-based assessments require an individual to exercise certain skills in the presence of an examiner; however, it must be noted that these assessments can be subjective due to participant motivation (Harvey, 2012; Gevins et al., 2012). For instance, a non-impaired individual who is not motivated to do well on these assessments may have poor performance-based assessment scores, but not have an issue with their cognitive abilities (Gevins et al., 2012). The cognitive assessments in this study include the Weschler Memory Scale Fourth Edition (WMS-IV; Wechsler, 2008),

Weschler Adult Intelligence Scale Fourth Edition (WAIS IV; Wechsler, 2008), Advanced Clinical Solutions (ACS; Pearson, 2009), and Faux Pas test (FP; Baron-Cohen et al., 1999).

After audiological testing and open-ended interviews, participants were given these four assessments in a randomized order. All tests were administered in a well-lit and quiet room. Participants were given ample opportunities to take breaks and were told that they could resume testing on another day if they felt fatigued or frustrated.

4.5.6.1 Wechsler Memory Scale (WMS)

Lezak et al., (2004) recommend that for a memory evaluation to be considered comprehensive, it should include orientation, prose recall, rote learning, visuospatial memory, remote memory, and personal memory. Orientation is the awareness of time, place, and person (Berrois, 1982). Prose recall explains the learning and retention of information from auditory stimuli. Rote learning is the memorization of information based on repetition; functionally, it is an individual's ability to more quickly recall information the more it is repeated. Remote memory encompasses episodic, personal semantic, and general semantic memory, which involves events and people (Rich, 2011). Additionally, personal-autobiographical memory refer to memories of the past. It is also recommended that assessments be given that contain immediate and delayed recall.

The Wechsler Memory Scale (WMS-IV) is a neuropsychological test to measure different memory and learning functions using both auditory and visual stimuli. The WMS-IV is the most widely used memory assessment, since it assesses the many domains of memory (Lezak et al., 2004). There are ten total subtests that are categorized

into two modes of presentation: auditory or visual. WMS-IV is acceptable to give to adults up to the age of 90.11 years. Psychometric properties improved from the WMS-III to this current version, and there is evidence that reliability and validity are good (Wechsler, 2008). Subtests were completed in the following order: Visual Reproduction I, Logical Memory I, Spatial Addition, Visual Reproduction II, Logical Memory II, Verbal Paired Associates I, Designs I, Symbol Span, Verbal Paired Associates II, and Designs II. From start to finish the WMS-IV took approximately one hour per participant. A breakdown of each auditory and visual subtest can be found in table 4.2.

Auditory subtests include Logical Memory (LM) I and II and Verbal Paired Associates (VPA) I and II. LM assessed narrative memory using free recall. During LM I testing, participants were told two short stories that were given verbally by the researcher and after each story they were required to repeat back the story as they heard it. Approximately 20-30 minutes after administering LM I, participants were again asked to repeat each story as they remembered it (this constituted LM II). During LM I, participants were awarded a point for each part of the story that recited correctly for a total of 50 points (25 points per story). For LM II, given 20-30 minutes after LM I, participants could receive 50 points (25 points per story). VPA assessed verbal memory for word pairs. VPA I and II contained fourteen word-pair lists which were given verbally by the researcher. Each word-pair remained the same during testing, but the order of the pairs was different each time. After each list was given, the participant was told the first word of the pair and had to give the second word given. In total the word-pairs were given four times and after each presentation the participant was assessed on how many pairs they remembered. Participants could receive a total of 56 points. VPA II

was administered 20-30 minutes after VPA I was completed. The raw scores from these subtests can be combined to determine an Auditory Memory Index (AMI). AMI is an individual's ability to memorize and repeat auditory information immediately and at a delay. A breakdown of these auditory subtests and subdomains assessed can be seen in Table 4.2.

Table 4.2: Auditory Subtests and Subdomains Assessed

Auditory Tasks	**IM**	**DM**	**VEM**	**VM**
Logical Memory I	X		X	
Logical Memory II		X	X	
Verbal Paired Associates I	X			X
Verbal Paired Associates II		X		X

Note: IM= immediate memory; DM= delayed memory; VEM= verbal episodic memory; VM: verbal memory

Visual subtests include Designs (DE) I and II, Visual Reproduction (VR) I and II, Spatial Addition (SA), and Symbol Span (SSP). DE assessed spatial memory using unfamiliar objects. DE I required participants to review a page with a grid drawn on it and remember the ten designs and where the designs were placed in the grid. Participants were then given a grid and twenty cards, each of which had designs on them. Ten cards had the correct designs while ten distractor cards had designs that were similar to yet different from the target cards. Participants were asked to place ten cards that matched the designs that were seen on the previously displayed page on the grid in the correct spots. Participants were shown the same page three more times and were asked to place

the cards on the grid after each time. Approximately 20 to 30 minutes after DE I was completed, DE II was completed by asking the participants to place the correct cards in the correct location. Participants could receive a maximum of 120 points for each DE task, with points accumulating for having the correct card on the grid (content score), a card in the correct location (spatial score), and extra points for the correct card in the correct location.

VR assessed non-verbal memory using visual stimuli. VR I required participants to view a page with a design for ten seconds after which they drew the design by memory on a response booklet with a pencil. Participants were shown five different items; three items had one design while two items have two designs side-by-side. Approximately 20 to 30 minutes after completion of VR I, participants were asked to draw any designs that they remembered for VR II. Designs did not have to be drawn in order but if two designs appeared side-by-side those designs had to be drawn together. During each task, participants were awarded points per item based on the design's replication. Participants could obtain five points each for items one and two, seven points for item three, and thirteen points each for items four and five for a total of 43 points each for VR I and II.

SA assessed visual-spatial working memory. During SA testing, participants were told that they would see two pages, one at a time, for five seconds each. On each page there would be a grid with 16 spots which may or may not have a blue or red circle in a spot. After the participant saw the two pages, they were then given cards that had a blue, red, or white circle on it. They were directed to place the correct circle in the correct spot on the grid. Participants were then given another sample which showed two blue circles in the same spot on two different pages. They were directed that if two blue circles

were in the same spot on both pages that these then became a white circle, so a white circle should be placed in the grid. This task contained 24 items which became more difficult with each item. If the participants missed three consecutive items, this task was considered complete. Participants could obtain one point for each correct item for a total of 24 points.

Visual working memory was assessed in SSP using novel stimuli. During the SSP task, participants were shown a page with a varying number of symbols on each page. Participants were able to look at each page for five seconds and the page was turned to another page with a varying number of symbols on them. Participants were required to point to the symbols they saw on the previous page in order from their left to right. At first, participants were shown a page with one symbol and had to pick from two symbols. If participants continued to pick the correct symbols in order, they could see up to seven designs on one page. SSP contains 26 items for a total of 50 points. After four consecutive imperfect scores, meaning that not all the correct symbols were recalled or the correct symbols were recalled in the wrong order, the task was considered complete. This task was never administered between VR I and VR II due to symbol and design confusion. The scores from these subtests could be combined and scaled to determine Visual Memory (VM I) and Visual Working Memory (VWM I). VM I is the ability to remember information as soon as it is visually presented. This is assessed through DE I and II, and VR I and II. VWM I assessed the ability to identify objects and perceive where these objects are in space. This function is assessed through the SA and SSP tests. A breakdown of these auditory subtests and subdomains assessed can be seen in Table 4.3.

Table 4.3: Visual Subtests and Subdomains Assessed

Visual Tasks	IM	DM	WM	SM
Designs I	X			X
Designs II		X		X
Visual Reproduction I	X			X
Visual Reproduction II		X		X
*Spatial Addition			X	
Symbol Span			X	

Note: IM= immediate memory; DM= delayed memory; WM= working memory; SM=spatial memory

4.5.6.2 Wechsler Adult Intelligence Scale (WAIS)

The WAIS is an assessment of intelligence and cognitive ability (Axelrod, 2001; Pearson, 2008). It is currently in its fourth version, called the WAIS-IV. While the WAIS-IV is composed of 14 subtests, only Working Memory (Arithmetic and Digit Span) and Processing Speed (Symbol Search and Coding) were utilized. WAIS-IV is acceptable to give to adults up to the age of 90.11 years (Wechsler, 2008). Similar to the WMS-IV, there is evidence that the WAIS-IV has good reliability and validity. Subtests were completed in the following order: Digit Span, Arithmetic, Symbol Search, and Coding. From start to finish, the WAIS-IV took approximately 20 minutes to complete per participant (Pearson, 2008).

Digit Span (DS) assesses an individual's ability to listen to a set of digits and immediately repeat the digits back. DS contains three different tasks with eight items

each. Each item contained two trials. The first task, Digits Forward, required the participant to repeat the digits back as they were heard. The second task, Digits Backward, required the participant to repeat the digits in the reverse order in which the researcher stated them. The third task, Digits Sequencing, required the participant to repeat the digits back from smallest to largest. For each task, participants could obtain 16 points, for a total of 48 points. Each task was discontinued if the participant scored a 0 during an item. The arithmetic subtest measures concentrating memory and reasoning. The 22 items in this subtest required participants to solve simple problems. Participants were not able to use a pen or paper which required the participant to retain figures in their memory while manipulating the figure. Each item could be repeated once, and participants had 30 seconds to respond before an item was scored as incorrect. After three consecutive incorrect answers, the task was discontinued. Participants could obtain 22 points for this subtest (Pearson, 2008).

Working Memory Index (WMI) assesses the ability to memorize new information, hold it in short term memory, and manipulate that information to produce a result. These tasks require working memory processes to be applied to the manipulation of orally-presented verbal sequences. These sub-scales involve attention, concentration, mental control, and reasoning. WMI was assessed by combining the two raw scores from DS and Arithmetic (Pearson, 2008).

The Symbol Search (SS) subtest measures processing speed and organization accuracy. Participants are shown two geometric target figures, which they must then visually search for amongst five other figures and determine whether the targets were there by drawing a diagonal line through the matching symbol. If none of the target

symbols are present, then the participant must draw a diagonal line through a box with 'no' in it. Each participant was given 120 seconds to try to complete the 60 items within this subtest. For symbols correctly identified the participant was awarded one point for a total of 60 points. Coding measures visual-motor dexterity, degree of persistence, speed of performance, and ability to learn an unfamiliar task. Participants are first shown a key which contains the numbers one through nine with each number having a particular symbol matched to it. Participants were given 120 seconds to visually scan a grid of 135 numbers and place the correct symbol above each number. Participants were awarded 1 point for each correctly coded number for a total of 135 points. The Processing Speed Index (PSI) was obtained by testing symbol search and coding, which assessed a person's visual-motor skills in focusing attention and quickly scanning, as well as discrimination between and ordering visual information sequentially. These tasks also required executive control of attention and sustained effort (Pearson, 2008).

4.5.6.3 Advanced Clinical Solutions (ACS)

Social cognition refers to the brain's processing of social information, such as the ability to determine others' emotions and how to respond to those emotions appropriately (Henry et al., 2015). Research suggests that there are five areas of social cognition: ToM, social perception, social knowledge, attributional bias, and emotional processing (Green & Leitman, 2008; Harvey & Penn, 2010; APA, 2015). ToM is the ability to attribute beliefs, desires, emotions, intents, and knowledge onto oneself and others (Frith, 1992). Social perception is the ability for a person to identify social roles, social context, and societal rules (Toomey et al., 2002; Sergi & Green, 2003). Social knowledge, otherwise known as social schema, is the awareness of the goals, rules, and roles that govern social

interactions and social situations (Corrigan & Green, 1993; Subotnik et al., 2006). Attributional bias is the ability to infer the causes of negative or positive events (Kinderman & Bentall, 1996). Emotional processing is the ability to perceive and understand emotions and is thought to have four components: identifying emotions, understanding emotions, facilitating emotions, and managing emotions (Mayer et al., 2003). Research suggests that there are between five and eight core emotions. The core emotions are usually comprised of anger, disgust, fear, joy, sadness, and surprise (Ekman, 1999; Tracy & Randles, 2011).

Advanced Clinical Solutions (ACS) is an assessment that enhances the utility of the WMS-IV and WAIS-IV by containing tasks which assess social cognition (Pearson, 2009). The ACS measures affect labeling, affect recognition from both faces and prosody, ability to identify sarcasm, the ability to verbalize intent of a speaker, and facial memory (including face recognition, the recall of names, and the recall of pertinent information about a person from facial images). The ACS contains three subtests which can be used independent of each other: Social Perception, Faces, and Names.

The ability to comprehend social communication was measured by the Social Perception subtask. Within this subtask, facial affect recognition, naming affect recognition from prosody and facial expressions, and affect recognition from prosody and interactions between individuals were measured. During affect naming testing, the participant viewed 24 individual photographs of a person and was required to determine what facial affect was depicted using a list of six different emotions. These emotions included happy, sad, afraid, angry, disgusted, and no feeling/neutral. Prosody-Face Matching required the participant to listen to 12 recorded sentences and

determine which face from six photographs best matched the tone expressed by the speaker in the sentence. During Prosody-Pair Matching, the participant listened to twelve recorded statements and had to determine which of the four photographs best matched the tone expressed by the speaker. After individuals picked the best picture, the researcher probed the individual in determining the tone of the speaker's voice, if the tone of voice changed the meaning of the sentence (sarcasm), and what the speaker meant if the tone of voice changed the meaning. Two scores were determined from the Prosody-Pair Matching: Prosody-Pairs Matching and Social Perception. To obtain the Social Perception score, the raw scores from Affect Naming, Prosody-Face, and Prosody Pair were combined, for a maximum score of 48. To determine the Social Perception Prosody score, the raw scores from Prosody-Face Matching and Prosody-Pair Matching were combined, for a maximum score of 24 (Pearson, 2009).

Faces assesses an individual's ability to discriminate faces and recognition in two conditions: immediate and delayed. In this subtest individuals were shown a grid with 10 faces for 10 seconds. Individuals were shown the same grid with the same faces four times in total. After each trial, the individual was then given a blank grid and twenty cards with faces on them and asked to place the correct faces in the same places as they were just shown. After each trial the grid was graded, and the cards were removed. The subtest was graded based on if the correct card was placed in the grid (learning/encoding) and in the correct spot on the grid (spatial memory). Bonus points are awarded if the correct card was placed in the correct spot. Three scores are obtained: Content, Spatial, and Total Score. The maximum scores for each were 40, 40, and 120 consecutively.

Approximately 10 to 15 minutes after the fourth trial the participant was asked to place the cards in the grid from memory (Pearson, 2009).

Names measures the ability to recall first and last names and semantic information. This subtest is measured by face-name association, face-activity association, and incidental recall for facial expression of emotion. The participant was shown 10 photographs of children's faces in different states of affect for three different trials. The researcher told the participant a first name, last name, and activity. After each trial, the individual had to recall and verbally state the child's name and activity. Approximately 10 to 15 minutes after the third trial was completed, the individual was asked to remember the names and activity from memory. During the delayed recall, the individual also had to state what affect the child had during the first three rounds. The delayed recall assesses long-term memory for both names and semantic information (Pearson, 2009).

4.5.6.4 Faux Pas Test (FPT)

A faux pas is defined as a "social blunder," or when someone mistakenly says something that they should not have (Merriam-Webster, 2017). Awareness and detection of a faux pas is a skill that is typically acquired by the time an individual is 9-11 years old. Proficiency with this skill can be affected by damage to the orbito-frontal cortex and in the presence of some forms of dementia (Baron-Cohen et al., 1999). The FPT contains a total of 20 recorded short stories, 10 of which contain faux pas and 10 that are control stories that contain a minor conflict. Each short story was read aloud to a subject and the text of each story was placed in front of the subject, to reduce the demands on working memory. After each of the short stories, subjects were asked the same eight questions. The first two questions attempt to determine if a faux pas was detected. The third question

requires the subject to understand inappropriateness. The fourth question requires the subject to understand the speaker's intentions or motivations. The fifth question asks about belief: if it is either a false or true belief of the story's character. The sixth question attempts to determine empathy. The final two questions pertain to story comprehension. Subjects can score a total of 60 points on the faux pas stories. When the subject answers "no" to the first question of a faux pas story, they will score a total of 0 for the entire story. Since the participants for this study did not have global cognitive issues, only the 10 faux pas stories were given. Soderstrand & Almkvist (2012) assessed healthy, normally functioning Swedish adults (N=68) to determine if the FPT test was a valuable assessment in those with Asperger's and high-functioning autism. Cronbach's alpha suggested that the internal consistency was excellent for ToM stories and poor for control stories. Split half reliability, which assesses the extent to which all parts of the test contribute equally to what is being measured, was excellent for FPT stories and poor for control stories (Baron-Cohen et al., 1999).

4.5.6.5 Bluegrass Short-Term Memory Task and Electroencephalography

Performance-based assessments require an individual to exercise certain skills in the presence of an examiner; however, the outcome of these assessments can be greatly impacted by an individual's behavior (Harvey, 2012; Gevins et al., 2012). For instance, an individual who is not motivated to do well on assessments or is tired may have poor performance-based assessments scores, but not have an issue with their cognitive abilities (Gevins et al., 2012). As such, performance-based assessments can have limited sensitivity and specificity if alertness or motivation is affected. To offset such confounding variables, neurologically-based tests can be completed to make cognitive

evaluations more sensitive and efficient (Harvey, 2012; Gevins et al., 2012). Examples of neurologically-based tests include computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and electroencephalography (EEG). The application of neurologically-based tests paired with a task that requires attention and/or memory (task-controlled) could allow researchers to factor in physiological brain activity in analyses of data on cognitive performance. Task-controlled EEG testing is a less expensive approach to imaging, yet more information is obtained in a smaller timeframe than fMRI (Gevins et al., 2011).

Due to the potential impact of an individual's behavior, a short-term memory paradigm was chosen to assess working memory and attention and paired with EEG. Specifically, the Bluegrass Short-Term memory task (Jiang et al., 2000) is a 10-minute short-term memory paradigm where individuals were asked to hold a sample target in working memory and indicate whether subsequent images matched or did not match by using keyboard strokes and a computer monitor. This task utilized a portable EPOCH Emotiv headset to collect EEG data associated with this task. Data was obtained at five frequencies (delta, theta, alpha, beta, and gamma) from 14 different channels (electrode sites) during two different resting states. The two resting states were either eyes open or eyes closed (Jiang et al., 2016).

Prior to task initiation, the Emotiv software on a Windows desktop was opened to assist with placement of the EEG headset, which contained electrodes. All electrodes were inspected to ensure that they were in place and functioning properly. The participant was then moved into an adjacent room containing a dim light, chair, and desktop that mirrored the researcher's screen. Participants were directed that the first part of this task

was a practice round of the actual task. Once participants read the screen with instructions, a white "plus" sign on a black screen was presented, which would indicate that the task was beginning. The screen would then reveal the target (match) pictures, which were two white pictures with black objects in the middle highlighted in green that had to be held in their memory. After a few seconds, one white picture with a black object would appear for approximately 100 milliseconds. Participants had to make a decision if the picture matched one of the pictures highlighted in green by pressing a match and non-match key, which was based on the individual's hand dominance. Participants were told to place their hands on the A and L keys on the keyboard. If the person was right-handed, they were told to press the L key if a picture matched and the A key if the picture did not match. For left-handed individuals their match key was the A key and non-match was the L key. After the practice round was completed, individuals were asked if they understood the testing directions. If participants did not understand the initial instructions, they were re-instructed and given the opportunity to complete the practice round again. If participants expressed understanding, the next step was resting state testing with and without eyes open for 90 seconds each. Then, participants were directed that the next two rounds were similar to what was practiced and would last approximately five minutes each. The first round consisted of the match key being the dominant hand, while the second and final data collection round consisted of the match key being the non-dominant hand (Jiang et al., 2016).

CHAPTER 5: FINDINGS

Both quantitative and qualitative data provided the empirical foundations for this dissertation's research. Quantitative data were obtained using self-reported questionnaires through the REDCap application, and included information measuring overall health, health status and conditions, and lifestyle factors. Additional metrics were obtained from cognitive and depression screenings, specifically the MoCA and PHQ-9, administered to each participant. Participants then underwent audiological and cognitive assessments. From this data, statistical analyses were completed using two-way Analysis of Variance (ANOVA) and two-way Analysis of Covariance (ANCOVA). These analyses were used to determine the interactions on cognitive assessments between hearing loss and age, and the covariates that may have an impact on cognition and hearing loss. Additionally, qualitative data were collected from responses to standardized, open-ended questions. Information obtained from participant responses was transcribed and evaluated using NVIVO.

Previous power analysis for quantitative data determined that 48 (n=48) participants were necessary to conduct a two-way ANOVA and ANCOVA. All data met the assumptions to run these statistical analyses and normality was determined through the Shapiro-Wilk test. Twenty-eight participants (females=17; 60.7%; males=11; 39.3%) completed the study. Demographic characteristics were summarized based on participant responses to the modified version of the WHO Health Survey obtained through REDCap (Appendix C). There were slightly more participants (n=15) in the older (60 to 69 year) age group than the younger (50 to 59 year) age group (n=13) (Table 5.1). The mean age for all participants was 60.64 years (SD=6.37 years). Females (59.41 years; SD=6.46)

were slightly younger than males (62.45 years; SD=6.11). Between groups, there was less than a year's difference in the average age of NH (59.71 years) and HL groups (61.50 years). Participants included more females (n=17) than males (n=11). Male participants tended to be approximately three years older than female participants (62.45 years versus 59.41 years). The population of this study was mainly female, white, well-educated, non-smoking, healthy overall, and working full-time.

Statistical analysis revealed that participants were homogenous based on age and sex across groups. Specifically, a two-way ANOVA indicated no significant interaction for hearing loss (HL) based on age (*F (1, 26)=.266, p=.717*) and sex (*F (1, 26)= .213, p=.560*) (Table 5.1).

Table 5.1: Demographic and Hearing Characteristics

	Age 50-59	**Age 60-69**	**Total**	**Significance (p-value)**
Sex				
Female	10	7	17	.560
Male	3	8	11	
Hearing Status				
Normal Hearing (NH)	7	7	14	.717
Hearing Loss (HL)	6	8	14	
Ethnicity				
White	12	13	25	.397
Asian	1	1	2	
European	0	1	1	

Table 5.1 (continued)

Relationship Status				
Never Married	2	2	4	.124
Currently Married	9	12	21	
Separated	0	1	1	
Divorced	2	0	2	
Education				
High School	4	2	6	.796
College	4	3	7	
Postgraduate	5	10	15	
Work Status				
Employed full time	7	11	18	.243
Employed part time	3	3	6	
Self-employed	2	0	2	
Unemployed but looking for work	1	0	1	
Unable to work	0	1	0	

Otoscopy for all participants was unremarkable (clear or non-occluding cerumen in the ear canals). These findings suggest healthy outer and middle ear canals that should not directly influence test results. Middle ear pressure, compliance, and ear canal volume were all within normal limits-based tympanometry for every participant. These findings further suggest a healthy middle ear system for all participants. The mean and standard deviation (SD) scores across four cohorts from speech recognition testing (SRT), pure tone averages (PTA) from 1000-4000Hz, word discrimination scores (WDS), and HINT

testing are summarized in Table 5.2. Detailed analysis on the audiometric findings is presented later in section 5.3.

Table 5.2: Mean and Standard Deviation for Audiometric Findings Between Groups

	NH 50-59	**HL 50-59**	**NH 60-69**	**HL 60-69**
	(n=7)	(n=6)	(n=7)	(n=8)
SRT R (dB)	7.86 (5.67)	14.17 (5.85)	11.43 (8.02)	13.13 (7.53)
SRT L (dB)	6.43 (4.76)	14.16 (3.76)	12.14 (6.99)	22.75 (12.22)
WDS R (%)	98.86 (1.95)	94.00 (6.57)	97.71 (3.15)	97.5 (2.07)
WDS L (%)	99.43 (1.51)	94.00 (6.07)	99.43 (1.51)	93.00 (7.64)
PTA R (dB)	8.93 (7.51)	24.17 (8.08)	14.82 (3.34)	21.09 (7.57)
PTA L (dB)	9.36 (4.56)	22.38 (5.71	16.07 (3.57)	24.69 (7.78)
HINT (%)	100 (0.00)	97.67 (2.45)	97.71 (2.69)	93.25 (5.45)

Based on responses obtained from pure tone testing, 14 participants had normal hearing (NH) and 14 had hearing loss (HL, greater than 25dBHL at 2000 Hz). Participants were thus divided into four groups based on age and hearing status: NH 50-59; HL 50-59; NH 60-69; and HL 60-69.

Overall, the sample contained mainly white participants (n=25), with remaining participants stating their ethnicity as Asian (n=2) and European/German (n=1). The majority of participants reported their relationship status as being married (n=21), work status as working full time (n=18), and completed education at the post-graduate level (n=15). A two-way ANOVA showed no differences between groups based on ethnicity

(*F (1, 24)= .742, p=.397*), relationship status (*F (1, 24)= 2.547, p=.124*), work status (*F (1, 46)= 1.430, p=.243*), and education (*F (1, 24)= .068, p=.796*).

5.1 Health Status and Condition

The REDCap survey asked participants to rate their overall health based on a five-point Likert scale ranging from very good (1) to very bad (5) (Table 5.3). A two-way ANOVA determined no statistical significance between groups (*F (1, 24)= 3.527, p=.073*) in terms of overall health.

Table 5.3: Comparison of Self-Reported Overall Health Between Groups

Health	**NH 50-59**	**HL 50-59**	**NH 60-69**	**HL 60-69**	***Significance (p-value)**
Status	(n=7)	(n=6)	(n=7)	(n=8)	
Very Good	5	2	3	6	.073
Good	1	2	3	2	
Moderate	1	2	1	0	

*significance represents all responses to self-reported overall health

Questions then focused on health status and health conditions. A majority of participants (n=24) wore glasses or contacts for either nearsightedness or farsightedness. Nine participants reported being diagnosed with arthritis. Six participants (3 NH/3 HL) were diagnosed in the last 12 months with depression based on self-report. No participant reported diabetes or angina. A majority of individuals (n=21) reported a mild degree of body aches/pain and energy issues. When asked about difficulties in learning and concentration, no individual reported more than a mild issue. Two-way ANOVAs revealed no statistical significance between groups for vision (*F (1, 24)= 4.080, p=.075*),

arthritis (*F (1, 24)= .008, p=.928*), body aches/pain (*F (1, 24)= 1.041, p=.318*), sleep (*F (1, 24)= ..347, p=.562*), energy (*F (1, 24)= 1.779, p=.195*), worry (*F (1, 24)= .347, p=.562*), concentration (*F (1, 24)= 1.076, p=.310*), learning (*F (1, 24)= .514, p=.480*), and depression (*F (1, 24)= .013, p=.910*). A further breakdown of health status/conditions is presented in Table 5.4.

Table 5.4: Health Status and Conditions Between Groups

Health Status/Condition	**NH 50-59 (n=7)**	**HL 50-59 (n=6)**	**NH 60-69 (n=7)**	**HL 60-69 (n=8)**	**Total**	***Significance (p-value)**
Vision						
No	1	0	0	3	4	.075
Yes	6	6	7	5	24	
Body Aches/Pain						
None	0	1	0	1	2	.318
Mild	6	3	6	6	21	
Moderate	1	2	1	0	4	
Severe	0	0	0	1	1	
Sleep Issues						
None	0	0	3	3	6	.562
Mild	5	3	1	3	11	
Moderate	2	3	3	2	10	
Severe	0	0	0	0	0	

Table 5.4 (continued)

Energy Issues						
None	2	1	1	1	5	.195
Mild	5	4	4	7	20	
Moderate	0	1	2	0	3	
Worry						
None	3	2	4	3	12	
Mild	3	3	3	3	12	.562
Moderate	1	1	0	2	4	
Concentration						
None	2	3	4	3	12	
Mild	5	3	3	5	16	.310
Learning						
None	4	4	7	7	22	
Mild	3	2	0	1	6	.480
Depression						
No	6	6	4	6	22	
Yes	1	0	3	2	6	.675

*significance represents all responses to self-reported health status and conditions

Questions focusing on lifestyle factors such as smoking and alcohol use and physical activity are summarized in Table 5.5. Two participants reported daily current smoking, and only one participant reported zero use of alcohol. Two-way ANOVAs revealed no statistical significance between groups based on smoking (*F (1, 24)= 3.588, p=.070*), alcohol use (*F (1, 24)= .990, p=.330*), and walking (*F (1, 24)= 3.305, p=.082*).

Significance reported below reflects analysis for all responses to self-reported habits of smoking, alcohol, and walking across groups.

Table 5.5: Number of Participants and Self-Reported Habits

Health Behavior	NH 50-59 (n=7)	HL 50-59 (n=6)	NH 60-69 (n=7)	HL60-69 (n=8)	Total	*Significance (p-value)
Smoking						
Daily	0	2	0	0	2	
Yes, not daily	0	0	0	1	1	
Previously	2	1	0	3	6	.070
Not at all	5	3	7	4	19	
Alcohol Use						
No	1	0	0	0	1	
Yes	6	6	7	8	27	.330
Walking in last 7 days						
None	0	0	0	0	0	
One	0	1	1	0	2	
Two	0	1	1	0	2	
Three	2	0	0	0	2	.082
Four	0	1	0	0	1	
Five or More	5	3	5	8	21	

*significance represents all responses to self-reported habits

5.2 Data from Depression and Cognitive Screeners

The PHQ-9 was the depression screener completed via REDCap. This screener contains nine questions related to depression over the last two weeks. No statistical significance was noted between groups and for any individual question using a two-way ANOVA. There was also no statistically significant interaction between HL and age on PHQ-9 (*F (1, 24)= 1.354, p=.256*). A breakdown of the nine responses by group is shown in Table 5.6.

Table 5.6: Participant Responses for PHQ-9 Questions and ANOVA

	NH 50-59 (n=7)	**HL 50-59 (n=6)**	**NH 60-69 (n=7)**	**HL 60-69 (n=8)**	***Significance (p-value)**
Little interest/pleasure in doing things					
Not at all	4	4	7	7	
Several days	2	2	0	0	.283
More than half the days	1	0	0	1	
Feeling Down/depressed/hopeless					
Not at all	6	4	7	7	
Several days	1	2	0	0	.279

Table 5.6 (continued)

More than half the days	0	0	0	1	
Trouble falling/staying asleep					
Not at all	1	2	4	4	
Several days	5	3	2	3	.575
More than half the days	0	1	1	1	
Nearly every day	1	0	0	0	
Tired/having little energy					
Not at all	3	3	5	4	
Several days	3	3	2	3	.838
More than half the days	1	0	0	1	
Poor appetite/overeating					
Not at all	5	4	7	6	.433
Several days	1	2	0	2	
Nearly every day	1	0	0	0	

Table 5.6 (continued)

Feeling bad about yourself/failure/have let family down					
Not at all	5	5	7	6	
Several days	2	1	0	1	.549
Nearly every day	0	0	0	1	
Trouble concentrating					
Not at all	7	3	7	7	
Several days	0	3	0	1	.709
Thoughts that you would be better off dead/hurting yourself					
Not at all	7	6	7	7	.459
Several days	0	0	0	1	

*significance represents all responses to self-reported questions regarding depression

The total summed scores from the PHQ-9 data revealed the majority (n=24) of participants' responses ranged from none to minimal evidence of depression. Four participants scored outside of this range. Two individuals scored within the mild depression range and two individuals scored within the moderate depression range. Between group analysis (ANOVA) indicated no statistical difference on overall PHQ-9 score (*F (1, 24)= .354, p=.256*). There was also no statistical significance between those who reported being diagnosed with depression on the modified WHO survey and PHQ-9 individual questions about depression.

At the start of the study, all participants met the inclusion criteria based on scoring above 25 points on the MoCA. Scores from the MoCA revealed that all participants scored within the normative range (26-30). The mean score and standard deviation of scores from each group are noted in Table 5.7.

Table 5.7: Depression and Cognitive Screening Scores between Groups

	NH 50-59	**HL 50-59**	**NH 60-69**	**HL 60-69**	***Significance (p-value)**
	(n=7)	(n=6)	(n=7)	(n=8)	
Mean (SD) of PHQ-9 scores	29.86 (.378)	29.17 (.983)	29.57 (.535)	28.75 (1.035)	.256
Range of PHQ-9 scores	28-30	28-30	27-30	27-30	
Mean (SD) of MoCA scores	29.86 (.378)	29.17 (.983)	29.57 (.535)	28.75 (1.035)	.607
Range of MoCA scores	28-30	28-30	27-30	27-30	

Several variables (covariates) are known to be highly correlated with cognitive function. To control for these covariates (sex, education, overall health, tobacco use, walking, and depression screening scores [PHQ-9]), a two-way ANCOVA was completed for the cognitive screener (MoCA) to determine if there were group differences. This is important since covariates may interact with the independent variables and obscure the actual relationship between the independent and dependent

variables. No significant difference was revealed between groups on the MOCA when controlling for covariates listed above (*F (1, 18)= .274, p=.607*).

5.3 Audiometric Findings

Audiometric findings from this study included speech recognition testing (SRT), pure tone averages (PTA) from 1000-4000Hz, word discrimination scores (WDS), and HINT testing.

Several variables (covariates) are known to be highly correlated with hearing loss, as discussed in Chapter Two. To control for these covariates (sex, education, overall health, tobacco use, walking, and depression screening scores [PHQ-9]), a two-way ANCOVA was completed for all audiometric tests to determine if there were significant group differences. Significant group differences ($p<.05$) were found between the groups on two of the audiometric tests: PTA R (*F (1, 19)= 4.57, p=.047*), and WDS R (*F (1, 19)= 34.93, p=*<.005). Table 5.8 displays the subtest, R-squared value (variance), partial eta squared value (effect size), and significance, and is further described below.

Table 5.8: ANCOVA Comparing Audiometric Results Between Groups

Audiometric Findings	R-Squared Values	Partial Eta Squared	Significance (p-value)
SRT R (dB)	.260	.061	.293
SRT L (dB)	.466	.028	.479
***PTA R (dB)**	.547	.186	.047

Table 5.8 (continued)

PTA L (dB)	.679	.021	.541
***WDS R (%)**	.785	.660	<.005
WDS L (%)	.464	<.005	.992
HINT (%)	.603	.036	.425

*significant at p<.05

As expected, in the two NH groups, better PTAs were seen than in those with HL. With the exception of the HL 50-59 group, findings revealed that the mean PTAs for each group were found to be slightly better in the right ear than the left ear, which was also found to have a larger range (5-41.25dB) than the right ear (0-33.25dB). For all participants, SRTs ranged from 0 dBHL to 25 dBHL. Those in the older age group, regardless of HL, displayed greater variability in SRT measures as reflected by the standard deviation than those in the young age group. Nevertheless, ANOVA revealed no differences on SRTs among the four groups based on HL and age.

Traditionally, results from WDS are categorized based on the percentage correct. Values that range from 90-100% are considered excellent or within normal limits, while results from 78-88% are considered good or slight difficulty (Schoepflin, 2012). Five participants scored within the good or slight difficulty range, while all other participants scored in the excellent or within normal limits category. Similar to PTA, all groups revealed differences on WDS in the right ear. The HINT was the only speech-in-noise task completed for this study. No group differences were found for this task.

5.4 Analysis of Specific Aim One

The first aim of this study was to allow adults (aged 50-69), with and without hearing loss, to describe the impacts of HL and their communicative abilities through responses to standardized, open-ended questions. These questions were added to determine the perceived impacts of HL, communication abilities with others, and the detection of thoughts and emotions in conversations. Due to the qualitative nature of this aim, no hypotheses were stated. All but one participant allowed for their answers to be digitally recorded. For the exception, detailed handwritten notes were taken by the researcher. These questions took participants three to fourteen minutes to answer.

Prior to the start of any cognitive assessments, all individuals were asked structured questions, which were discussed in Chapter 4. Qualitative analysis began with delineating units of meaning, clustering the units of meaning to form main themes, summarizing each interview, and validation (Groenwalkd, 2004). Analysis employed Nvivo software. Two main overall themes appeared: impacts of HL and conversations with others. Within each of these themes, different subthemes emerged.

For the first theme, the impacts of HL, 10 subthemes were identified, as shown in Table 5.9, along with the number of participants, number of references, and representative quotes that discussed each theme. Quotes provided here do not include vocalized pauses (in one instance, a pause is replaced by elipses), and reflect only the actual words spoken by the participants without any grammatical editing.

Table 5.9: Subtheme, References, and Illustrative Quotes Surrounding Impact of HL

Subtheme	References	Participants	Quotes
Social Isolation	21	15 (NH=6) (HL=9)	*"Honestly it just causes me to withdraw from certain situations so if it's taking too much effort I just withdraw. So, I don't know if that's part of why I kind of tend to keep to myself in my office during the day because it's a lot of effort."* (HL51F-09) *"I supposed if you had an extreme hearing loss, you might feel socially isolated because you would feel like you couldn't really take part in conversations."* (NH60F-13
Frustration/Shame	15	10 (NH=6) (HL=4)	*"I think what I see happening is that… that there's frustration and people around them get frustrated because they keep having to repeat themselves and then I think that, or my perception is, that they may*

Table 5.9 (continued)

			at times feel some shame about not being able to hear it, cause they can tell when people are getting frustrated." (NH54F-10) *"Well there was that and there was also the sort of frustration of not being able to join in conversations."* (HL50M-06)
Unaware of Impacts	14	10 (NH=3) (HL=7)	*"I haven't really thought beyond communication how hearing loss impacts you. I mainly just thought it was conversations."* (HL66M-28) "Well I guess I really haven't thought about it much with my hearing being so good. I don't think about it." (NH59F-05)
Hearing is Impacted by Environments	11	7 (NH=3) (HL=4)	*"I have noticed that I have been unable to hear as well intricate sounds because it is overshadowed by peripheral sound and background noise.*

Table 5.9 (continued)

			So that has prevented me from processing as quickly or at all." (HL67F-03) *Yes but no, because I don't really like big, loud, crazy places, I never have and so what I've noticed is everybody of my age and older is saying: 'Let's not go there, it's too loud'.* (NH58F-01)
HL Impacts Safety	11	7 (NH=4) (HL=3)	*"So overall I would say safety. Be it in various capacities at home, on the road, or any kind of transportation. An announcement at the airport, safety reasons, an announcement in a subway system. Just generally transportation and safety and home and fire issues."* (HL68M-12) *"I would think there are times… well okay running… its nice to hear those cars coming. Its nice to hearing bicycles*

Table 5.9 (continued)

			coming or things coming from behind you and certain situations you kind of want to know." (NH69F-27)
Conversational Issues due to HL	7	6 (NH=4) (HL=2)	*"Well if I don't hear something clearly, I'm not going to understand and maybe because I'm not understanding, I could respond to a person in a way that doesn't make sense or that I may not respond as completely as I should, or miss the point."* (HL59F-22) *"Well I would say that probably some of the nuances… how someone is expressing themselves and whether there is a hesitation in their voice or a sadness being expressed somehow in inflection but that's little stuff, right?"* (NH67F-25)
HL Impacts Cognition	8	6	*"The brain forgets how to hear as if you just*

Table 5.9 (continued)

		(NH=2) (HL=4)	*no longer know how to hear even if you can."* (HL66M-17) *But when you don't hear it you can't possibly begin to process and understand it so there is a whole lot of cognitive stuff going on in the brain that isn't happening if you are not hearing whatever it is that someone is saying to you. Or, any auditory information. You know, someone honking their horn behind you if you can't hear that you don't know to get your face out of your screen and go, right.* (NH67F-25)
QoL is Impacted by HL	4	4 (NH=3) (HL=1)	*"Yeah. I mean I would maybe get used to it but it would definitely impact your functioning, daily functioning."* (HL53F-18) *"Hearing loss may impact well-being, hearing loss may impact productivity. But of course, one of*

Table 5.9 (continued)

			the great composers, Beethoven was deaf and still wrote operas and symphonies. So to a certain extent, yes." (NH66M-14)
HL Inhibits Learning/Curiosity	3	3 (NH=1) (HL=2)	*"As I think about it, I wonder if it's part of the reason my education didn't go further or… the idea that it affects relationships never occurred before. So, kind of got me thinking a little about that."* (HL50M-06) *I think it affect his interest in the outside world. He stopped learning and he stopped his curiosity about anything he may not know. Sometimes his kids just laugh at him.* (NH55F-07)
Loss of enjoyment due to HL	4	3 (NH=1) (HL=2)	*I do not hear the words in the music. Where, when I am speaking to people I hear but its- I don't enjoy music as much because I don't understand*

Table 5.9 (continued)

	the words and the songs. It's the enjoyment. I still listen to it often but it's lost its enjoyment. (HL68F-15)
	"Also, it seems like it would be negative as far as enjoyment just in life because you couldn't hear the music or you couldn't hear a program on television or in the theater or wherever you are." (NH63M-08)

All subthemes had responses from both NH and HL individuals. For those with NH, they either expressed impacts that they have noticed in friends/family or things that they would expect. The most common sub-theme of the impact of HL revolved around social isolation or withdrawal from society, friends, and family due to hearing loss. Frustration/shame and lack of awareness of HL issues were the next two most discussed sub-themes (n=10). Individuals (n=7) also noted that environments, such as those with music or background noise, have an impact on communication. Safety was also a concern that was expressed by participants (n=7). Six individuals discussed the major impact HL has surrounding communication issues. Individuals did discuss how the brain and cognition (n=6) as well as QoL (n=4) were impacted by hearing loss. The last two sub-themes were minimal observations, with three references each, focused on the perceived

negative effects of HL. Participants discussed how HL inhibits learning, curiosity, and enjoyment in life. All of these subthemes focused on the perception that individuals have towards the impacts of HL on an individual.

The second main theme revolved around how adults described their communicative abilities with others. Individuals were asked questions which surrounded if they could accurately convey their own thoughts/feelings/emotions/viewpoints and understand others' thoughts/feelings/emotions/viewpoints. Within this theme, two other subthemes arose: conversations with others and ability to detect emotions. When asked if participants could convey their own thoughts/feelings/emotions/viewpoints, all participants (n=10) felt that they could accurately express themselves. Participants were then asked if they could understand other thoughts/feelings/viewpoints. Only two participants, both in the HL60-69 group, expressed some issues with understanding others' thoughts/viewpoints. Interestingly, these two participants were a married couple.

Participants were then asked if they could understand both positive and negative emotions during conversations. All participants expressed that they could understand both emotions, but they had differing views on if they understood the emotions equally or one more so than the other. To understand if there was statistical significance present, a two-way ANOVA (Table 5.10) was conducted to examine the interaction between groups and the type of emotion expressed. This analysis yielded no statistically significant interaction (p=.657). Table 5.11 highlights the number of references and quotes from individuals.

Table 5.10: Group Breakdown of the Ability to Detect Negative and Positive Emotions

	NH 50-59 (n=7)	HL 50-59 (n=6)	NH 60-69 (n=7)	HL 60-69 (n=8)	Total	*Significance (p-value)
Positive	1	0	1	0	2	
Negative	3	3	1	4	11	.657
Equally	3	3	5	4	15	

*significance represents all responses to all emotions

Table 5.11: Subtheme Surrounding the Ability to Detect Emotions with References and Illustrative Quotes

Emotion	References	Participants	Quote
Negative and Positive Emotion Equally	15	15 (NH=9) (HL=6)	*"I pick them both up a lot. I feel like I am very empathetic, and I absorb a lot of energy, positive and negative."* (HL67F-03) *Don't think so. I try to be a very balanced person and look for everything.* (NH69F-27)
Negative Emotions	11	11 (NH=4) (HL=7)	*"Hmm, I think I tend to be more aware of negative aspects of things. So maybe I pick up a tiny bit more on negative than positive."* (HL66M-28) *"Maybe negatives more because you pay attention to it. You don't want the negative, you pick up negatives saying, "this is so negative.*

Table 5.11 (continued)

			Sometimes positive you just ignore right you take it for granted." (NH55F-07)
Positive Emotions	2	2 (NH=2) (HL=0)	*"More positive or negative… I like to hear positive emotions, so negative, I block."* (NH66M-14) *Well, I mean it would just have to be the positive because people don't really talk negative like that, you know* (NH59F-05)

The first aim of this study was to examine how adults (aged 50-69), with and without hearing loss, describe their communicative abilities and the impacts of HL. Participants described the ways that HL could influence an individual's life by way of social isolation and frustration/shame. The next common sub-theme was that individuals had no thoughts on the influence that HL may have on cognitive abilities. Of the participants, six participants described how HL could affect cognitive abilities. Questions regarding communication issues revealed that all participants felt that they could accurately express themselves. When discussing understanding others' thoughts/feelings/viewpoints, only 2 participants expressed some issues with understanding others' thoughts/viewpoints. All participants stated that they could understand both emotions, but when probed if they detected one emotion more than the other, they had differing views. Only 2 participants detected positive emotions more, 11 detected negative emotions, and 15 detected these emotions equally.

5.5. Analysis of Specific Aim Two

The second aim of this study was to determine if group differences existed on social cognitive tasks in adults 50-69 years old with NH and HL using performance-based social cognition/executive functioning assessments while controlling for health and lifestyle covariates. The hypothesis of this aim was that there would be group differences between all social cognitive abilities on cognitive performance-based assessments and degree of hearing loss and age, even when covariates are controlled.

In order to determine if group differences were present on social cognitive function, each participant underwent two social cognitive assessments: the Advanced Clinical Solutions (ACS) and Faux Pas test (FPT). The ACS was comprised of 13 subtests, while the FP was one test. Participants could score a total of 60 points on the FPT. All participants (n=28) obtained full points on this assessment; as such, no differences were noted on the FPT. All participants (n=28) completed both assessments. The mean score and standard deviation of the ACS scores from each group are noted in Table 5.12.

Table 5.12: Mean Scores and Standard Deviation for ACS Subtests Between Groups

ACS Subtest	NH 50-59	HL 50-59	NH 60-69	HL 60-69
	(n=7)	(n=6)	(n=7)	(n=8)
Social Perception	38.14 (4.22)	37.00 (2.61)	38.29 (4.31)	34.88 (3.87)
Affect Naming	18.29 (2.06)	18.17 (1.33)	18.43 (1.99)	16.37 (2.45)
Prosody	19.86 (2.27)	18.83 (1.47)	19.86 (3.46)	18.63 (1.69)
Pairs	35.29 (4.57)	35.33 (2.58)	37.71 (5.02)	29.50 (9.15)

Table 5.12 (continued)

Faces I	84.29 (11.09)	83.00 (4.78)	92.00 (6.51)	71.13 (14.51)
Faces II	23.57 (5.06)	22.83 (2.40)	27.43 (2.44)	20.00 (1.77)
Content	39.43 (4.50)	38.67 (1.51)	40.43 (6.08)	36.25 (3.66)
Spatial	42.43 (2.70)	40.17 (0.98)	43.14 (2.97)	35.75 (2.49)
Names I	50.71 (11.46)	21.50 (4.81)	44.43 (10.36)	23.25 (4.20)
Names II	23.29 (6.10)	10.50 (4.51)	17.71 (3.09)	11.63 (2.39)
Proper Names	42.86 (11.26)	18.50 (5.32)	37.86 (9.55)	20.00 (2.98)
Activity	32.14 (5.34)	13.17 (3.97)	24.29 (4.23)	14.14 (3.59)
Emotion	2.57 (1.13)	1.50 (0.84)	2.43 (1.40)	1.50 (1.51)

A two-way ANOVA was conducted to examine the interaction of HL and age on the ACS assessment. Five subtests had a statistically significant interaction between groups ($p<.05$). These subtests include Faces I (*F (1, 24)= 6.19, p=.020*) and II (*F (1, 24)= 7.74, p=.010*), Spatial (*F (1, 24)= 7.55, p=.011*), Names II (*F (1, 24)= 4.12, p=.046*), and Activity (*F (1, 24)= 8.72, p=.007)*. Table 5.13 summarizes ANOVA findings for the each of the subtests within the ACS.

Table 5.13: ANOVA Comparing ACS Subtests Between Groups

ACS Subtest	R-squared	Eta Squared	Significance (p-value)
Social Perception	.137	.100	.447
Affect Naming	.176	.085	.224
Prosody	.065	.064	.909
Pairs	.168	.058	.268

Table 5.13 (continued)

***Faces I**	.396	.233	.020
***Faces II**	.464	.287	.010
Content	.139	.094	.309
***Spatial**	.637	.464	.011
Names I	.731	.708	.217
***Names II**	.632	.534	.046
Proper Names	.678	.658	.292
***Activity**	.787	.677	.007
Emotion	.154	.152	.884

*significant at p<.05

ANCOVA was also completed for the ACS to control for interactions of covariates (Table 5.14). There was a statistically significant interaction between HL and age on five subtests while controlling for covariates of sex, education, overall health, tobacco, walking, and PHQ-9 scores. These five subtests included the Faces I (*F (1, 18)= 8.06, p=.011*) and II (*F (1, 18)= 6.63, p=.019*), Spatial (*F (1, 18)= 5.65, p=.029*), Names II (*F (1, 18)= 2.51, p=.048*), and Activity (*F (1, 18)= 2.03, p=.044*).

Table 5.14: ANCOVA Comparing ACS Subtests Between Groups

ACS Subtest	R Squared	Partial Eta Squared	ANCOVA Significance (p-value)
Social Perception	.376	.000	.949
Affect Naming	.350	.000	.994
Prosody	.388	.002	.844
Pairs	.254	.010	.690

Table 5.14 (continued)

***Faces I**	.583	.309	.011
***Faces II**	.866	.480	.019
Content	.415	.070	.274
***Spatial**	.637	.239	.029
Names I	.754	.013	.645
***Names II**	.632	.155	.048
Proper Names	.724	.002	.840
***Activity**	.864	.218	.044
Emotion	.504	.056	.331

*significant at $p<.05$

The second aim of this study was to determine if group differences existed on social cognitive tasks while controlling for health and lifestyle covariates. Results from ANOVA and ANCOVA testing support the initial hypothesis; differences in cognition were detected between those with NH and HL. Of the thirteen subtests on the ACS, five subtests revealed a statistically significant interaction while controlling for covariates. There was no significant interaction between HL and age on the FPT.

5.6 Analysis of Specific Aim Three

The aim of the first question was to determine if group differences existed in cognitive function (specifically attention and memory) in adults 50-69 years old with and without HL. This was assessed using cognitive performance and neurologically-based tests. There were two hypotheses for this aim:

Hypothesis 1: There will be group differences in cognitive abilities (attention and memory) based on cognitive performance assessments.

Hypothesis 2: There will be group differences in cognitive abilities (short-term memory) on a neurologically-based test and EEG assessment.

In order to determine if group differences were present on cognitive function, participants underwent cognitive performance assessments (WMS and WAIS) and neurologically-based tests that paired the Bluegrass Short-Term Memory task with EEGs. All participants completed the WMS and WAIS, while the Bluegrass Short-Term Memory task was successfully completed only by 24 of the 28 total participants. Three participants were unable to be tested due to COVID-19 restrictions and one participant, even after repeated re-instruction, did not comprehend the task. The adjusted sample size, mean score, and standard deviation of scores from each group are noted in Table 5.15.

Table 5.15: Mean Scores and Standard Deviation for Memory and Attention Subtests Between Groups

WMS Subtest	NH 50-59 (n=7)	HL 50-59 (n=6)	NH 60-69 (n=7)	HL 60-69 (n=8)
Logical Memory I	44.86 (1.86)	33.50 (2.51)	41.57 (2.15)	26.00 (3.42)
Logical Memory II	39.71 (1.70)	20.83 (2.23)	29.14 (2.79)	14.88 (2.36)
Verbal Paired Associates I	42.29 (9.43)	35.33 (11.39)	37.57 (4.12)	30.75 (6.61)
Verbal Paired Associates II	12.86 (1.35)	10.00 (3.10)	11.57 (1.62)	9.75 (1.39)
Designs I	78.43 (12.65)	68.17 (6.40)	75.86 (7.97)	65.50 (6.66)
Designs II	60.71 (9.45)	58.67 (4.13)	60.71 (13.67)	59.25 (6.52)
Visual	38.14 (1.46)	27.50 (5.35)	39.71 (1.25)	30.38 (1.69)
Visual	33.43 (2.82)	14.67 (5.05)	27.43 (5.26)	15.75 (4.06)
Spatial	10.43 (1.27)	11.67 (3.08)	12.86 (2.79)	10.50 (1.41)
Symbol Span	23.00 (7.14)	19.17 (5.78)	21.24 (4.81)	20.25 (7.54)
Logical	27.57 (1.90)	24.00 (2.68)	28.43 (0.98)	23.00 (3.82)

Table 5.15 (continued)

Verbal Paired Recognition	39.71 (0.49)	33.50 (13.04)	39.57 (0.79)	38.75 (1.04)
Designs I	39.86 (3.53)	37.67 (2.42)	37.71 (4.99)	38.88 (1.13)
Designs I	17.00 (3.42)	17.17 (2.14)	16.71 (3.20)	15.88 (2.70
Designs II	38.86 (2.61)	37.00 (1.79)	37.14 (5.46)	38.88 (1.73)
Designs II	10.71 (0.95)	14.00 (3.52)	12.43 (2.76)	12.62 (2.39)
Designs II	17.57 (2.23)	14.83 (1.60)	17.00 (2.31)	13.75 (1.67)
Visual Reproduction II Recognition	6.57 (0.54)	6.00 (1.10)	6.43 (0.54)	6.00 (0.93)
WAIS Subtest				
Digit Span	31.29 (3.25)	28.33 (2.42)	31.71 (2.75)	27.37 (2.13)
Arithmetic	19.29 (1.50)	18.00 (1.10)	17.63 (2.26)	16.29 (2.36)
Coding	70.86 (15.49)	64.67 (16.48)	71.57 (5.16)	59.88 (6.96)
Symbol Search	35.43 (5.44)	30.67 (3.27)	30.57 (3.16)	24.63 (5.24)
Bluegrass Short Term				
Correct Responses Trial 1 (%)	91.67 (5.56)	96.88 (0.85)	84.72 (8.48)	87.71 (7.34)
Incorrect Responses Trial 1(%)	2.29 (2.69)	1.56 (0.60)	9.03 (13.02)	2.26 (1.15)
Missed Responses Trial 1 (%)	6.04 (4.06)	1.56 (0.60)	6.25 (5.21)	10.21 (7.00)
Mean Reaction Time Correct Responses Trial 1	0.64 (0.05)	0.62 (0.03)	0.69 (0.07)	0.72 (0.06)
Mean Reaction Time Incorrect Responses Trial 1	0.45 (0.41)	0.61 (0.08)	0.48 (0.42)	0.73 (0.13)
Correct Responses Trial 2 (%)	80.00 (19.25)	96.35 (2.48)	89.24 (4.69)	87.08 (9.36)

Table 5.15 (continued)

Incorrect Responses Trial 2 (%)	12.50 (21.60)	1.04 (0.85)	1.39 (0.60)	3.54 (4.69)
Missed Responses Trial 2 (%)	7.50 (4.96)	2.60 (1.80)	9.38 (5.21)	9.36 (5.21)
Mean Reaction Time Correct Responses Trial 2	0.63 (0.06)	0.63 (0.02)	0.69 (0.05)	0.71 (0.03)
Mean Reaction Time Incorrect Responses Trial 2	0.57 (0.13)	0.52 (0.35)	0.67 (0.18)	0.61 (0.36)

A two-way ANOVA was conducted to determine if group differences were present on each individual subtest. There was a statistically significant interaction between four subtests of the WMS and one of the WAIS subtests. These subtests included Logical Memory I (*F (1, 24)= 4.55, p=.043*) and II (*F (1, 24)= 6.91, p=.015*), Visual Reproduction II (*F (1, 24)= 4.57, p=.043*), Spatial Addition (*F (1, 24)= 4.57, p=.043*), and Arithmetic (*F (1, 24)= 5.34, p=.030*). The two-way ANOVA for the Bluegrass Short-Term Memory task revealed no statistically significant interaction between groups on any of the responses from this task. Table 5.10 lists ANOVA results for WMS subtests, WAIS subtests, and Bluegrass Short-Term memory tasks between groups.

EEG energy output was measured and calculated through MATLAB software version R2020a. Data were extracted into EEG signatures based on frequency (delta, theta, alpha, beta, and gamma) and channel (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8,

FC6, F4, F8, and AF4) during resting state eyes open and eyes closed. The data obtained is the mean power during one-minute eyes open and eyes closed (uV^2/Hz). A two-way ANOVA revealed only two EEG signatures having a statistically significant interaction, both during eyes open: left theta frontal (theta AF3) (*F (1, 21)= 5.113, p=.034*) and right frontal beta (beta O1) (*F (1, 21)= 4.835, p=.036*). Due to the large number of possible signatures only the significant ANOVA results are reported in Table 5.16. (Full EEG results are listed in Appendix E).

Table 5.16: ANOVA Comparing Memory and Attention Subtests Findings and EEG Signatures Between Groups

	R-Squared Values	**Eta Squared**	**Significance (p-value)**
WMS Subtest			
*Logical Memory I	.908	.777	.043
*Logical Memory II	.852	.759	.015
Verbal Paired Associates I	.244	.173	.983
Verbal Paired Associates II	.338	.293	.484
Designs I	.306	.289	.989
Designs II	.011	.010	.934
Visual Reproduction I	.792	.751	.543
*Visual Reproduction II	.792	.732	.043
*Spatial Addition	.193	.020	.043
Symbol Span	.050	.034	.556
Logical Memory Recognition	.479	.460	.361

Table 5.16 (continued)

Verbal Paired Recognition	.160	.067	.248
Designs I Content	.079	.005	.195
Designs I Spatial	.034	.006	.655
Designs II Content	.080	<.001	.161
Designs II Spatial	.189	.100	.120
Designs II Recognition	.431	.400	.737
Visual Reproduction II Recognition	.106	.101	.817
WAIS Subtest			
Digit Span	.371	.357	.499
*Arithmetic	.265	<.000	.030
Coding	.172	.253	.542
Symbol Search	.478	.152	.731
Bluegrass Short Term Memory			
Correct Responses Trial 1	.233	.021	.520
Incorrect Responses Trial 1	.134	.035	.404
Missed Responses Trial 1	.253	.136	.092
Mean Reaction Time Correct Responses Trial 1	.266	.010	.652
Mean Reaction Time Incorrect Responses Trial 1	.082	.003	.792
Correct Responses Trial 2	.200	.136	.091
Incorrect Responses Trial 2	.146	.085	.185

Table 5.16 (continued)

Missed Responses Trial 2	.275	.057	.284
Mean Reaction Time Correct Responses Trial 2	.330	.001	.887
Mean Reaction Time Incorrect Responses Trial 2	.019	.002	.827
EEG Signatures			
*Theta AF3	.275	.196	.035
*Beta O1	.128	.201	.036

*significant at p<.05

To control for the effects of known covariates on cognition, a two-way ANCOVA was completed for all assessments. Covariates such as sex, education, overall health, tobacco use, walking, and PHQ-9 scores were included. There was a statistically significant interaction between HL and age on three WMS subtests while controlling for these covariates. These three subtests included Logical Memory I (*F (1, 18)= 9.43, p=.011*) and II (*F (1, 18)= 2.63, p=.028*) as well as Spatial Addition (*F (1, 18)= 5.99, p=.010*). Only one subtest, Visual Reproduction II, was no longer statistically significant after controlling for these variables. On the WAIS, the interaction between HL and age on Arithmetic (*F (1, 18)= 5.91, p=.026)* was still significant after controlling for covariates. As stated previously, data obtained from the Bluegrass Short-Term Memory task included the percentage of correct, incorrect, and missed responses as well as reaction times for these responses. No changes were noted on the correct, incorrect, and missed responses or response times for the Bluegrass task. For the EEG signatures, there was one signature that still showed an interaction during analysis: theta AF3 (*F (1, 16)= 4.254, p=.050*). ANCOVA analysis revealed that the beta F8 (*F (1, 16)= 11.181, p=.007*)

signature was significant while controlling for variables. The interaction between HL and age on beta O1 was no longer considered significant after completing the ANCOVA (p= .340). Table 5.17 summarizes significant ANCOVA findings for the each of the subtests within the WMS, WAIS, Bluegrass Short-Term Memory, and significant EEG signatures.

Table 5.17: ANCOVA Comparing Memory and Attention Subtest Findings and EEG Signatures Between Groups

WMS Subtest	R Squared ($R^{2)}$	Partial Eta Squared (η2)	Significance (p-value)
*Logical Memory I	.950	.336	.011
*Logical Memory II	.959	.452	.028
Verbal Paired Associates I	.544	.022	.542
Verbal Paired Associates II	.668	.086	.222
Designs I	.005	.573	.779
Designs II	.451	.021	.552
Visual Reproduction I	.892	.013	.638
Visual Reproduction II	.843	.051	.351
*Spatial Addition	.677	.480	.010
Symbol Span	.020	.382	.568
Logical Memory Recognition	.633	.084	.228

Table 5.17 (continued)

Verbal Paired Recognition	.576	.024	.527
Designs I Content	.384	.099	.190
Designs I Spatial	.420	.074	.258
Designs II Content	.383	.055	.336
Designs II Spatial	.364	.161	.089
Designs II Recognition	.561	.016	.609
Visual Reproduction II Recognition	.226	.019	.573
WAIS Subtest			
Digit Span	.592	.099	.191
*Arithmetic	.380	.247	.026
Coding	.420	.003	.820
Symbol Search	.647	.012	.662
Bluegrass Short Term Memory Task			
Correct Responses Trial 1	.537	<.005	.558
Incorrect Responses Trial 1	.492	.061	.358
Missed Responses Trial 1	.508	.055	.089

Table 5.17 (continued)

Mean Reaction Time for Correct Responses Trial 1	.458	.018	.624
Mean Reaction Time for Incorrect Responses Trial 1	.357	<.005	.971
Correct Responses Trial 2	.346	.157	.090
Incorrect Responses Trial 2	.254	.072	316
Missed Responses Trial 2	.457	.080	.287
Mean Reaction Time for Correct Responses Trial 2	.608	.058	.368
Mean Reaction Time for Incorrect Responses Trial 2	.216	.007	.758
EEG Signatures-Eyes Open			
*Theta AF3	.514	.233	.050
*Beta F8	.636	.415	.007

*significant at p<.05

The two hypotheses for this aim stated that there would be group differences in cognitive abilities based on cognitive performance assessments and neurologically-based tests and EEGs. Both hypotheses were confirmed. The first hypothesis was confirmed since statistical analysis determined group differences were noted on 4 of

the 22 subtests in the WMS and WAIS. The second hypothesis stated that there would be group differences between a short-term memory task and EEG findings. While no group differences were noted on the Bluegrass Short-Term Memory task, differences were noted on EEGs, since there were two EEG signatures out of 140 that revealed a statistically significant interaction between HL and age.

5.7 Findings Summary

Twenty-eight adults enrolled in this study, which had the overall purpose of describing the group differences on perceived and performance based cognitive assessments of adults with and without HL. The first aim examined how adults described the impacts of hearing loss and their communicative abilities. Individual responses highlighted what impacts adults thought HL had beyond communication and their communicative abilities. The majority of adults expressed that they did not have any communication errors and could accurately express their own thoughts/viewpoints/emotions and understand others' thoughts/viewpoints/emotions.

The second and third aim utilized cognitive and neurologically-based assessments to determine if group differences were present. Group differences were present on three of the 18 memory subtests from the WMS: Logical Memory I and II and Spatial Addition. One of the four attention subtests from the WAIS, Arithmetic, revealed a significant interaction between scores and HL and age. While there was no significant difference between responses on the Bluegrass Short-Term Memory task, there was an interaction on theta AF3 and beta F8 EEG signatures. The ACS revealed group differences on five of the 13: Faces I and II, Spatial, Names II, and Activity. The

hypotheses from these two aims were supported by the findings since group differences were noted on memory, attention, and social cognition tasks.

In the midst of analyses of study findings, certain factors became points of interest that require further discussion. The discussion of these factors is discussed in the following chapter.

CHAPTER 6. DISCUSSION AND CONCLUSION

6.1 DISCUSSION

This dissertation was developed to add to the current knowledge and understanding about what differences exist in cognition in adults between the ages of 50-69 years with and without hearing loss (HL). Specifically, the author sought to explore the cognitive domains of memory, attention, and social cognition in individuals with and without hearing loss (HL). This relationship between cognition and HL is a multifaceted one as a result of the complexity of both of these systems. While there is a current research trend toward addressing these concepts in large population studies with cognitive screening tools, there is no known research about the effect of hearing status on neurologically-based assessments in persons aged 50-69 years. Furthermore, there is little research centered around aging adults in this age range and their perception of the impacts of age-related HL. This chapter will first summarize and discuss demographic characteristics of this study population and specific aims. Each specific aim was developed to contribute to the growing literature on the interaction between HL and cognition. The first aim evaluated the perception of adults with and without HL about the impacts of HL on their own communication abilities. The second and third specific aims evaluated group differences that may be present when assessing HL and memory, attention, and social cognition abilities, while controlling for variables that may have an influence. The findings from each aim will be addressed along with additional findings that emerged within the context of research that supports or contradicts these findings. This will be followed by a discussion of the limitations of the study, clinical implications, future directions, and conclusions.

Demographic Characteristics (n=28)

All demographic, health status, and health condition information was obtained via self-report. While self-reporting is a common approach to obtain data for health research, such data may be unreliable; it has the potential to be threatened by self-reporting biases, such as social desirability or recall bias (Althubaiti, 2016). Limitations associated with self-reporting are discussed late in this chapter.

Demographic characteristics of the study population were assessed to determine domains of representativeness. The population of this study was mainly female, white, well-educated, non-smoking, healthy overall, and working full-time. As such, this study was homogeneous to a degree that may have had an effect on all findings. Thus, even though sex was controlled for during analyses, findings related to memory and verbal learning tasks could be affected as sex differences are observed in cognitive functioning, where females often outperform men on memory and verbal tasks (Jorm et al., 2004; Van Hooren et al., 2007; Munro et al., 2012; Rochette et al., 2017). However, such sex differences are not found on tasks of attention and executive functioning (Van Hooren et al., 2007; Munro et al., 2012).

The study population was also well educated, with more than half of the participants completing post-graduate degrees (M.D., Ph.D.) (n=15). Although education was controlled for, prior research has shown that higher levels of education often equate with better cognitive domain performance and IQ later in life (Ritchie et al., 2013; Guerra-Carrillo et al., 2017). While statistical analysis determined that overall health did not have a significant interaction with hearing loss and age ($F\ (1, 24)= 3.527, p=.073$), the p-value approached significance and suggested a potential for significance.

Six of the 28 participants on the REDCap survey self-reported being diagnosed with depression in the last 12 months, yet only four participants scored outside of the none-to-minimal depression range on the PHQ-9. Further, no participant reported the use of antidepressants in their list of medications. Individual responses to every question on the PHQ-9 were analyzed for each participant who scored outside of the none-minimal depression range. However, no patterns among questions were observed. Comparably, scores on the MoCA were all within normal limits and had minimal variance, with scores ranging from 27 to 30 points. While the MoCA is known to be sensitive enough to detect MCIs, this screener may not be sensitive enough to describe cognitive function. Although the MoCA screener does assess a wide variety of cognitive domains, the results from the present study suggest that the MoCA may not be taxing enough on the auditory and cognitive systems in cognitively intact individuals to demonstrate changes in cognitive function. As such, future research may need to focus on evaluating individuals using more targeted episodic memory tasks, such as LM. Given that previous research has suggested that episodic memory is a key early marker in prodromal stages of Alzheimer's disease (MCI) (Marruff et al., 2004; Rabin et al., 2009) this may help to earlier identify cognitive impairments.

Research has indicated that HL is independently correlated with depression and cognitive decline using screeners (Arlinger, 2003; Lin et al., 2013; Dawes et al., 2015). This research did not find a correlation between these factors, which could be due to the age of participants and HL compared to other studies. Previous research often assessed adults over the age of 70, particularly ones who had HL ranging in the moderate to profound range (Lin et al., 2013; Dawes et al., 2015), while this research focused on

adults between the ages of 50-69 years with normal to moderate HL. Pronounced degrees of HL and advanced age will cause marked structural and functional changes in the brain, which can lead to higher rates of social isolation, depression, and cognitive decline (Lin et al., 2013; Dawes et al., 2015).

To divide participants into groups, audiometric findings from pure tone (PT) testing were applied to separate participants among four different groups based on hearing status and age: NH 50-59, HL 50-59, NH 60-69, and HL 60-69. Given that PT testing is considered the "gold standard" of hearing tests, it is sensitive to the changes that occur in aging adults (Hewitt, 2018). In fact, most HL and cognitive research defines hearing based on PTA (pure tone averages from each individual from 500-4000 Hz) thresholds (Lin et al., 2014).

While PT testing is still considered to be the most useful audiometry assessment, it is not reliable in predicting perceptual difficulty with speech in quiet and in noise (Crandell et al., 1991). Speech audiometry testing (SRT, WDS, and HINT), on the other hand, is more complex and requires more cognitive processing (attention, working memory, concentration, vocabulary and speed of processing) than PT testing; as such, it is a useful audiometric assessment (Wong et al., 2010; Hoth & Baljic, 2017).

When assessing PTA and WDS, each of the four groups had a better overall mean score for the right ear than the left ear. These right ear findings may be due to a phenomenon called the right ear advantage, or REA. REA is thought to be based on the unique pattern of auditory and neurological pathways inherent to the central auditory system. As auditory signals from the cochlea are sent to the primary auditory cortex of the ipsi- and contralateral hemispheres, these signals are predominantly sent to the

contralateral side of the originating ear (Westerhausen & Hugdahl, 2008). The left hemisphere of the brain is dominant in speech processing, perception, and production, plus it receives the majority of auditory information directly from the right ear (Wettstein & Probst, 2018). When auditory information is sent from the left ear, information must travel from the right hemisphere through the corpus callosum to the left hemisphere, which causes a slight time delay. As such, right ear is known to be more sensitive to simple sounds and processing complex sounds due to its direct communication with the left hemisphere (Chung et al., 1983; McFadden, 1993; Tadros et al, 2005; Westerhausen & Hugdahl, 2008). This advantage is mainly noted for the mid-frequency range for both males and females (Pirila, 1991). Interestingly, while REA has been noted in all audiometric tests, this current study only found it to occur in PTA and WDS findings. Previous research assessing REA in age-related HL determined no statistical significance in PT testing but there was significance in speech-in-noise testing (Tadros et al., 2005). While WDS was not assessed in the previous study, the design contained a similar grouping to the current study based on NH and HL and age range (56-76 years). This finding suggests that REA in adults 50-69 remains intact.

The HINT was the only speech-in-noise task completed for this study. No group differences were found for this task. Unlike speech tasks that are completed in quiet, speech-in-noise tasks require the individual to target speech while ignoring other unwanted acoustical signals, hold relevant acoustic speech signals, sustain attention, and hold speech segments in working memory (Lad et al., 2020). With increasing age, an individual's capacity to perceive speech in noise diminishes, either due to cochlear sensitivity declines or temporal processing deficits (Gordon-Salant & Fitzgibbons, 1993;

Frisina & Frisina, 1997; Frisina and Walton, 2001; Ison et al., 2001). While research has determined that the capacity to perceive speech in noise diminishes with increasing age, there is often a large degree of variability when compared to PT results. This could potentially be explained by varied cognitive processes and functional levels (different types of attention and memory) used for listening in complex environments. The extent to which central factors contribute to this variability has yet to be identified (Akeroyd, 2008; Holmes & Griffiths, 2019; Lad et al., 2020). When comparing adults 18-27 years old to adults 62-75 years old in fMRI studies with speech perception tasks, it was found that older adults experienced a decline in volume and cortical thickness of the prefrontal cortex (PFC), which may reveal the link between neural anatomy and speech perception in older adults (Wong et al., 2010). Previous research has attempted to link speech-in-noise perception to attention and working memory, but no reliable correlations have arisen (Akeroyd, 2008). Due to the variety of cognitive resources needed to complete the HINT, the researcher expected for this task to show the most group differences, yet it did not. There could be several reasons for this. First, perhaps the HINT paired with white noise was not complex enough to stress the cognitive resources and impact cognitive load as compared to other speech-in-noise tests (Lee et al., 2015). Second, participants in the current study were younger than those in previous studies (Frisina and Walton, 2001; Ison et al., 2001; Wong et al., 2008; Wong et al., 2010). Third, the degree of HL noted in the current study was between the mild to moderate range unlike previous studies which included HL from moderate to profound (Frisina and Walton, 2001; Ison et al., 2001; Wong et al., 2008; Wong et al., 2010). Given that age and HL both have an impact on speech perception, the findings here suggest that this younger aging adult population with

less hearing loss, does not present with the same overall deficits related to speech in noise as older aging adults with more hearing loss. HL was not as severe as to have a measurable impact on these scores when compared to previous research (Walton et al., 2002; Wong et al., 2008; Wong et al., 2010)

6.2 Aim One Discussion

The first aim of this research was to understand how adults with and without hearing loss described the impacts of HL beyond communication and their own communicative abilities. When participants were probed with open-ended questions about the impacts of hearing loss beyond communication, two primary themes emerged: social isolation and frustration/shame. This is consistent with previous research that suggested that, other than communication difficulties, social isolation is the most substantial consequence of HL and, furthermore, that individuals with HL experience shame/frustration as a result (Strawbridge et al., 2000; Kramer et al., 2002; Dalton et al., 2003; Pronk et al., 2013). Other questions which focused on communicative abilities determined that adults in this study did not notice any difficulties with receptive or expressive language, even when reflecting on their ability to understand differing emotions.

Another subtheme centered around unawareness of the impact of HL on an individual. Many of the participants in this study assumed that they had some degree of HL prior to testing but never actively considered the impacts. For example, one participant (HL50M-06) initially stated that he related HL primarily to issues in communicating but at the end of the interview he wondered if the HL that he had had since his early 20s hindered his education and relationships throughout his life.

Although individuals were specifically asked about the impacts of HL beyond communication, communication was still the main issue that came to mind. Two individuals discussed issues with accents, three discussed regularly missing the main point in conversation, and one discussed missing out on the nuances of conversations. Six individuals explained that HL has an impact on cognition, such as the brain forgetting how to hear, shutting down, and processing issues:

> "*The brain forgets how to hear as if you just no longer know how to hear even if you can"* -HL66M-17
>
> "*You aren't hearing well and then just that part of your brain shutting down"* -NH58F-02
>
> "*But when you don't hear it you can't possibly begin to process and understand it so there is a whole lot of cognitive stuff going on in the brain that isn't happening if you are not hearing whatever it is that someone is saying to you."* -NH67F-25
>
> "*Well, what I have experienced myself is being able to hear intricate sounds as far as communication inhibits that processes of what that information would be. So, if I am hearing it at a slower rate than I am processing it slower or not at all."* -HL67F-03

Four participants discussed QoL being impacted on an everyday basis. Two of these participants stated that while QoL may be impacted, that they may "get used to it" (HL53F-18; NH66M-14). While participant NH66M-14 expressed QoL being impacted, he also reported it may only occur to a certain extent:

> "*Hearing loss may impact well-being, hearing loss may impact productivity. But of course, one of the great composers, Beethoven was deaf and still wrote operas and symphonies. So to a certain extent, yes."*

The last two subthemes centered around HL inhibiting learning/curiosity and leading to loss of enjoyment. Two participants with HL noticed an impact on their learning due to not understanding conversations. As discussed above, one participant felt that his HL only impacted conversations but later questioned if his education had also

been impacted. Another participant felt that her father-in-law's HL had hindered his learning and curiosity. She reported:

"*He stopped learning and he stopped his curiosity about anything he may not know."*

A loss of enjoyment due to HL was discussed by three individuals. Each of these participants, two with HL and one NH, discussed losing enjoyment centered around music. One participant started dancing a few years ago at a local dance company and has noticed a loss of enjoyment in this new hobby. She stated:

> "*It has impacted the… absolutely, the dancing. But it starts with hearing the beats, the musical beats. I can hear the music just fine. I can hear the language and the lyrics; I can hear all that. It's those intricate beats that I cannot hear so I cannot feel them. So, then I cannot keep time with my feet well enough."* -HL67F-03

This participant felt that she could understand the words but not the beats, while the other HL participant felt that she could not understand and enjoy the words in the music. The individual with NH felt that losing hearing meant that one would be unable to hear the music.

All participants felt that they could accurately express their own thoughts/viewpoints. This finding is not supported by previous research which has suggested that those with HL will have issues with conversational fluency, or communication with minimal struggle (Cassie & Rockwell, 1993; Cassie, 2000; Erber, 2002). Findings suggest that while fluency issues may be measured based on clinical assessments, the participants in this study with HL did not notice these issues. Previous research utilized clinical assessments and did not utilize open-ended questions to determine perceived effects. In addition, the participants in this study were relatively

younger and had better hearing than those in previous research, since the previous research had participants as old as 95 years with severe hearing loss (Erber, 2002).

The majority of individuals (n=26) stated they could understand others' thoughts/viewpoints during information exchanges. Only two participants with HL (who were married) reported that they had issues understanding others' thoughts/viewpoints. This question was used to address self-reported receptive language observations, since the exchange of information with others is an aspect that may be negatively impacted in those with HL and cognitive issues (Dalton et al., 2003; Kricos, 2006). The findings from this question do not correlate with previous research. Research has suggested that those with HL will have issues with conversational fluency and verbal comprehension when measured via clinical assessments (Cassie & Rockwell, 1993; Cassie, 2000; Erber, 2002; Loderio-Fernandez et al., 2015). In a review of the literature, research has noted that there is often a mismatch between clinical assessments and self-reported data. While there may be a mismatch, it is important to obtain self-reported data when attempting to understand an individual's perceived effects. Perceived impacts may provide insight as to what the individual is experiencing, which may be missed in clinical assessments.

All participants in the current study stated that they could perceive emotions, but they had differing views on which emotion they could detect the most regularly. Only two participants (7%) felt as though they detected positive emotions the most frequently; 11 participants (39%) detected negative emotions more frequently and 15 (54%) detected both emotions similarly. Understanding and expressing emotional content, both vocally and physically, is important both for and in social interaction (Ryan et al., 2010). The findings from this question do not precisely align with previous research which

determined that aging is associated with difficulties recognizing facial expressions that are negative, such as fear, anger, and sadness (Calder et al., 2000; Birmingham et al., 2018). While older adults may have difficulties processing negative affect, this is not true for their ability to process positive affect (McDowell et al., 1994). Older adults (60-84 years old) are consistently less accurate than younger peers (20-38 years old) while recognizing expressions of anger, sadness, and fear, but older adults are more accurate recognizing happiness and surprise both visually and auditorily (Sullivan & Ruffman, 2004). Structural age-related changes to the brain may account for these findings since the right hemisphere is the dominant region for processing facial expression, body posture, and prosody (Gainotti, 2019). Along with the right hemisphere, the frontal and temporal lobe regions are necessary to process emotions that are expressed both visually and auditorily (Kumfor et al., 2014). Coincidently, the right hemisphere, frontal lobe, and temporal lobe are the regions of the brain that undergo the most structural changes due to age (Cowell et al., 1994; McDowell et al., 1994; Marner et al., 2003).

When comparing self-report to cognitive abilities tasks, some differences were found on the Emotion task within the ACS. During the Emotions task, adults were asked to recognize 10 emotions from static pictures of children. There was only one participant who recognized five emotions while the majority of adults could only remember one (n=8) to two (n=8) emotions from the visual delayed task. The self-reported findings contradict other research findings and ACS findings, which reveals inconsistencies between assessment measures and self-report. No participants reported any difficulties understanding emotions, although research suggests that they should (Calder et al., 2000; Birmingham et al., 2018). Participants also revealed difficulty recalling emotions based

on visual stimuli on the ACS but did not have issues with identifying emotions on auditory tasks. Interestingly, studies on older adults related to emotional recognition determined that adults have issues in both modalities and may have increased difficulty on auditory emotion recognition tasks due to the increased cognitive load (Sullivan & Ruffman, 2004; Mill et al., 2009).

Individuals within this study did not perceive cognitive or communication difficulties. Findings from Aim One also underscore that adults with NH and HL are not actively pondering the impacts that sensory changes to the auditory system may have on cognition. While no individual within this study noted cognitive deficits as evidenced by self-report, Aims Two and Three suggest that cognitive differences are noted between NH and HL in this age group on performance-based tasks. This points to the possibility that subtle cognitive changes have occurred without any perceived effects by an individual with HL. With these differences being noted between NH and HL peers, this implies that there is a need for additional education and outreach to individuals regarding the wide-ranging impacts that HL may have beyond communication. Overall, this aim described the impacts of HL and communicative abilities in adults with and without HL. Social isolation and frustration/shame were the most common impacts of HL noted by adults. While the majority of adults in this study did not express issues with receptive and expressive language, previous research findings state that they should. These differences may be due to the use of open-ended questions in this research versus structured assessments in previous research.

6.3 Aim Two Discussion

The second aim of this study was to determine if group differences existed on social cognitive tasks (FPT and ACS) between older and younger adults with and without hearing loss. The hypothesis associated with this aim stated that group differences would be present on social cognitive tasks. This hypothesis was supported by statistical analysis of the ACS, but not of the FPT, which revealed group differences on social cognitive abilities when comparing those with and without HL. As such, the hypothesis for this aim was proven correct.

All participants within this study obtained full points for FPT; as a result, there were no differences in performance on this test. This finding could be due to the fact that the population of this study had no clinical pathology such as autism or TBIs. Most research which utilizes the FPT is completed in adults with autism and TBI (Bosco et al., 2016; Thiébaut et al., 2016). There appears to be no prior research which used the FPT in adults with HL so while the FPT has good psychometric properties when assessing those with clinical pathologies it may not have been the most useful test for assessing this particular study population. All individuals completed subtests within the ACS. Scores from each of the 22 subtests were obtained for every participant for these two tests. Similar to the WMS and WAIS, the ACS is typically summed and scaled for an overall score. Since the participants of this study were cognitively intact, each individual subtest was analyzed to determine the differences that emerged on each of the subtests instead of the test as a whole. This allowed for the researcher to determine variations based on different subdomains assessed within each test. The mean and standard deviation from each of the subtests based on groups can be found previously in Table 5.12.

The ACS contained 13 subtests, of which five subtests revealed statistical significance between groups: Faces I and II, Spatial, Names II, and Activity. Three of these subtests were visual tasks while two were auditory tasks, which suggests that both modalities can be affected by mild HL and age. A breakdown of the subtests and subdomains for the ACS can be found in Table 6.1.

Table 6.1: ACS Subtests and Subdomains

ACS	FA	AF	P	E	SM	FM	FNAA	FE	IM	DM
Social Perception	**X**	**X**								
Affect Naming		**X**								
Prosody			**X**							
Pairs			**X**							
***Faces I**				**X**	**X**	**X**			**X**	
***Faces II**				**X**	**X**	**X**				**X**
Content					**X**					
***Spatial**					**X**					
Names I							**X**	**X**	**X**	
***Names II**							**X**	**X**		**X**
Proper Names							**X**			
***Activity**							**X**	**X**	**X**	
Emotion								**X**		**X**

Table 6.1 (continued) Note: X=subthemes tested; FA= facial affect; AF= affect recognition; P= prosody; E= encoding; SM= spatial memory; FM= facial memory; FNAA= face-name/activity- association; FE= facial expression of emotion; IM=immediate memory; DM=delayed memory

Group differences were noted for the Faces I and II subtests, which measured facial discrimination and recognition with immediate and delayed recall conditions. These tasks also assessed encoding of facial features and SM. Although other SM tasks in the WMS did not reveal group differences, these contradicting findings could be due to the differences in stimuli. As previously noted, there were differences in the nature of stimuli used since Faces subtests had more complex stimuli and a greater variety of distraction cards than the WMS. This suggests that the Faces subtest taxed the cognitive resources more than the WMS subtests. As discussed previously, encoding is one of the three core concepts of memory and one of the most complex. Due to the complexity of this task, those with HL may require more attentional resources which may impact encoding (Tun et al., 2009).

The Names subtest measured face-name association, face-activity association, and recall for facial expression of emotion via semantic information with a visual cue. Of the subtests within Names, only Names II and Activity were found to have group differences. Both of these tasks were delayed recall measures which assessed long-term memory. There is agreement between the findings on the Names II and Activity with LM from the WMS, since all of these were auditory tasks with semantic information. The findings from the delayed tasks are also in agreement with previous research indicating that HL is negatively correlated to semantic long-term memory issues when compared to NH individuals, but not for short-term memory tasks (Rönnberg et al., 2011).

No group differences were noted on facial affect, affect recognition, or prosody tasks. Findings from this current research versus previous research are contradictory (Birmingham et al., 2018; Christensen et al., 2019). Aging adults have increased difficulty in recognizing negative facial expression, but not facial expressions of happiness or disgust (Birmingham et al., 2018). Perhaps group differences were not noted due to the younger age of these adults when compared to previous research. In such previous research, adults were included up to 74 years of age with a mild to severe symmetrical HL (Christensen et al., 2019). When compared to NH peers, those with HL were found to have reductions in accuracy and increased reaction times to recognizing emotions in speech (Christensen et al., 2019). This raises the question of whether both modalities of emotion recognition are affected by age and HL. Given that HL affects the auditory system, it is logical to assume that only auditory tasks related to cognition may be impacted. However, the findings from the present study suggest that both auditory and visual modalities are impacted by HL.

The findings from social cognitive testing could be explained by the Capacity Theory/FUEL, CR, and STAC-r theories. Social cognition does rely on other cognitive domains to function properly, such as memory, attention, and executive function. For example, while Faces assessed encoding for facial stimuli it also assessed two forms of memory (spatial and facial memory). Due to the interaction between social cognition and other cognitive domains, the group differences which were noted on social cognitive tasks could also be due to memory and attention changes, as discussed in Aim Three.

The findings from Aim Two are also supported by the model created for this study (figure 3.1). When individuals were presented with visual and auditory information

related to social cognition, the normal auditory system processed this information with a low cognitive load. In individuals with HL, the incoming sensory social cognitive information was processed through a degraded system with a potential high cognitive load, which could have impacted findings on cognitive tasks. While the findings from Aim Two may be due to the differences in auditory function, one must continue to assess lifespan conditions, experiences, and environments to understand the complex changes occurring to cognitive domains.

Social cognition has been previously explored in those with autism and traumatic brain injury, yet it has not yet been assessed in those with HL. HL has been documented to lead to increased rates of social isolation and communication difficulties, yet the domain behind these skills has not been assessed in individuals with HL. Findings from this study suggest that measurable differences are noted on both auditory and visual social cognitive tasks based on HL. Previous research efforts have focused on memory and attentional changes in those with HL but have neglected to also assess social cognition in these individuals. This is an area of research which is untapped, and more research is clearly needed in this area of study to fully understand the relationship between social cognition and HL. Overall, the second aim of this study focused on determining if group differences were present on social cognitive performance assessments. The hypothesis associated with this aim was supported by data obtained from the ACS only, since ANCOVA results revealed group differences on five tasks in the ACS. No differences were found on the FPT, which could have been due to the cognitively intact participants who took part in this study. There is a lack of research

surrounding the combined impacts that HL and age may have on social cognitive functioning; some of the current findings are consistent with previous research while others are contradictory (Ruffman et al., 2008; Tun et al., 2009; Rönnberg et al., 2011; Birmingham et al., 2018; Christensen et al., 2019). Group differences in adults between the ages of 50-69 with and without HL were noted in certain aspects of social cognition: encoding, spatial and facial memory, face-name activity-association and facial expression of emotion.

6.4 Aim Three Discussion

The third aim of this study focused on determining if group differences were present on cognitive performance assessments and neurologically-based tests. Two hypotheses were associated with this aim, which stated that group differences would be present on both cognitive performance assessments and neurologically-based tests. Both of these hypotheses were supported by the data, since ANCOVA results revealed group differences on performance assessments within the WMS, WAIS, and EEG signatures. Generally, these findings are consistent with previous research that identified differences in memory and attention tasks among those with and without HL (Lin et al., 2011; Rönnberg et al., 2011; Lin & Albert, 2014; Rönnberg et al., 2014; Wayne & Johnsrude, 2015).

All individuals completed subtests within the WMS and the WAIS, while 24 participants completed the Bluegrass Short-Term Memory and EEG. In this study, overall scores for WMS and WAIS were not reported because the assessments were not administered in their entirety; however, means and standard deviations from each subtest based on groups were reported in Table 5.9. Typically, when scoring the WMS and

WAIS, normative ranges and confidence intervals are based on the entire test. To detect group differences, each subtest was assessed instead of the test as a whole. Individuals in this study were also cognitively intact. As such, by not assessing each individual subtest within an assessment there could have been small and hidden differences present on subtests.

Current assessments and research on cognition often separates cognitive domains and their subdomains. It is important to remember that while these domains are hierarchical in nature, they are not independent of each other (Harvey, 2019). In fact, due to the complexity of the cognitive systems, a decline in one cognitive function may be associated with a decline in another function (Valentijn et al., 2005). For example, executive function (EF) refers to top-down mental processes that are necessary to complete all of the tasks in this study (Burgess & Simons, 2005). A decline in this cognitive domain may impact the ability of other domains, such as attention and memory, to function in an efficient manner (Collins & Koechlin, 2012; Diamond, 2013). In fact, a cross-sectional cohort study of adults over the age of 55 years determined that HL is independently associated with lower scores on EF tasks (Lin et al., 2011). Even though the exact connection between EF and other domains has yet to be fully understood, interactions between all domains are a reality and findings may represent top-down cognitive issues instead of individual issues (Fisk & Sharp, 2003).

In the present study, group assignments were made prior to analysis based on age and hearing: NH 50-59; HL 50-59; NH 60-69; and HL 60-69. Neurocognitive scores from each of the subtests based on groups were presented in Table 5.9. Performance differences between groups were observed on four subtests of the WMS and WAIS based

on ANCOVA results that included: Logical Memory (LM) I and II, Arithmetic, and Spatial Addition (SA) subtests. Table 6.2 offers a visualization of all of the auditory subtests in the WMS and WAIS and the subdomains assessed, while Table 6.3 represents the visual subtests and subdomains.

Table 6.2: Auditory Subtests and Subdomains Assessed

Auditory Tasks	**IM**	**DM**	**WM**	**VEM**	**VM**	**Att**	**Con**
*Logical Memory I	X			X			
*Logical Memory II		X		X			
Verbal Paired Associates I	X				X		
Verbal Paired Associates II		X			X		
Digit Span			X				
*Arithmetic			X			X	X

*statistically significant (p<.05)

Note: IM= immediate memory; DM= delayed memory; WM= working memory; VEM= verbal episodic memory; Att= attention; Con= concentration

Table 6.3: Visual Subtests and Subdomains Assessed

Visual Tasks	**IM**	**DM**	**WM**	**PS**	**STM**	**SM**	**Att**	**Con**
Designs I	X					X		
Designs II		X				X		
Visual Reproduction I	X					X		

Table 6.3 (continued)

Visual Reproduction II	X			X		
*Spatial Addition	X					
Symbol Span	X					
Coding	X	X	X		X	X
Symbol Search		X	X		X	X
Bluegrass Short Term Memory Task	X		X			

*statistically significant ($p<.05$) *Note: IM= immediate memory; DM= delayed memory; WM= working memory; PS= processing speed; STM= short-term memory; VEM= verbal episodic memory; SM=spatial memory; Att= attention; Con= concentration*

The most frequently administered subtest on the WMS is for Logical Memory (LM), which assesses episodic memory by addressing the three processes involved in memory: encoding, storage, and recall (Weschler, 2008; Li et al., 2006). The narrative nature of this subtest has been found to be sensitive enough to detect subtle memory changes in individuals with MCI and early dementia (Robinson-Whelen & Storandt, 1997; Li et al., 2006; Ahn et al., 2019). Research has suggested that episodic memory is a key early marker in prodromal stages of Alzheimer's disease (MCI) (Marruff et al., 2004; Rabin et al., 2009). Structural declines in the hippocampal and entorhinal cortices are thought to be the defining reason behind these declines in episodic memory (Becker et al., 2006; Petrella et al., 2006). This body of research has several implications with regard to the current findings. Delayed LM scores from this study are in agreement with previous research (Kinugawa et al., 2013; Rönnberg et al., 2014). Previous research has determined that there are age-related declines associated with episodic memory.

Additional research reported negative relationships between HL and episodic memory, specifically long-term episodic memory, even when chronological age was controlled. (Rönnberg et al., 2014). Since episodic memory tasks are complex, even a mild HL may require more attentional resources, which may impact memory encoding (Tun et al., 2009). In this case of episodic memory, cognitive capacity resources may be exceeded; such an overload could explain the changes noted in episodic memory which have been noted on both previous research findings and findings from this current study.

Additional differences were noted on two of the six subtests assessing WM. Of those, one of the auditory subtests (Arithmetic) and one visual (SA) revealed group differences. Arithmetic also assessed attention and concentration while SA assessed visual-spatial WM. Similar to these findings, previous research has determined that in the presence of HL, the short-term/WM system experiences a negative effect even when age is controlled (Schneider et al., 2010; Verhaegen et al., 2014). Negative relationships were also reported between HL and visuo-spatial WM tasks (Rönnberg et al., 2014). As such, previous research (Schneider et al., 2010; Verhaegen et al., 2014; Rönnberg et al., 2014) is consistent with the findings from this current study, which determined differences on WM subtests, Arithmetic and SA. Compellingly, one aspect of WM is processing speed, but while previous studies have suggested that processing speed can be affected by HL (Yumba, 2017), this was not demonstrated in this current study, as neither Coding nor SS revealed any group differences.

Two tasks evaluated attention, with one being auditory (Arithmetic) and the other being visual (Bluegrass Short-Term Memory). While group differences were noted in Arithmetic, no statistically relevant differences were found in the Bluegrass Short-Term

Memory task. However, two responses (missed response for trial one and correct responses for trial two) revealed a potential for significance (refer to Table 5.11). It should be noted that since this task only had responses from 24 of the 28 individuals, this could have hidden significant findings. Previous attention research has often focused on deaf adults and visual attention; such research has determined that deaf adults perform better than their NH peers on visual search and detection tasks (Rettenbach et al., 1999; Tharpe et al., 2008). Similarly, in the current study, even those with a mild to moderate HL actually obtained more correct responses on trial two within the Bluegrass Short-Term Memory task than their peers with NH. An explanation for this finding may be due to the compensatory role that the visual system plays in those with HL (Tharpe et al., 2008). This compensation may be why HL individuals in the present study performed better on the visual Bluegrass Short-Term Memory tasks compared to those with no hearing loss.

An additional component of WM is the visuo-spatial sketchpad (refer to Chapter Two), which by storing visual and spatial information allows for an individual to locate objects in space (Chai et al., 2018). In this current study there were four spatial memory (SM) tasks on the WMS, all of which showed no group differences; however, there were three SM tasks on the ACS that revealed group differences. The difference between these two subtests is the nature of the stimulus. The WMS includes shapes as the stimulus whereas the ACS uses faces as the stimulus. The ACS is discussed in more detail in section 6.2. Research in adults between the ages of 40-70 as well as that on mice determined that HL is associated with declines in SM and spatial learning (Rönnberg et al., 2014; Liu et al., 2016). Previous mouse research determined that in the

presence of noise-induced HL, SM declines could be seen after just three months of noise exposure (Liu et al., 2016). In fact, in neurocognitive assessments, those with HL were found to have poorer performance on tasks that were both auditory and visual tests (Tay et al., 2006; Lin, 2011; Lin et al., 2011). The findings from the WMS SM tasks are not consistent with previous research, while the findings from the ACS SM tasks are consistent. This suggests that the nature of the stimulus potentially has an impact on these tasks, perhaps due to relevance or complexity of the stimuli. An explanation for this finding may be due to the compensatory role that the visual system has been revealed to have in those with HL or due to this highly educated population (Tharpe et al., 2008).

In this study, ANCOVAs identified two WM tasks that revealed group differences; however, four tasks did not. The lack of strength in these findings is not consistent with previous research. As cognitive capacity and the FUEL theorizes, when the speech signal is degraded (as it is in HL), listeners must rely more on WM to process speech, which leaves fewer resources for other cognitive tasks (Pichora-Fuller et al., 1995; Arehart et al., 2013). It is possible that the tasks in this study were not complex enough to fully tax the WM system in the study's population, which could explain why only two of the six WM tasks revealed group differences. However, another possibility is that this study focused on younger old adults with only mild to moderate hearing loss whereas previous studies assessed older adults with a higher degree of HL (Pichora-Fuller et al., 1995; Akeroyd, 2008). Perhaps the age and hearing loss of the current study's population did not fully tax the WM system. These findings could suggest that there is potentially a lower limit to which hearing loss and age have an impact on WM. Due to the complexity of WM and its components, the theoretical models informing this

research, and the structural changes in the brain due to age, the researcher assumed that group differences would be noted on the majority of WM tasks, For example, previous research has suggested that there are marked fronto-parietal and prefrontal structural changes in the brain, which is where WM is thought to occur (Li et al., 2014; Chai et al., 2018). Furthermore, a relationship between HL and its impacts on WM has been suggested by previous research (Pichora-Fuller et al., 1995; Akeroyd, 2008).

Physiological measures, such as those gained through imaging technologies and EEG, have increased in use in an effort to understand the functional and structural relationship in the brain. This could be due to advances in technology which allow for uniform quantification and a reduction of possible bias (Klimesch, 1999; Marsella et al., 2017). In addition, these measures can provide information on structural changes that may impact functional results. Research centered around theta activity have determined that theta activity is diminished in the frontal regions during auditory oddball tasks, which may be associated with attention and working memory issues (Ishii et al., 2009; Kardos et al., 2014).

EEG information from this study was obtained during eyes open and eyes closed resting states. ANCOVA results reported significant group differences on two of the EEG signatures from the eyes open resting state: left frontal theta oscillation (memory & decision-making related), and right frontal beta frequency (attention-related). These findings also support the hypothesis of the first aim. The effects of aging on EEG findings have focused on brain activity during resting states, the results of which have suggested a reduction in the amplitude of alpha activity and a decrease of theta activity (Klass & Brenner, 1995; Klimesch, 1999). For the 50-59 age group, those with NH (8.08

uV^2/Hz) had higher frontal theta activity than their HL (1.43 uV^2/Hz) peers. The reverse was noted in the 60-69 age group, where those with HL had higher frontal theta (3.56 uV^2/Hz) activity than their NH (2.03 uV^2/Hz) peers. Previous research has suggested that due to the normal aging process, increased delta and/or theta power in often noted on EEG measures (Coben et al., 1990; Prichep, 2007; Becerra et al., 2012). One study also suggested that the best EEG predictor of cognitive impairment in elderly adults is abnormally high theta activity (Becerra et al., 2012). Theta activity was also determined to be higher in those with mild probable Alzheimer's disease when compared to healthy elderly controls during resting state EEGs (Coben et al., 1990). Additionally, those with MCI and dementia have been found to have higher theta and delta activity (Prichep, 2007).

For the 50-59 age group, those with NH (0.78 uV^2/Hz) had lower frontal beta activity than their HL (1.10 uV^2/Hz) peers. The reverse was noted in the 60-69 age group, where those with NH had higher frontal beta activity (0.94 uV^2/Hz) than their NH (0.78 uV^2/Hz) peers. Beta wave changes based on age are not as commonly reported as are alpha, theta, and delta wave changes. In those with MCI and AD, beta power is found to decrease in frontocentral regions when compared to healthy controls in WM tasks (Kurimoto et al., 2012). A reduction of beta as well as alpha is noted in individuals with AD when compared to their normal aging peers (Rossini et al., 2007). In addition, resting state data from prior research suggests a decline in overall brain activity during resting state in those with AD and MCI (Cole et al., 2012; Franzmeier et al., 2017).

Regardless of age, those with NH had higher theta activity (5.05 uV^2/Hz) than their HL (2.49 uV^2/Hz) peers. With regard to right frontal beta activity, those with NH had higher activity (0.94 uV^2/Hz) than their HL (0.78 uV^2/Hz) peers. Unfortunately, there is a lack of research that combines EEGs and HL. Studies that do address HL and use EEGs often utilize speech processing tasks or auditory oddball tasks instead of visual tasks as used in this study. Speech tasks paired with EEG measures have indicated a right lateralization of theta power in those with HL when compared to their NH peers (Giroud et al., 2018). This right lateralization in speech tasks may be explained by existing research showing that the right hemisphere is integral in processing spectral information (Zatorre & Belin, 2001). Most studies on HL have been designed around neurophysiological imaging, such as MRI and fMRI. Research using MRIs has determined that those with HL experienced overall brain volume declines as well as regional volume declines in the right temporal lobe, declines which were not recorded from among NH peers (Lin et al., 2014). Furthermore, analysis via fMRIs determined a decrease in gray matter in the frontal cortex (Peelle et al., 2011). Additionally, those with HL experienced gray matter loss in the frontal cortices, decreased response in the superior temporal cortex, thalamus, and brainstem, and disordered white matter tracks entering and exiting the auditory cortex (Wong et al., 2010; Peelle et al., 2011; Hussain et al., 2011a; Hussain et al., 2011b).

Comparison between the two age groups determined that when assessing the mean power obtained from EEG signatures, adults 50-59 had higher mean power on both of the signatures as compared to adults 60-69. Based on age, the theta findings are in agreement with previous research since a reduction of mean power was found correlating

with age for these two signatures. Based on the structural changes that occur in the right hemisphere, frontal lobe, and temporal lobe, the researcher posited that these areas would be affected the most by HL and age (Cowell et al., 1994; McDowell et al., 1994; Marner et al., 2003). Both signatures in the present study were from the frontal regions, results which correspond with structural changes. While the only two signatures were from the frontal regions, theta was obtained from the left anterior frontal area and beta was obtained from the right frontal lobe. The researcher further posited that since the right hemisphere typically exhibits greater structural changes than the left hemisphere that the functional aspects noted on the EEG would also be impacted most markedly, which was not the case as measured by the task. This may suggest that perhaps there are protective or mitigating factors that are occurring in adults between the ages of 50-69 years.

Although a correlation between cognition and HL is noted in the current study as well as previous literature, the association is not fully understood. In an attempt to understand this convoluted relationship, theories were applied to frame the current research. Three theories were discussed in Chapter Three which underpinned this research: Capacity Theory/Framework for Understanding Effortful Listening (FUEL; Kahneman, 1973; Pichora-Fuller et al., 2016), Cognitive Reserve (CR; Stern, 2012; Robertson, 2013)., and the Scaffolding Theory of Aging and Cognition (STAC-r; Park & Reuter-Lorenz, 2009; Park & Reuter-Lorenz, 2014).

Group differences that were noted on attention and memory tasks in this study could be supported by Capacity Theory. Research which examined the effects of HL on cognitive load determined that in conditions where HL was present, more cognitive

resources were dedicated to the listening, attending, and processing of auditory information (Pichora-Fuller et al., 1995; Wingfield & Grossman, 2006; Tun et al., 2009). As a whole, Capacity Theory and FUEL stipulate that when an individual is in complex listening or visual environments, their working memory and attention can be negatively impacted because both processes are competing for a fixed number of (Kahneman, 1973; Pichora-Fuller et al., 2016). Findings from the LM task support this theory. Due to the complexity of episodic memory tasks, an individual's cognitive system could have been taxed beyond its capabilities, in turn creating differences between those with NH and HL. The same could be said for the differences noted on the arithmetic task, spatial addition (SA) task, and EEG signatures, all of which required an individual to attend and process auditory or visual memory information. The findings from this research suggest that even in the presence of a mild HL, adults between the ages of 50-69 years do not perform as well as their NH peers on tasks of attention and memory.

Covariates were critical to consider in this research since they are crucial to the life-course approach, as they may act as mitigating factors for age-related cognitive decline (Stern, 2012; Robertson, 2013; Park & Reuter-Lorenz, 2014; Kivimäki & Singh-Manoux, 2018; Ortega et al., 2019). Both CR and STAC-r theorize that education, exercise, participation in cognitive training, high levels of engagement in novel activities, lifelong experiences, leisure activities, occupational complexity, and premorbid intelligence can mitigate age-related cognitive decline. Research has suggested while approximately 65% of risk factors for dementia are potentially non-modifiable, 35% are indeed modifiable (Ortega et al., 2019). Current research suggests that education (8%),

smoking (5%), depression (4%), and physical inactivity (3%) are some of the top modifiable risk factors; however, HL is noted as the highest modifiable risk factor for dementia (Ortega et al., 2019). Interestingly, neither CR or STAC-r discuss HL as being apotential mitigating or protective factor for age-related cognitive decline. While factors such as education, exercise, and occupation were included as covariates in the current study, none of these factors were found to have an interaction between cognitive assessments, HL, and age.

Many models and theories, some of which have been discussed previously, have attempted to shed light on the complex relationship that exists between hearing ability and cognition. While these systems have an impact on one another, there are other factors at play that can further help or harm the functioning of the individual. The model which was discussed in Chapter Three (figure 3.1) attempted to shed light on the multitude of lifespan factors which can impact HL and cognition. As far as the theoretical model created for this study is concerned, Aim Three findings are in agreement that HL does have an impact on the cognitive domains of attention and memory. When individuals were presented with visual and auditory information from attention and memory tasks, the normal auditory system processed this information with a low cognitive load, and even in the presence of normative age-related brain changes, cognitive abilities were preserved. In individuals with HL, the incoming sensory information was processed through a degraded system with a potential high cognitive load, which could have impacted findings on cognitive tasks. The model was designed based off previous models and research which suggested that that certain covariates (overall health, education, leisure activities) may have mitigating/protective effects on cognitive decline. This study

determined that none of the covariates assessed had any impact on cognitive findings. This may be due to the homogeneous population that was seen in this particular study, a possibility which is further discussed later. While the findings from Aim Three may be due to the differences in auditory function, one must continue to assess lifespan conditions, experiences, and environments to understand the complex changes occurring within cognitive domains. Findings related to this aim may be due to the differences in auditory function, but researchers must continue to understand the role that an individual's conditions, experiences, and environments throughout life have on the age-related changes occurring to cognitive domains.

The findings from Aim Three could have major implications for clinical recommendations and future research. This study suggests that even a mild hearing loss in adults can impact findings on memory and attention assessments in adults between the ages of 50-69 years. With this finding in mind, clinical recommendations regarding hearing screenings may have to change with regard to the age at which adults should be routinely screened for HL. Additionally, recommendations may have to change surrounding assistive listening devices such as hearing aids. Continued research on these areas is crucial in order to understand the interaction between both HL and aging on the structural and functional aspects of brain. Overall, the first aim of this study focused on determining if group differences were present on cognitive performance assessments (WMS and WAIS) and neurologically-based tests (EEG). The two hypotheses associated with this aim were supported by the data, with ANCOVA results revealing group differences on performance assessments within the WMS, WAIS, and EEG signatures.

6.5 Study Challenges and Limitations

Throughout the process of conducting this research, several challenges and limitations were identified. These challenges and limitations included recruitment, sample size, length of testing issues, and the use of self-reported health information. As discussed repeatedly throughout this study, there are many variables which are thought to influence an individual's cognitive health later in life. This study's sample was mainly white, well-educated, and had very few underlying health issues. All of these variables are known to influence cognition, in addition to the impacts of gender and other lifestyle factors (Adenzato et al., 2017; NIA, 2017). Kentucky reports that 87.6% of its population is white, while Fayette County reports 77.4% of its population is white (Census, 2017). Fayette County reports that 90.9 % adults over the age of 25 have obtained a high school degree or higher, while 42.9% obtained a bachelor's degree or higher (Census, 2017). The majority of this particular sample had obtained a bachelor's degree or higher (78.6%). While flyers were placed around the university campus, local businesses and gyms, as well as the senior center, the researcher was not proactively seeking a diverse population.

The final sample size of this study was 28, even though recruitment was targeted for 48 participants to achieve adequate statistical power. Power is the probability to reject the null hypothesis when the null hypothesis is false (Case & Ambrosius, 2007). While initial recruitment provided a steady number of subjects between October 2019 to March 2020, research restrictions were put in place as a direct result of COVID-19. The Office of Research Integrity at the University of Kentucky halted research studies that were not life-sustaining in mid-March 2020 through August 2020. As such, data

collection for this project was halted and ultimately suspended, and the diminished sample size increased the likelihood of a possible Type I error occurring, or falsely rejecting the null hypothesis (Case & Ambrosius, 2007).

While cognitive testing is often lengthy, this research required between three to four hours of time from each participant. The amount of testing time could have caused exhaustion, anxiety, and a lack of motivation in participants, even though participants were afforded the ability to take multiple breaks and pause testing for the day. The amount of testing required by participants did hinder the recruitment of potential participants. Throughout the span of recruitment, 11 individuals expressed interest in the study but later declined after the length of testing was discussed. Finally, when utilizing self-reported health data, biases (either social desirability or recall bias) may occur. Social desirability occurs when participants wish to obtain approval from their answers, while recall bias occurs when responses are provided erroneously. These biases on surveys may result in under- or overestimates of the association between those variables being assessed (Paeratakul et al., 1998; Althubaiti, 2016).

6.6 Future Projects and Implications

Based on findings from this study as well as those from previous research, there are a number of areas of research that need to be further assessed. The first would be evaluating all cognitive domains in regard to HL and age. Previous research has suggested an interaction between the cognitive domains; therefore it is critical to assess all domains in order to fully understand what parts of cognition are impacted by HL. Such an analysis is important since all cognitive domains interact with each other. A decline in one domain could negatively impact another, which could potentially lead to a

snowball effect on other cognitive domains. Another area of further study would be to broaden the age range of participants. Age-related hearing loss (ARHL) can be seen in those as young as 30 or 40 years of age, as a result, research that only assesses those 65 years and older is clearly neglecting younger individuals who may be affected. By neglecting to include younger individuals in research, it could lead to continued gaps in research in understanding the early impacts that ARHL has on cognition. By noting and understanding these early changes, one can better understand the whole scope of effects that HL has on cognition throughout the life span. Understanding these early changes of ARHL could also lead to improved aural rehabilitation and therapies which may assist in alleviating negative impacts noted on cognition. Understanding early changes due to ARHL could also allow for researchers to understand and identify factors that impact quality of life (QoL) in individuals with HL. Identifying these factors could lead to more successful intervention strategies for ARHL (Punch et al., 2019).

In addition, incorporating varying degrees of HL should also be included in further research. A mild hearing loss is known to have a negative impact on an individual's communication skills, yet research is often focused on higher degrees of hearing loss. As such, all degrees of HL should be assessed to gain a full understanding on how the varying levels of HL may impact cognition. Lastly, research efforts should continue utilizing neurophysiological testing in regard to HL in order to understand the structural and functional impacts of HL on the brain.

A dynamic interaction is present between all cognitive domains, one which has yet to be fully solved. With this overlay of domains upon one another, it is important to address all domains in research related to HL. While attention, memory, and executive

functioning are crucial for everyday functioning, other domains are also critical for functioning as well. For example, there is significant literature on the social implications that HL has on an individual, but social cognition related to HL has not been addressed. Understandably, memory, attention, and executive functioning have been the focus of research efforts since these are the cornerstones of all of the cognitive domains. The findings from this current study suggests that there are differences on social cognitive tasks in those with and without HL. Further research must continue to assess all domains of cognition including social cognition, perceptual-motor function, language, and learning in an attempt to understand the wider implications of these associations. It should also begin to assess those with HL who are not cognitively intact.

Research must continue in order to broaden the understanding of the relationship between HL and cognitive changes. To do this, research must maintain its focus on these two areas of research and the effects that they may have on one another. Cognition and HL can occur as early as the third or fourth decade of life, yet research has continued to focus on adults over the age of 65 years, thus neglecting younger individuals who may also be experiencing issues. Therefore, this research is novel because it is an initial step in an attempt to address this gap. Future research must expand on the typical age range in order to conceptualize the effects that these factors may have on an individual at different ages. By assessing younger aging individuals, researchers may also be better equipped to understand life span factors and the interaction between hearing and cognition.

Research topics must also expand on hearing levels to include degrees of hearing of all types. Prior research has determined that even a mild HL in adults is associated with changes in cognitive functioning (Arlinger, 2003; Mathers, Lopez, & Murray, 2006;

Lin et al., 2011; Rönnberg et al., 2014; Surprenant & DiDonato, 2014). Along those lines,future projects should attempt to elucidate on whether PTA are the best markers for understanding this relationship or if speech-in-noise tasks may be better suited due to their complexity.

Research on these areas should also focus on objective assessments since they are less prone to patient and researcher bias and could provide further insight on the structural changes in the brain due to HL (Newson & Thiagarajan, 2019). The field of objective measures for HL and cognition should incorporate EEGs, electrophysiology testing such as auditory brainstem response, and fMRIs. EEG signals associated with cognitive events, or event-related potentials (ERPs), have been found to be altered in those with MCIs and AD, but have not been thoroughly investigated. When ERPs have been assessed in individuals with HL, they have been focused on speech-sound processing and not on the impacts surrounding higher level cognition. Research must expand on the use of EEGs regarding the connection between HL and cognition to understand the structural and functional changes to the brain. Cognition and HL research should incorporate both resting state EEGs and ERPs in neurologically normal adults as well as those with suspected MCI and AD.

Any future research should have clinical implications and directly impact patient care. Previous research has determined that there is a relationship between HL and cognitive decline, and future research should not only focus on determining a complete understanding of this relationship but also how to incorporate these findings into practice to assist individuals. Currently there is a lack of incorporating cognitive discussions into hearing healthcare, even though these factors are shown to affect one another.

Practitioners should view each individual through the lens that age-related HL and cognitive changes will have an impact on an individual as a whole. A more comprehensive history and probing questions centered around cognitive abilities should be included in discussions. If these questions raise concerns, then cognitive screeners should be utilized. There are a variety of cognitive screeners available for use in clinical settings. Certain screeners do assess the domains of memory and attention which were found to be impacted in this study, while others do not. The MoCA and the Saint Louis University Mental Status exam (SLUMs) are both screeners which assess these domains.

Cognitive abilities should also be addressed while counseling individuals to determine their specific needs and abilities. For example, cognitive differences are noted on both auditory and visual tasks, so clinicians should give individuals directions and suggestions in both modalities. Ongoing research efforts with these factors should also focus on the impact that possible interventions may have on HL. While HL interventions are accessible and could improve outcomes, they are often not utilized by adults when hearing loss is present, despite the potential benefits. Additional research is needed in this area in an attempt to potentially prevent and treat cognitive decline and HL.

Furthermore, future research should focus on creating a comprehensive model that addresses the life course (conditions/experiences) in relation to the auditory and cognitive system to improve QoL. While the model created for this study did fit the overall findings, personal life span conditions and experiences did not appear to have an impact on cognition and HL. The lack of association to conditions/experiences may be due to the homogeneous study population but it could also be related to some unknown covariate which could have impacted findings but was not assessed. As a result, this

model could be further improved by incorporating different covariates which may affect the auditory and cognitive systems. Perhaps this model should separate cognitive abilities into individual domains instead of grouping all domains together. This separation could provide a better explanation as to how individual domains are impacted. Additionally, this model should incorporate QoL into consideration. Previous research has documented the impacts that HL has on QoL, yet QoL has often not been included in models related to HL. These models could assist in the effort to identify factors that may be further impacted in individuals with HL.

The avenues on this research topic are plentiful and researchers should continue to address them. HL is a major public health issue that occurs for numerous reasons including age, noise exposure, and chronic disease. The number of adults living with HL is only expected to grow, so research must continue in order to deepen the understanding of its wide-ranging effects.

6.7 Conclusion

Auditory and cognitive processing have previously been viewed as separate and distinct factors that are crucial for communication, yet a growing body of literature suggests that these are actually intimately coupled. Previously, HL was assumed to simply influence auditory system and associated neural networks, but findings from both this current and previous research alongside theories on HL and cognition suggest a far more complicated relationship (Wayne & Johnsrude, 2015). HL can and does have an influence on higher-level cognitive functioning (Peelle & Wingfield, 2016). This research yielded evidence that even a mild HL in adults between the ages of 50-69 is associated with changes in cognitive functioning. The current research also broadened current

knowledge on how HL and age has an impact on cognition by including younger adults with lower degrees of HL. Previous research often focuses on adults over the age of 65 with moderate to profound HL.

While not widespread, there appear to be early deficits in the areas of memory, attention, and social cognition. Research interests have focused on understanding the role that HL has on the domains of executive functioning, memory, and attention, but has neglected to understand the impacts on social cognition. Findings from this research have provided more evidence to support the association between HL and cognitive domains of memory and attention. This research broadens the extremely limited but expanding amount of research on social cognition and HL. Additionally, this research strengthened subjective measures with objective measures, both of which support the hypotheses of this study that there are functional changes due to HL. This research and previous research continue to address that while cognitive changes and HL occur later in life, researchers should be aware of the implications that life course factors may have on these conditions and the individual. The framework provided by this research attempts to include a life-span view on how factors can impact HL and cognition later in life. The connection between these two factors remains largely unexplained as a consequence of the many and diverse factors that can affect both HL and cognition throughout the life span.

The qualitative interviews revealed that researchers and clinicians need to continue to address the wide-ranging impacts of HL in all adults. While adults did recognize impacts of HL beyond communication, some participants also reported no thoughts on the impact beyond communication. This suggests that adults need to be

further educated about the prevalent public health matter of HL. Although information about the impact of HL is readily available through different audiology-based platforms, this information is not reaching adults who are susceptible to HL. The entirety of this research points to the cascading effects that HL and cognition may have on an individual.

These findings stress the critical importance of understanding early cognitive changes that may occur due to even mild changes in hearing. These findings highlight the necessity of understanding when cognitive changes can be observed in aging individuals with HL. Age-related changes to both cognition and hearing occur in mid-life yet research on these topics focus on adults well after this age. Early detection of these changes may assist in minimizing the impacts that HL may have on cognition through the use of aural rehabilitation or assistive listening devices. Additionally, findings revealed changes to the social cognitive domain, an area which has not gained as much research attention when compared to memory and attention domains. Ultimately, this suggests that HL has wide-ranging impacts on cognitive domains. Public health initiatives should focus on including more education surrounding the relationship and impacts that HL may have on cognition in aging adults. This current research suggests that more education is required since older individuals did not perceive any cognitive changes or concerns, yet performance-based assessments revealed differences between groups based on age and HL.

In conclusion, this research assisted in filling in the present gaps in the research by assessing younger aging individuals with a lower degree of HL than what is typically assessed. Overall, this study suggests that even a mild hearing loss in adults can impact findings on performance-based abilities of memory, attention, and social cognition in

adults between the ages of 50-69 years. While there are subtle changes to the three of these cognitive domains, adults are not yet perceiving any differences in their cognitive or communicative abilities. By understanding these early changes to even mild degrees ofHL, researchers may also be better equipped to understand lifespan factors and the interaction between hearing and cognition. The relationship between hearing loss and cognitive decline is a critical issue in public health, one which requires ongoing research. By better understanding this complex relationship, it may lead to improved rehabilitation options, such as aural rehabilitation and assistive listening devices, as well as elevated awareness about the combined effects of these age-related issues.

6.8 Statement of Funding

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APPENDICES

APPENDIX A: RECRUITMENT FLYER

UNIVERSITY OF KENTUCKY RESEARCH

HEARING LOSS AND COGNITION IN ADULTS

Researchers at the University of Kentucky are inviting you to participate in a study to examine the relationship between hearing loss and cognition.

You may be eligible to participate if you:

- Are between the ages of 50-69 years
- Are interested in understanding more about your hearing
- Have NOT used a hearing aid within the past six months
- Have NO history of dementia

For more information, contact:
Karah Gottschalk, Au.D.
(502) 219-2451
kgo252@uky.edu

UK Research

An Equal Opportunity University

For more information on research studies see, www.UKclinicalresearch.com.

APPENDIX B: CONSENT FORM

IRB Approval
8/21/2019
IRB # 50192
ID # 183908

Consent to Participate in a Research Study

KEY INFORMATION FOR: Social cognition in hearing loss: Perceived and performance abilities of adults related to Theory of Mind (ToM)

We are asking you to choose whether or not to volunteer for a research study about the relationship between hearing loss and attention, memory, and social cognition. We are asking you because you are an adult between the ages of 50-69 years that may have normal hearing or a mild to moderate hearing loss. This page is to give you key information to help you decide whether to participate. We have included detailed information after this page. Ask the research team questions. If you have questions later, the contact information for the research investigator in charge of the study is below.

WHAT IS THE STUDY ABOUT AND HOW LONG WILL IT LAST?

By doing this study, we hope to learn about the relationship between hearing loss and cognition. Recent research has revealed that hearing loss can have an impact on different aspects of an individual's cognition. Your participation in this research will last about five hours over the course of two days: one day online and one in person.

WHAT ARE KEY REASONS YOU MIGHT CHOOSE TO VOLUNTEER FOR THIS STUDY?

You might choose to volunteer with this study because you are interested in determining your hearing status. You might also choose to volunteer for this study because you are interested in discussing your everyday experiences with and without hearing loss.

WHAT ARE KEY REASONS YOU MIGHT CHOOSE NOT TO VOLUNTEER FOR THIS STUDY?

You should NOT volunteer to take part in this study if you are not between the ages of 50-69 years of age, if you do not speak English, if you have a neurocognitive disorder, and if you cannot sit for long periods of time. For a complete description of risks, refer to the Detailed Consent and/or Appendix.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you want to volunteer. You will not lose any services, benefits or rights you would normally have if you choose not to volunteer.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS OR CONCERNS?

The person in charge of the study is Karah Gottschalk, Au.D./Ph.D. Candidate of the University of Kentucky, Department of Gerontology. There will be two other people (undergraduate research assistants) and a faculty advisor (Anne Olson, Ph.D.) working on this project at different times during the study. If you have questions, suggestions, or concerns regarding this study or you want to withdraw from the study her contact information is: kgo252@uky.edu or 859-257-1450.

If you have any questions, suggestions or concerns about your rights as a volunteer in this research, contact staff in the University of Kentucky (UK) Office of Research Integrity (ORI) between the business hours of 8am and 5pm EST, Monday-Friday at 859-257-9428 or toll free at 1-866-400-9428.

DETAILED CONSENT:

ARE THERE REASONS WHY YOU WOULD NOT QUALIFY FOR THIS STUDY?

You should NOT take part in this study if you:

- Do not communicate well in English
- Diagnosed with neuro-cognitive degenerative illnesses
- Diagnosed with moderate to severe depression
- If you live in a nursing homes or long-term care facility
- Are unable to sit for long periods of time

WHERE WILL THE STUDY TAKE PLACE AND WHAT IS THE TOTAL AMOUNT OF TIME INVOLVED?

The research procedures will be conducted at Charles T. Wethington building (Room 110) and Medical Behavioral Science building (Room 116), both of which are located on University of Kentucky's campus in Lexington, KY. You will need to come one time during the study. This one visit will take about four hours. The total amount of time you will be asked to volunteer for this study is five hours over the next month, which includes time for you to complete an online questionnaire.

WHAT WILL YOU BE ASKED TO DO?

Once you express interest in this study, you will be contacted via phone and/or email to discuss the details of the study and to set up a visit to have your hearing and cognition tested. Prior to this visit, you will have to complete a screening procedure through RedCap to ensure you met inclusion criteria for the study. REDCap is a web application that allows researchers to collect information such as age, sex, marital status, race/ethnicity, health information, employment status, and education. If you do not feel comfortable completing these forms online, you can ask to complete these questions on a paper form which can be mailed to you.

When you arrive for your hearing and cognitive testing, you will sign a consent form. This form states that you agree to be a part of this study and that you understand the risks of this research. After the consent form is signed you will be given a copy of the consent form. Next, the researcher will look in your ear canal to make sure you do not have wax blocking your ear drum. Then a soft tip will be placed in your ear which will measure your ear drum movement and how part of your inner ear is working. For these three tests, you will just have to sit quietly. Next, the researcher will place headphones over both ears. You will have to listen to words that change in how loud they sound and repeat them. You will also listen to tones that change in how loud they are, and you will have to let the researcher know when you hear the tone. After the hearing test is completed you will have a break. You will then sit down with the researcher and have an open discussion about your hearing and how it may have an impact on you. After this discussion, you will complete the cognitive testing. For this testing you will be asked to remember things, repeat things, draw items, and write on paper. After these are complete you will get a break. The last task you will have to complete is EEG testing. For this testing you will have a headband placed around your head, with foam tips sitting on your head. While looking at a computer screen you will be shown two images. You will then be shown a series of images and you will have to mark if the images match or not match.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

There is no more than minimal risk to participating in this study. One risk in participation might be fatigue, frustration, and/or annoyance in completing tasks. You will be allowed to take breaks during the session as needed. Additionally, during audiological testing, you may experience slight discomfort. This discomfort may be due to placement of tips in the ears or headbands during testing.

While confidentiality is assured in this study, there is a small chance that someone not on our research team could find that you took part in the study or somehow connect your name with the information we collect about you. To reduce this risk, we are using a number code on all forms with the key with your

name stored in a different place in a locked file cabinet. If your data is used in a publication, your name or other identifying information will not be used. Instead, you will be given a code number to guarantee your anonymity. At the end of the study, the key with any identifiers will be destroyed. Another breach in confidentiality may occur while using RedCAP, since it is an internet-based program. We will make every effort to safeguard your data in REDCap. However, given the nature of online surveys, we cannot guarantee the security of data obtained by way of the Internet.

There is always a chance that any research/procedures can harm you. The research /procedures in this study are no different. In addition to risks described in this consent, you may experience a previously unknown risk or side effect.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

We do not know if you will get any benefit from taking part in this study. However, some people have experienced benefit by understanding their hearing status. However, if you take part in this study, information learned may help others with your condition.

IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

If you do not want to be in the study, there are no other choices except not to take part in the study.

WHAT WILL IT COST YOU TO PARTICIPATE?

You will be reimbursed for parking for your visit. You will be given a stamped garage ticket at the end of each visit to campus. You will also be given a $10 Visa gift card.

However, these costs will be your responsibility:

- Transportation costs related to travel to UK's campus.
- Missed time at work.
    - To prevent this, every effort will be made to plan the visit at your convenience.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

When we write about or share the results from the study, we will write about the combined information. We will keep your name and other identifying information private. Researchers will use a number code on all forms with a key with your name and personal identifying information stored in a locked cabinet and/or password protected computer. At the end of the study, the key with any identifiers will be destroyed. Social security numbers will not be collected for this research.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. We will use the following security procedures to protect the confidentiality of your information: 1. Only encrypted software programs will be used and; 2) All notes, evaluation results, or any other documents containing personal information (names, addresses, birthdates, etc.) will be kept in a locked and unmarked cabinet or password protected computer. Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

You should know that in some cases we may have to show your information to other people because of certain circumstances.

For example, the law may require us to share your information with:

- authorities, if you report information about a child being abused; or if you pose a danger to yourself or someone else.

Officials of the University of Kentucky may look at or copy pertinent portions of records that identify you.

CAN YOU CHOOSE TO WITHDRAW FROM THE STUDY EARLY?

You can choose to leave the study at any time. You will not be treated differently if you decide to stop taking part in the study.

If you choose to leave the study early, data collected until that point will remain in the study database and may not be removed.

The investigators conducting the study may need to remove you from the study. You may be removed from the study if:

- you are not able to follow the directions,
- we find that your participation in the study is more risk than benefit to you.

ARE YOU PARTICIPATING, OR CAN YOU PARTICIPATE, IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may take part in this study if you are currently involved in another research study, as long as it is not a study related to hearing loss or cognition. It is important to let the investigator/your doctor know if you are in another research study. You should discuss this with the investigator/your doctor before you agree to participate in another research study while you are in this study.

WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

If you believe you are hurt or if you get sick because of something that is due to the study, you should call Karah Gottschalk at 859-257-1450 immediately.

Karah Gottschalk will determine what type of treatment, if any, is best for you at that time.

It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

Medical costs related to your care and treatment because of study-related harm will be your responsibility

You do not give up your legal rights by signing this form.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

Study participants will receive a $10 VISA gift card for participating in this study. Gift cards will be given once the participant has completed all testing required.

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

We will tell you if we learn new information that could change your mind about staying in the study. We may ask you to sign a new consent form if the information is provided to you after you have joined the study.

WILL YOU BE GIVEN INDIVIDUAL RESULTS FROM THE RESEARCH TESTS?

Generally, tests done for research purposes are not meant to provide clinical information. We will provide you with individual results related to hearing assessments. Other individual results will not be given to the participant.

There is a slight possibility that during a research project, an investigator could discover something that could affect the health of you or your family. If this occurs, the finding will be reviewed by a special committee to determine if it is in your best interest to contact you.

Do you give permission for us to contact you about research results or incidental findings that are determined to be important to you/your family's health? (Incidental findings are unforeseen findings discovered during the course of the research that may affect you or your family's health).

□ Yes □No _____Initials

You may also withdraw your consent to be contacted with information about research results or incidental findings by sending a written request to Karah Gottschalk, Multi-Disciplinary Building, 725 Rose Street, Room 448, Lexington, KY 40536 (phone number: 859-257-1450).

WHAT ELSE DO YOU NEED TO KNOW?

If you volunteer to take part in this study, you will be one of about 60 people to do so.

PI is a Ph.D. student and she is being guided in this research by Anne Olson, Ph.D. There may be other people on the research team assisting at different times during the study.

University of Kentucky is providing financial support and/or material for this study.

WILL YOUR INFORMATION (OR SPECIMEN SAMPLES) BE USED FOR FUTURE RESEARCH?

All identifiable information (e.g., your name, medical record number, or date of birth) will be removed from the information or samples collected in this study. After we remove all identifiers, the information may be used for future research or shared with other researchers without your additional informed consent.

INFORMED CONSENT SIGNATURES

This consent includes the following:

- **Key Information Page**
- **Detailed Consent**

You will receive a copy of this consent form after it has been signed.

_____ **Signature of research subject**	_____ **Date**
_____ **Printed name of research subject**	
_____ Printed name of [authorized] person obtaining informed consent	__ __ _____ Date
_____ Signature of Principal Investigator or Sub/Co-Investigator	

APPENDIX C: REDCAP SURVEY

Confidential

Demographic Information

This first section will ask you demographic questions, or questions about your age, sex, and occupation.

1)	What is your first and last name	
2)	What is your birthday?	
3)	How old are you in years?	
4)	What was the language you learned first, or your mother tongue?	◯ English ◯ Spanish ◯ Chinese (including Cantonese, Mandarin) ◯ French/French Creole ◯ Tagalog ◯ Vietnamese ◯ Other
5)	What sex were you assigned at birth?	◯ Male ◯ Female
6)	What is your current height in inches?	
7)	What is your current weight in pounds?	
8)	What is your current marital status?	◯ Never Married ◯ Currently Married ◯ Separated ◯ Divorced ◯ Widowed ◯ Cohabiting
9)	What is your highest level of education that you have completed?	◯ No formal schooling ◯ Less than primary school ◯ Primary school completed ◯ Secondary school completed ◯ High school (or equivalent) completed ◯ College/pre-university/University completed ◯ Post graduate degree completed
10)	What ethnic group / racial group do you identify as (E.g., White, Black, African American, Asian, Native American, Latino, Pacific Islander, etc.)?	
11)	What is your current ob?	◯ Employed full time (40 hours a week) ◯ Employed part time (less than 40 hours a week) ◯ Self-employed ◯ Unemployed (currently looking for work) ◯ Unemployed (not currently looking for work) ◯ Student ◯ Retired ◯ Unable to work

12)	What is or was your main occupation? Please pick the best response.	◯ Legislator, Senior Official, or Manager ◯ Professional (engineer, doctor, teacher, clergy, etc.) ◯ Technician or Associate Professional (inspector, finance dealer, etc.) ◯ Clerk (secretary, cashier, etc.) ◯ Service or sales worker (cook, travel guide, shop salesperson, etc.) ◯ Agricultural or fishery worker (vegetable grower, livestock producer, etc.) ◯ Craft or trades worker (carpenter, painter, jewelry worker, butcher, etc.) ◯ Plant/machine operator or assembler (equipment assembler, sewing-machine operator, driver, etc.) ◯ Armed forces (government military) ◯ Other
13)	If you are not working, what is the main reason you are not working for pay?	◯ Homemaker / caring for family ◯ Looked but can't find a job ◯ Doing unpaid work / voluntary activities ◯ Studies / training ◯ Retired ◯ Ill health ◯ Other ◯ Currently working

Health Status

This second section will ask you questions about your personal health.

1)	In general, how would you rate your health today?	◯ Very good ◯ Good ◯ Moderate ◯ Bad ◯ Very bad
2)	Overall in the last 30 days, how much difficulty did you have with work or household activities?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do

Now I would like to review different functions of your body.

When answering these questions, I would like you to think about the last 30 days, taking both good and bad days into account.

When I ask about difficulty, I would like you to consider how much difficulty you have had, on average, in the past 30 days, while doing the activity in the way that you usually do it. By difficulty I mean requiring increased effort, discomfort or pain, slowness or changes in the way you do the activity.

3)	Overall in the last 30 days, how much difficulty did you have with moving around?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
4)	Overall in the last 30 days, how much difficulty did you have with self- care, such as washing or dressing yourself?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
5)	In the last 30 days, how much difficulty did you have in taking care of and maintaining your general appearance (e.g. grooming, looking neat and tidy etc.)	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
6)	Overall in the last 30 days, to what degree did you experience bodily aches or pains?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
7)	In the last 30 days, how much bodily discomfort did you have?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
8)	Overall in the last 30 days, how much difficulty did you have with concentrating or remembering things?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do

9)	In the last 30 days, how much difficulty did you have in learning a new task (for example, learning how to get to a new place, learning a new game, learning a new recipe etc.)?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
10)	In the last 30 days, how much difficulty did you have in dealing with conflicts and tensions with others?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
11)	Do you wear glasses or contact lenses?	◯ Yes ◯ No
12)	In the last 30 days, how much difficulty did you have in seeing and recognizing a person you know across the road (i.e. from a distance of about 20 meters)?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
13)	In the last 30 days, how much difficulty did you have in seeing and recognizing an object at arm's length or in reading?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
14)	Overall in the last 30 days, how much of a problem did you have with sleeping, such as falling asleep, waking up frequently during the night or waking up too early in the morning?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
15)	In the last 30 days, how much of a problem did you have due to not feeling rested and refreshed during the day (e.g. feeling tired, not having energy)?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
16)	Overall in the last 30 days, how much of a problem did you have with feeling sad, low or depressed?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do
17)	Overall in the last 30 days, how much of a problem did you have with worry or anxiety?	◯ None ◯ Mild ◯ Moderate ◯ Severe ◯ Extreme/Cannot do

Lifestyle Factors

This third section will ask you questions about your personal life.

1)	Do you currently smoke any tobacco products such as cigarettes, cigars, or pipes?	◯ Daily ◯ Yes, but not daily ◯ No, not at all ◯ Previously smoked, but not currently
2)	If you currently or previously smoked, how many years have you or did you smoke daily? If you have never smoked, please answer this question with 0.	
3)	Have you ever consumed a drink that contains alcohol (such as beer, wine, etc.)?	◯ Yes ◯ No
4)	During the past 7 days, how many alcoholic beverages did you have in total?	
5)	How many servings of fruit do you eat on a typical day?	◯ None ◯ One ◯ Two ◯ Three ◯ Four ◯ Five or more
6)	How many servings of vegetables do you eat on a typical day?	◯ None ◯ One ◯ Two ◯ Three ◯ Four ◯ Five or more
7)	Now, think about the vigorous activities which take hard physical effort that you did in the last 7 days. Vigorous activities make you breathe much harder than normal and may include heavy lifting, digging, aerobics, or fast bicycling. Think only about those physical activities that you did for at least 10 minutes at a time. During the last 7 days, how many days did you do only vigorous physical activities?	◯ None ◯ ◯ ◯ One ◯ Two ◯ Three Four Five or more

8) Now think about activities which take only moderate physical effort that you did in the last 7 days.

Moderate physical activities make you breathe somewhat harder than normal and may include carrying light loads, bicycling at a regular pace, or doubles tennis. Do not include walking.

Again, think about only those physical activities that you did for at least 10 minutes at a time.

During the last 7 days, how many days did you do only moderate physical activities?

- ◯ None
- ◯ One
- ◯ Two
- ◯ Three
- ◯ Four
- ◯ Five or more

9) Now think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

- ◯ None
- ◯ One
- ◯ Two
- ◯ Three
- ◯ Four
- ◯ Five or more

Health Conditions

This fourth section will ask you questions about any health conditions you experience. Thank you!

1)	Have you ever been diagnosed with arthritis (a disease of the joints)?	◯ Yes ◯ No
2)	Have you ever been diagnosed with angina or angina pectoris (a heart disease)?	◯ Yes ◯ No
3)	Have you ever been diagnosed with diabetes (high blood sugar)?	◯ Yes ◯ No
4)	Are you currently taking any medications?	◯ Yes ◯ No
5)	If you are taking medications, can you list your medications and what condition are you taking it for?	
6)	When was the last time you had your eyes examined by a medical professional?	◯ Within the last 12 months ◯ 1-2 years ago ◯ 3-4 years ago ◯ 5 years ago ◯ More than 5 years ago ◯ Never
7)	Have you been diagnosed with a cataract (that is, an opacity in the lens of the eye)?	◯ Yes ◯ No

Now I would like you to answer questions about some health problems or health care needs that you may have experienced.

During the last 12 months, have you experienced any of the following:

8)	Stiffness in the joint in the morning after getting up from bed, or after a long rest of the joint without movement	◯ Yes ◯ No
9)	Pain, aching, stiffness or swelling in or around the joint (like arms, hands, legs or feet) which were not related to an injury and lasted for more than a month?	◯ Yes ◯ No
10)	Have you ever been diagnosed with depression?	◯ Yes ◯ No
11)	Have you ever been diagnosed to have a mental health problem such as schizophrenia or psychosis?	◯ Yes ◯ No
12)	Cloudy or blurry vision?	◯ Yes ◯ No
13)	Vision problems with light, such as glare from bright lights, or halos around lights?	◯ Yes ◯ No

14) Problems with your mouth and/or teeth?

◯ Yes
◯ No

Patient Health Questionnaire

This final section will ask you questions about how you are feeling.

Thank you!

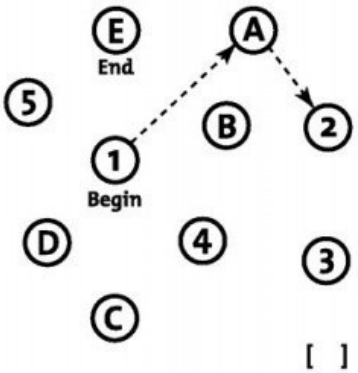
	Over the last 2 weeks, how often have you been bothered by any of the following problems?	
1)	Little interest or pleasure in doing things	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
2)	Feeling down, depressed, or hopeless	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
3)	Trouble falling or staying asleep, or sleeping too much	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
4)	Feeling tired or having little energy	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
5)	Poor appetite or overeating	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
6)	Feeling bad about yourself- or that you are a failure or have let yourself or your family down	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
7)	Trouble concentrating on things, such as reading the newspaper or watching television.	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
8)	Moving or speaking so slowly that other people could have noticed. Or the opposite- being so fidgety or restless that you have been moving around a lot more than usual	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day
9)	Thoughts that you would be better off dead, or of hurting yourself	◯ Not at all ◯ Several days ◯ More than half the days ◯ Nearly every day

APPENDIX D: MONTREAL COGNITIVE ASSESSMENT

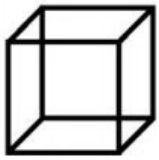
MONTREAL COGNITIVE ASSESSMENT (MOCA)

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



Copy cube



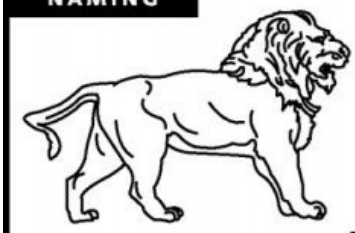
[ ] [ ]

Draw CLOCK (Ten past eleven) (3 points)

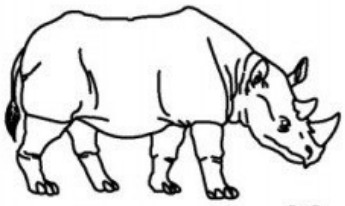
[ ] Contour [ ] Numbers [ ] Hands

__/5

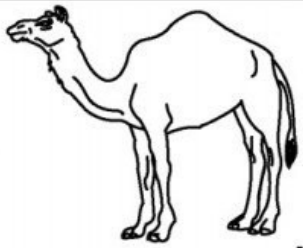
NAMING



[ ]



[ ]



[ ]

__/3

MEMORY — Read list of words, subject must repeat them. Do 2 trials. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION — Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4

Subject has to repeat them in the backward order [ ] 7 4 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE — Repeat : I only know that John is the one to help today. [ ]

The cat always hid under the couch when dogs were in the room. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words)

__/1

ABSTRACTION — Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler

__/2

DELAYED RECALL

	Has to recall words WITH NO CUE	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION — [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

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Normal ≥ 26 / 30

TOTAL __/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

APPENDIX E: MEAN POWER OF ELECTRODES DURING RESTING STATE EEG IN EYES OPEN (REO) AND EYES CLOSED (REC)

Subject	REO AF3 D	REO AF3 T	REO AF3 A	REO AF3 B	REO AF3 G	REO F7 D	REO F7 T	REO F7 A	REO F7 B
NH58F-R-02	7.9443	1.5053	0.95114	0.67994	0.34989	12.236	2.628	2.3781	0.79219
NH59F-R-05	189.18	20.848	3.3079	0.64507	0.30774	283.94	39.816	4.6355	0.61008
NH55F-R-07	22.323	5.4885	2.3453	1.1738	0.23517	6.936	5.3112	3.1966	1.1342
NH54M-R-10	5.8974	3.1071	0.93285	0.25763	0.15624	39.044	5.0103	1.2743	0.42653
NH50F-R-11	124.95	15.018	1.4742	0.22418	0.11556	427.27	41.566	5.035	0.67015
NH51F-R-21	10.311	2.4923	0.72423	0.24163	0.14186	4.9766	1.1533	0.62965	0.2627
NH54F-R-26	X	X	X	X	X	X	X	X	X
NH64F-R-04	8.4307	1.3027	0.50883	0.55244	0.33255	43.758	4.622	1.4422	0.47068
NH63M-R-08	5.5292	0.6956	0.79047	0.39166	0.39206	18.573	2.4732	3.3337	4.4621
NH60F-R-13	8.9738	2.452	3.9573	1.6678	0.22438	5.6463	3.5342	5.377	2.5957
NH66M-R-14	51.592	5.1458	2.5306	2.0589	1.4849	9.7442	3.6082	3.5146	0.75995
NH66F-R-24	7.7	0.92029	0.38206	0.49488	0.31965	12.413	1.2786	0.53323	0.37429
NH67F-L-25	12.543	1.6525	0.90455	0.44616	0.16292	12.764	1.6313	1.1669	0.33367
NH69F-L-27	X	X	X	X	X	X	X	X	X
HL50M-R-06	5.1716	1.0506	0.27597	0.15094	0.13231	5.2175	0.79442	0.34947	0.24564
HL51F-R-09	12.433	2.5738	1.5183	0.38635	0.17016	9.1843	3.3214	2.3767	0.53239
HL53F-R-18	8.9738	2.452	3.9573	1.6678	0.22438	56463	3.5342	5.377	2.5957
HL59M-R-19	6.9626	1.1988	0.47734	0.2736	0.13261	21.659	3.0875	1.6128	1.7024
HL59F-R-20	5.5207	0.92612	0.65363	0.41653	0.16606	24.991	3.3619	1.8051	0.91195
HL59F-R-22	4.0739	0.39147	0.25242	0.29951	0.18093	15.427	2.1164	0.7263	0.34207
HL60M-R-01	21.918	3.2542	1.1349	0.34267	0.12905	5.7143	1.2867	1.2203	0.59076
HL67F-R-03	0.846	10.797	1.188	0.4753	0.2979	1.4582	44.733	1.257	0.476
HL68M-L-12	126.77	7.0674	1.609	1.4092	0.97143	5.1122	0.98889	1.6019	1.1033
HL68F-R-15	4.4582	1.7759	0.74971	0.41924	0.29578	57.196	20.977	3.763	1.5445
HL68M-L-16	2.9861	0.91037	0.87625	0.46671	0.2489	4.1037	1.1715	0.82104	0.46825
HL66M-R-17	0.89439	0.21166	0.10478	0.21969	0.20535	0.40408	0.086391	0.047044	0.11809
HL67M-R-23	10.151	0.9339	0.5482	0.27532	0.095498	15.768	1.9012	0.91063	0.39172
NH66M-R-28	X	X	X	X	X	X	X	X	X

REO F7 G	REO F3 D	REO F3 T	REO F3 A	REO F3 B	REO F3 G	REO FC5 D	REO FC5 T	REO FC5 A	REO FC5 B
0.48582	1.9926	0.91705	0.70937	0.37134	0.15432	3.7958	0.87979	0.93754	0.36989
0.41694	8.163	1.5719	0.59261	0.34706	0.26216	7.0194	1.2805	0.61418	0.37017
0.24577	1.7265	1.9721	1.7598	0.94257	0.14421	11.109	4.2596	1.7216	0.80381
0.25112	2.7222	1.5033	0.71615	0.29747	0.19391	29.909	1.5188	0.5125	0.50315
0.4172	22.048	0.97905	0.32176	0.22711	0.15578	42.409	3.9935	1.1716	0.88648
0.16242	2.0362	0.62468	0.34737	0.19082	0.10704	4.1594	0.5625	0.46988	0.23915
X	X	X	X	X	X	X	X	X	X
0.2156	1.3806	0.30542	0.31594	0.24214	0.12582	7.5419	0.83501	0.74416	0.34266
5.2263	15.325	1.5935	1.4521	0.42065	0.36469	4.3476	0.93308	1.4014	0.38579
0.29613	1.9433	1.9392	3.0467	1.4026	0.18173	3.1378	2.5361	3.6395	1.9922
0.54439	3.3655	1.2596	1.6283	0.29042	0.17706	4.8517	1.8538	1.993	0.50104
0.2581	3.9022	0.96228	0.56094	0.29492	0.14677	2.3005	0.47328	0.2943	0.26
0.11697	2.1768	0.71173	0.81139	0.4324	0.10436	6.6032	0.94659	0.822	0.32445
X	X	X	X	X	X	X	X	X	X
0.20163	2.5258	0.68329	0.31369	0.16266	0.10592	2.3641	0.6992	0.33197	0.20374
0.22521	5.1974	1.3928	1.6537	0.42059	0.1366	3.9697	1.6985	1.8994	0.69682
0.29613	1.9433	1.9392	3.0467	1.4026	0.1173	3.1378	2.5361	3.6395	1.9922
0.78237	2.6634	0.78342	0.31331	0.34847	0.11621	4.984	0.6708	0.51865	0.83503
0.26921	2.1737	0.89659	0.41511	0.30098	0.11605	3.0468	0.81362	0.75397	0.74312
0.16723	2.7855	0.52228	0.2454	0.28235	0.15964	16.236	1.0847	0.44828	0.30073
0.34157	2.1303	1.2937	1.2255	0.37915	0.1189	2.6894	0.76157	0.80592	0.47174
0.2018	0.7854	27.143	1.807	0.5064	0.2385	1.556	48.002	1.508	0.529
0.74365	3.7394	0.77297	0.95856	0.68748	0.21462	29.625	0.7771	0.86339	0.59677
0.94366	3.9145	1.5711	0.70758	0.38363	0.16524	32.411	8.2059	2.44494	1.1385
0.29936	1.831	0.89556	1.0094	0.45043	0.13576	3.0091	0.9389	0.69608	0.43151
0.11366	1.6369	0.35499	0.16333	0.44964	0.44474	0.50331	0.11723	0.073371	0.1998
0.19976	9.9844	0.7305	0.49895	0.25527	0.11446	2.7855	0.85363	0.65305	0.30649
X	X	X	X	X	X	X	X	X	X

REO FC5 G	REO T7 D	REO T7 T	REO T7 A	REO T7 B	REO T7 D G	REO P7 D	REO P7 T	REO P7 A	REO P7 B
0.21499	2.6754	0.6055	0.67544	0.20393	0.078525	2.4394	1.1486	1.5002	0.52853
0.29817	24.691	7.2133	3.246	6.168	4.7329	32.996	9.7958	2.2722	2.8446
0.1673	5.0026	2.2206	0.96208	0.48665	0.085255	15.645	3.5054	3.6956	1.7341
0.61618	10.965	3.2148	2.7817	2.1901	2.3655	9.5562	1.6583	0.9194	0.58011
0.69358	51.429	4.1321	0.91317	0.26049	0.17764	124.57	17.655	1.9842	0.77008
0.12862	1.2123	0.26091	0.24551	0.12925	0.049673	3.8947	1.1787	0.65442	0.40483
X	X	X	X	X	X	X	X	X	X
0.16487	9.6071	0.79356	0.72567	0.21015	0.058088	6.9423	1.2996	1.3752	0.63584
0.31236	8.7151	1.7633	2.9989	0.65534	0.39421	4.7387	1.2758	2.884	1.1271
0.27445	1.7941	2.0499	2.46	1.061	0.10585	3.2104	5.0247	89024	2.3681
0.40456	3.7715	1.7935	2.1457	0.28004	0.16199	12.87	3.4138	5.9473	0.69002
0.15705	1.9831	0.38313	0.24876	0.17881	0.078721	4.865	0.75329	0.55236	0.59063
0.1422	4.2815	0.90529	1.2835	0.39784	0.1269	3.6653	0.99508	2.3801	0.66642
X	X	X	X	X	X	X	X	X	X
0.15097	4.5301	1.0205	0.46926	0.30627	0.18338	3.1561	0.89432	0.55203	0.33744
0.5271	2.0317	1.0447	1.1257	0.25052	0.13094	1.3658	0.6512	1.0526	0.2231
0.27445	1.7941	2.0499	2.46	1.061	0.10585	3.2104	5.0247	8.9024	2.3681
0.32796	7.8641	1.4659	1.4937	1.9032	1.0417	59462	1.549	0.94367	0.57413
0.4703	4.6979	0.62201	0.51484	0.22874	0.084539	0.97568	0.16769	0.36353	0.22708
0.14282	7.1203	0.60514	0.26929	0.17417	0.10369	7.6131	0.77774	0.56259	1.2689
0.35567	1.5367	0.58956	0.7103	0.239	0.12219	6.641	1.7585	2.4863	0.58968
0.263	0.732	29.931	1.487	0.538	0.266	0.37	2.629	0.5133	0.169
0.32513	9.8371	1.2211	1.057	0.49348	0.24629	16.199	1.4266	0.92457	0.5769
0.65707	15.484	3.6883	1.0486	0.44359	0.27017	11.524	4.4873	2.6409	2.6779
0.29353	1.4756	0.52935	0.49423	0.22934	0.11961	1.4254	0.99184	1.3283	0.5723
0.19237	0.49999	0.16432	0.14503	0.21915	0.19408	1.7981	0.61216	0.51913	0.68196
0.13374	3.1881	0.63041	0.49177	0.16474	0.064021	0.57317	0.26179	0.49106	0.15949
X	X	X	X	X	X	X	X	X	X

REO P7 G	REO O1 D	REO O1 T	REO O1 A	REO O1 B	REO O1 G	REO O2 D	REO O2 T	REO O2 A	REO O2 B
0.16062	2.7027	1.1367	1.9969	0.47096	0.1498	4.7783	1.7638	2.5147	0.56474
3.0737	37.836	6.2054	1.6854	0.54725	0.19067	44.707	6.6082	1.769	0.75494
0.3928	18.349	4.157	3.2819	1.4118	0.27599	13.106	4.0659	2.5824	1.7142
0.55449	2.8822	1.0287	0.7086	0.39925	0.2951	4.7269	1.8006	0.94451	0.39079
0.48377	127.08	17.857	1.8691	0.38411	0.20854	125.12	17.183	2.0172	0.47636
0.14603	5.7325	1.0734	0.6036	0.36502	0.16112	5.2298	1.2184	0.63238	0.34705
X	X	X	X	X	X	X	X	X	X
0.13919	5.2283	1.1512	11456	0.82821	0.16088	7.9766	1.3116	1.0278	0.84017
0.9574	11.066	1.2537	1.1538	1.0417	1.0613	6.8717	0.9343	1.0044	0.55994
0.25404	3.7182	4.9271	10.502	2.2522	0.26817	7.0092	7.5881	14.133	2.4888
0.31484	10.805	2.977	5.8909	0.45131	0.16967	15.711	4.415	8.4984	0.67679
0.17978	4.2542	0.76736	0.5711	0.7858	0.18093	5.4117	1.0467	0.78688	0.8581
0.14109	41131	1.2523	2.0886	0.71011	0.13936	4.6342	1.612	2.7073	0.87751
X	X	X	X	X	X	X	X	X	X
0.17213	1.7877	0.41876	0.15516	0.087403	0.047416	4.4078	1.1196	0.47941	0.29795
0.081019	6.704	2.8907	4.6832	1.0687	0.32699	16.71	3.6101	4.456	0.94063
0.25404	3.7182	4.9271	10.502	2.2522	0.26817	7.0092	7.5881	14.133	2.4888
0.27287	5.815	1.5563	1.0482	0.6241	0.22386	6.4942	1.7531	1.0281	0.49465
0.054221	3.7069	0.97725	2.0994	1.226	0.24823	4.9766	1.9068	3.3228	1.1979
0.82863	8.6875	1.241	0.64906	1.5684	0.27699	18.518	5.2916	2.1768	0.76107
0.1533	6.9744	1.7578	2.763	0.58719	0.16406	8.3543	1.5382	1.8153	0.55846
0.133	0.973	10.377	0.906	0.383	0.335	0.90754	24.791	1.0413	0.30843
0.24523	20.41	1.5944	1.2044	0.63971	0.23824	17.886	1.4976	1.0337	0.65597
2.5823	6.9407	2.8639	1.4022	0.92709	0.41165	11.217	3.9124	2.4427	0.93006
0.24581	1.5352	1.055	1.0659	0.49661	0.20375	2.6844	1.2744	1.2794	0.78099
0.58803	3.8429	0.5441	0.44069	0.38381	0.29349	4.5693	0.68043	0.3535	0.35631
0.046285	3.919	1.1635	1.476	0.88463	0.13971	4.8517	1.2155	1.1384	0.71564
X	X	X	X	X	X	X	X	X	X

REO O2 G	REO P8 D	REO P8 T	REO P8 A	REO P8 B	REO P8 G	REO T8 D	REO T8 T	REO T8 A	REO T8 B
0.15899	4.1453	1.9197	3.3229	1.0062	0.22426	2.9673	0.97437	1.3047	0.48914
0.39268	48.806	6.7646	1.8561	1.1632	0.82646	48.25	7.0566	2.0505	2.5514
0.21272	12.705	2.6166	1.3274	0.75843	0.16035	26.746	6.8217	3.3472	1.8012
0.19453	5.3161	1.5204	1.2396	0.85424	0.64136	10.39	3.0743	2.9341	7.0191
0.25996	116.32	16.636	2.301	1.1736	0.79569	69.791	5.2966	1.0987	0.37816
0.13646	5.1976	1.1867	0.59688	0.33419	0.18998	3.9853	1.0609	0.83745	0.59527
X	X	X	X	X	X	X	X	X	X
0.17032	6.382	1.0621	1.0659	0.66814	0.15546	1866	1.7459	2.643	0.81973
0.49727	5.4357	1.2818	2.4559	1.2423	1.2706	9.7946	1.7319	3.7495	0.7923
0.27992	7.1249	7.1338	12.587	2.9383	0.33467	4.6294	5.1127	6.7237	2.7663
0.25365	15.96	5.1346	7.0992	0.95094	0.64004	5.1116	2.638	3.0346	0.35592
0.19312	4.1183	0.67002	0.66302	0.65344	0.17083	1.9375	0.40325	0.33573	0.27117
0.14231	3.8567	1.5079	2.5085	1.0533	0.16572	2.7274	0.55872	0.45264	0.26724
X	X	X	X	X	X	X	X	X	X
0.153653	3.0849	0.88778	0.48923	0.31485	0.17847	5.0169	0.88034	0.45413	0.28788
0.17918	9.6385	3.2967	8.1796	1.1892	0.30418	17.187	4.6521	7.5925	1.391
0.27992	7.1249	7.1338	12.587	2.9383	0.33467	4.6294	5.1127	6.7237	2.7663
0.21334	8.9613	1.7351	1.6019	0.94426	0.41129	4.8619	0.51661	0.52485	0.32487
0.24412	17.072	1.2532	1.3607	0.92732	0.19161	25.573	1.4826	0.63202	0.61272
0.15476	3.9276	0.63386	0.61894	1.2397	0.62423	21.529	1.9051	1.3238	1.5998
0.17773	6.6906	1.6999	2.106	0.6224	0.2347	7.6191	1.7182	2.2285	0.84448
0.18154	0.37423	10.789	0.64353	0.21715	0.12606	1.313	47.47	3.1942	0.97874
0.22651	16.811	1.5267	0.76803	0.64265	0.29905	9.0837	1.1431	1.5416	1.7632
0.32427	27.553	5.7574	2.0764	0.76706	0.43295	41.659	15.457	4.4721	2.0477
0.27647	2.807	1.4698	1.9768	0.8861	0.34608	9.042	2.2753	2.5435	1.2986
0.2635	1.9032	0.56501	0.51382	0.70564	0.69805	1.6393	0.59656	0.59335	1.4076
0.13334	5.9275	1.8231	1.9436	0.75942	0.29455	2.7453	0.81423	1.1331	0.22638
X	X	X	X	X	X	X	X	X	X

REO T8 G	REO FC6 D	REO FC6 T	REO FC6 A	REO FC6 B	REO FC6 G	REO F4 D	REO F4 T	REO F4 A	REO F4 B
0.17706	3.0795	0.66407	0.77395	0.29319	0.14117	2.6217	0.68831	0.68568	0.31197
2.2416	10.177	0.93133	0.43197	0.32317	0.2329	17.395	3.0314	1.0148	0.8231
0.45583	10.855	2.913	1.8884	1.7629	0.26338	6.1403	2.8657	2.9047	1.2402
4.1223	11.588	1.4426	0.97109	0.63418	0.56278	2.7	1.0517	0.51882	0.27996
0.2368	56.922	4.4897	1.1527	0.89143	0.62805	26.714	3.3314	0.43097	0.30756
0.31882	1.3782	0.34131	0.29961	0.17667	0.1121	2.6058	0.77471	0.43397	0.22826
X	X	X	X	X	X	X	X	X	X
0.16733	10.601	0.8805	0.81272	0.27504	0.079348	3.5225	0.49853	0.47792	0.29329
0.41433	6.3632	1.1439	1.5382	0.43235	0.41747	52373	0.93872	1.118	0.32294
0.57369	3.0477	3.147	4.9393	2.0847	0.28027	2.2694	2.3661	3.7232	1.6083
0.25238	9.0427	2.5181	2.6508	0.55681	0.63536	7.6145	2.103	2.543	0.64733
0.10309	1.8293	0.55764	0.43855	0.65877	0.36782	1.4626	0.73565	0.38823	0.36608
0.11675	6.3796	0.97231	1.0776	0.43413	0.11985	4.4723	1.0349	1.2126	0.58187
X	X	X	X	X	X	X	X	X	X
0.19878	2.1135	0.53708	0.31231	0.28342	0.18862	2.9467	0.67177	0.22515	0.14202
0.71622	8.5373	2.8918	3.1313	0.85868	0.39445	33.149	2.0332	1.8302	0.42132
0.57369	3.0477	3.147	4.9393	2.0847	0.28027	2.2694	2.3661	3.7232	1.6083
0.1526	3.3983	0.62808	0.73305	0.84535	0.53637	4.1634	0.6438	0.32066	0.30394
0.22373	47.236	1.2261	0.33642	0.35105	0.17939	2.1202	0.74486	0.44597	0.25362
0.88564	7.8645	0.6205	0.43479	0.31893	0.15254	3.85	0.42164	0.27301	0.2567
0.50568	4.5283	1.1115	1.2531	0.6123	0.25311	1.2794	0.9003	0.90583	0.32684
0.6111	1.1072	50.901	2.0836	0.6672	0.2675	0.90782	5.4795	0.92028	0.32313
2.1124	3.4814	0.58027	1.9962	3.122	3.7611	4.4669	0.73601	0.95114	0.73121
1.1935	29.044	10.632	2.3661	0.9458	0.77133	6.9313	2.54	0.93206	0.51771
0.70989	4.7483	1.2565	0.95793	0.66677	0.64821	54.645	21.512	6.113	1.8522
1.4305	0.69513	0.22968	0.2002	0.29703	0.32332	1.5676	0.34077	0.23901	0.40582
0.091341	2.997	0.74225	0.92989	0.28855	0.1668	3.0396	0.80582	0.6442	0.34951
X	X	X	X	X	X	X	X	X	X

REO F4 G	REO F8 D	REO F8 T	REO F8 A	REO F8 B	REO F8 G	REO AF4 D	REO AF4 T	REO AF4 A	REO AF4 B
0.14626	10.709	2.188	2.4398	0.71192	0.38918	12.507	1.8446	1.3556	1.1971
0.70869	98.496	11.16	2.8018	0.76454	0.5125	83.17	12.607	2.3903	0.62104
0.19681	32.75	15.1	2.623	1.6866	0.33245	112.72	25.933	4.2216	1.4813
0.17277	29048	1.9682	0.94724	0.54748	0.39338	7.7625	2.0863	0.79241	0.41039
0.24627	459.37	51.87	5.7195	0.65026	0.43784	868.44	79.013	7.0446	0.79598
0.1231	5.3107	1.1436	0.5358	0.29488	0.14756	19.114	2.7937	0.77103	0.35005
X	X	X	X	X	X	X	X	X	X
0.15228	42.891	3.2935	1.3227	1.1632	0.60946	1.8523	0.42276	0.31048	0.33124
0.29985	.25.482	3.5582	4.6508	1.1437	0.91851	6.6965	1.0072	1.2499	0.32059
0.17177	3.4767	4.7547	6.9075	2.218	0.34468	3.4776	3.0662	5.0233	2.2333
0.39458	9.8516	3.3051	3.6211	0.93391	0.77652	68.725	7.0513	3.3168	2.4274
0.18483	15.581	1.6942	0.96766	0.62395	0.33715	13.207	1.1917	0.71768	1.6501
0.11432	23.665	1.9339	1.5215	0.50247	0.15471	10.59	1.5058	1.0363	0.56216
X	X	X	X	X	X	X	X	X	X
0.094075	17.463	1.6181	0.60625	0.48462	0.37219	7.1318	1.1918	0.30757	0.14626
0.13249	11.814	4.3117	3.6926	0.78287	0.29335	13.774	2.5502	1.6937	0.48731
0.17177	3.4767	4.7547	6.9075	2.218	0.34468	3.4776	3.0662	5.0233	2.2333
0.11439	25.87	2.4439	1.1674	1.7246	0.82151	5.6317	1.4277	0.43724	0.25876
0.14847	45.71	2.731	0.73107	0.53589	0.17467	9.2191	0.71374	0.78627	0.44463
0.14739	36.474	2.1152	0.97478	0.4254	0.15314	5.1428	0.49326	0.31393	0.31625
0.12093	20.2	2.6083	1.6211	0.54424	0.22258	14.612	2.281	1.2255	0.33612
0.27586	0.29369	5.0181	0.30825	0.15882	0.096172	1.4266	9.406	1.2931	0.40493
0.15204	10.405	98481	0.79949	0.64507	0.61474	93.868	7.4484	1.7418	1.3471
0.27172	107.27	20.231	4.0417	1.1816	0.66252	65795	4.1779	2.1052	1.216
0.56391	10.841	1.8531	1.2956	0.61228	0.47516	8.1936	1.5675	1.1154	0.83747
0.48605	0.83431	0.24252	0.20409	0.34726	0.35946	1.972	0.46339	0.26605	0.56291
0.090602	5.3067	1.1941	1.1686	0.29345	0.1476	6.9025	1.0831	0.55877	0.37239
X	X	X	X	X	X	X	X	X	X

REO AF4 G	REC AF3 D	REC AF3 T	REC AF3 A	REC AF3 B	REC AF3 G	REC F7 D	REC F7 T	REC F7 A	REC F7 B
0.49209	3.6071	1.7013	4.571	0.70216	0.3434	5.7952	2.3728	5.9193	0.56462
0.35392	78.999	1.4976	0.78763	0.47235	0.18761	7.0768	2.0031	0.92523	0.46332
0.61223	7.1865	1.491	4.9731	1.01	0.1386	4.9051	1.376	3.9738	0.92722
0.35014	4.4784	1.6095	2.3616	0.28868	0.13241	3.9313	1.3913	1.9323	0.32
0.43156	24.949	1.7125	0.48834	0.3	0.12439	50.533	4.4451	1.6369	0.50866
0.20447	6.9507	0.96238	0.47932	0.21308	0.13045	5.9355	0.83128	0.58259	0.25714
X	X	X	X	X	X	X	X	X	X
0.19846	7.7453	0.79799	0.62937	0.29203	0.11897	23.386	1.5435	1.6229	0.40765
0.27357	5.078	0.6151	0.62484	0.18311	0.11084	5.8899	1.5542	2.4409	0.98806
0.5662	31.34	3.8518	5.3812	1.6722	2.8836	7.7773	4.9038	5.7176	1.7754
1.4226	8.2498	3.4249	3.921	0.90657	0.72086	15.56	7.2853	6.0433	0.54938
0.9286	4.716	0.90529	0.60487	0.30163	0.15426	6.4099	1.0465	0.66211	0.34245
0.16011	7.5066	1.0521	2.425	0.49769	0.14051	2.2552	0.73011	1.9479	0.39051
X	X	X	X	X	X	X	X	X	X
0.12758	5.288	0.57343	0.27978	0.14661	0.12117	2.7755	0.66566	0.35676	0.19928
0.23242	7.9075	1.1336	2.818	0.3194	0.14659	11.31	3.0318	3.8464	0.52017
0.5662	31.34	3.8518	5.3812	1.6722	0.28836	7.7773	4.9038	5.7176	1.7754
0.13072	4.8342	0.62595	0.8754	0.2575	0.11366	8.6928	1.3415	1.2742	0.72566
0.13065	3.8469	2.6106	7.0693	0.51354	0.13669	6.7833	2.1863	5.8152	0.57407
0.11673	2.9102	0.3935	0.40366	0.38941	0.11768	20.94	0.82213	0.59955	0.48166
0.12361	4.2807	2.2674	3.2692	0.55452	0.15305	4.6706	2.0614	2.2178	0.96161
0.2794	0.84619	10.797	1.1884	0.47529	0.29788	1.4582	44.733	1.2571	0.476
0.97422	29.407	1.5379	2.456	1.3308	0.93546	3.5001	1.1329	2.0589	0.95202
0.77264	22.014	2.8426	1.673	0.61979	0.20785	37.928	4.8828	2.1457	0.76929
0.53453	3.044	6.4779	7.8762	0.57715	0.14229	5.12	3.4914	4.4418	0.51775
0.60884	1.1546	0.26964	0.33915	0.1467	0.092492	0.47387	0.099292	0.10763	0.057771
0.13466	4.3196	0.85585	1.0345	0.32924	0.11947	5.5877	1.8283	2.2539	0.47358
X	X	X	X	X	X	X	X	X	X

REC F7 G	REC F3 D	REC F3 T	REC F3 A	REC F3 B	REC F3 G	REC FC5 D	REC FC5 T	REC FC5 A	REC FC5 B
0.25205	2.1821	1.814	3.484	0.44652	0.13505	1.7335	1.2957	3.2134	0.43825
0.27075	2.0185	0.71921	0.39009	0.28578	0.17842	2.8058	0.71518	0.61608	0.35804
0.19471	3.7893	1.3475	4.713	0.75543	0.12987	9.5635	0.92182	2.4632	0.78644
0.16758	2.7658	1.9421	2.7141	0.33912	0.1211	50664	1.1325	1.543	0.31402
0.31138	5.8946	0.98367	0.38914	0.30341	0.15057	12.34	1.2141	0.69333	0.62044
0.18259	2.3515	0.71505	0.37359	0.17654	0.0992	2.7889	0.52023	0.37736	0.20953
X	X	X	X	X	X	X	X	X	X
0.13883	1.3931	0.35493	0.45773	0.22667	0.097218	3.5688	0.56687	0.81687	0.35223
0.6568	18.93	1.6011	1.3435	0.28807	0.18229	5.1834	0.71687	1.2245	0.19549
0.3505	3.6478	2.3485	4.8533	1.3563	0.16219	9.3949	3.1841	3.9843	1.2378
0.42218	3.5264	2.9095	2.9915	0.27374	0.15199	3.9334	3.2054	3.2128	0.46378
0.18229	4.6144	0.87267	0.48565	0.26549	0.11667	1.3691	0.4659	0.39017	0.25229
0.11863	2.0592	0.91451	2.0805	0.53769	0.098633	4.1441	0.72274	1.4723	0.3473
X	X	X	X	X	X	X	X	X	X
0.21201	1.607	0.66272	0.41567	0.13808	0.10043	2.5668	0.58735	0.36803	0.19142
0.24544	4.7086	1.4283	2.9339	0.446	0.12775	7.7641	1.7748	2.8031	0.54616
0.3505	3.6478	2.3485	4.8533	1.3563	0.16219	9.3949	3.1841	3.9848	1.2378
0.24782	2.5926	0.73318	0.79808	0.23998	0.10216	3.5492	0.79436	0.81795	0.4575
0.20654	2.0034	1.9571	3.997	0.40513	0.13558	3.048	2.3377	6.1785	0.57374
0.17366	1.7797	0.46901	0.47148	0.46676	0.14629	9.3043	0.80505	0.57413	0.3854
0.44428	2.1336	1.4729	2.6154	0.46224	0.13145	2.3748	1.1271	1.3403	0.77199
0.20178	0.78537	27.143	1.8067	0.50636	0.23845	1.5556	48.002	1.5077	0.52975
0.63475	2.372	0.97446	1.6359	0.7826	0.20056	20.03	0.9424	1.3576	0.58932
0.29161	13.252	2.6073	1.3834	0.55662	0.21644	15	2.8115	1.7335	0.60669
0.18621	2.4229	5.7338	6.2828	0.6619	0.12004	3.4865	2.9879	3.83	0.4598
0.045226	1.6851	0.4279	0.46532	0.23621	0.16737	0.55121	0.13648	0.13076	0.04966
0.23374	2.68	0.69439	0.62782	0.27907	0.11115	1.7398	0.941	1.2149	0.43762
X	X	X	X	X	X	X	X	X	X

REC FC5 G	REC T7 D	REC T7 T	REC T7 A	REC T7 B	REC T7 D G	REC P7 D	REC P7 T	REC P7 A	REC P7 B
0.24249	1.3858	1.417	2.8599	0.26267	0.076431	4.5843	4.752	11.084	0.93701
0.17455	15.325	3.3754	2.5513	2.1937	2.1261	5.1703	1.0808	1.6787	1.1606
0.20968	3.4498	0.68479	2.9774	0.57866	0.071425	8.205	2.1362	27.24	2.0032
0.18814	2.1484	1.5983	2.9316	0.81273	0.62974	2.5249	1.9464	4.8631	0.49416
0.45197	12.431	1.0833	0.42154	0.2817	0.18781	20.718	1.271	1.0804	1.1919
0.11823	1.1759	0.29859	0.22201	0.11678	0.051039	2.3145	0.77836	0.62986	0.35716
X	X	X	X	X	X	X	X	X	X
0.12218	3.3086	0.32261	0.91892	0.24755	0.050514	5.5357	0.79438	1.9059	0.81502
0.089564	11.04	1.4968	2.0392	0.35907	0.21027	3.312	0.95265	2.395	1.345
0.27389	2.9368	2.2752	2.7758	0.79548	0.11989	5.8086	8.3142	13.87	2.7589
0.39137	2.8778	3.0003	2.8354	0.25092	0.14368	3.3017	8.7177	12.097	0.73239
0.14242	0.90727	0.30249	0.30591	0.16804	0.06247	2.4884	1.0459	1.0581	0.6438
0.15709	2.4539	0.90886	2.9595	0.42261	0.14201	2.3228	1.7834	16.323	0.66132
X	X	X	X	X	X	X	X	X	X
0.14504	7.5757	0.83524	0.54504	0.24323	0.14064	2.954	0.7638	0.62075	0.29655
0.32098	3.2125	1.0868	1.7476	0.24141	0.091226	1.6584	0.83354	3.0659	0.30415
0.27389	2.9368	2.2752	2.7758	0.79548	0.11989	5.8086	8.3142	13.87	2.7589
0.1909	4.808	0.83635	0.91123	0.42658	0.21146	7.8654	1.0242	2.092	0.44155
0.19048	1.8122	1.1801	2.7834	0.23992	0.058997	1.1105	1.5111	4.984	0.44438
0.13032	4.0162	0.32809	0.40166	0.26816	0.060944	6.4725	0.91993	1.3326	1.4334
0.35121	1.5687	1.0093	1.9357	0.45664	0.14275	5.1598	4.4679	17.744	1.1809
0.26289	0.7318	29.931	1.4867	0.53802	0.26591	0.36995	2.6289	0.51332	0.16903
0.3102	1.6333	0.67125	1.0222	0.46996	0.25022	2.667	0.81015	1.5397	0.53658
0.28996	6.0838	1.73	1.0826	0.35135	0.13175	22.272	4.4315	3.141	1.3789
0.1633	1.59	1.0703	1.5125	0.27303	0.069971	3.3444	8.1117	9.7895	0.72142
0.072458	1.0238	0.19271	0.23868	0.1023	0.085365	3.9682	0.74883	0.94211	0.37217
0.16351	1.437	0.68092	0.93138	0.2412	0.098827	0.81625	0.43582	1.0334	0.21536
X	X	X	X	X	X	X	X	X	X

RECP7 G	RECO1 D	RECO1 T	RECO1 A	RECO1 B	RECO1 G	RECO2 D	RECO2 T	RECO2 A	RECO2 B
0.18414	3.8581	3.0191	12.71	0.62371	0.15021	5.8289	4.958	16.645	0.82091
0.62035	4.5832	1.2286	1.9411	0.7578	0.12427	11.036	1.9951	2.862	0.96112
0.21274	5.9055	2.4585	33.412	1.8754	0.18316	6.8176	1.965	12.438	2.2314
0.20075	2.1346	1.5221	7.4893	0.48692	0.16398	3.3379	2.6953	12.58	0.57721
0.71812	12.307	1.1421	0.76334	0.4997	0.18509	14.861	1.4865	0.90793	0.54616
0.17373	2.8658	0.70976	0.64535	0.38179	0.16153	3.3986	0.77017	0.53786	0.33665
X	X	X	X	X	X	X	X	X	X
0.12322	5.3156	0.97852	2.8612	1.2742	0.14575	5.6202	1.111	4.2845	1.2516
1.0762	5.3667	0.77219	1.5683	1.1065	1.1236	3.1814	0.79542	1.122	0.54491
0.24151	8.1076	9.6826	15.283	2.9245	0.30181	11.737	12.465	19.391	3.0661
0.34732	2.7701	7.8415	14.011	0.46389	0.1855	6.546	13.587	18.522	0.61195
0.15324	3.1929	1.3639	1.9899	1.0519	0.15715	4.1307	1.4659	3.2763	1.2146
0.1347	2.8875	0.92792	12.094	0.71239	0.13547	2.6195	1.2564	9.0847	1.0255
X	X	X	X	X	X	X	X	X	X
0.17682	1.5478	0.26552	0.28778	0.078561	0.045368	3.1363	0.80951	1.325	0.27122
0.05822	6.5104	4.5494	19.46	1.3852	0.26407	9.1328	4.2215	21.271	1.353
0.24151	8.1076	9.6826	15.283	2.9245	0.30181	11.737	12.465	19.391	3.0661
0.15805	9.9702	1.4637	3.8193	0.5851	0.16988	5.6715	1.6172	4.3658	0.56212
0.046344	7.5982	10.912	43.979	2.6832	0.22073	6.9514	16.966	51.425	2.6881
0.27114	6.8338	1.3168	2.0376	2.6796	0.22433	17.756	1.8629	3.1396	2.5144
0.20706	4.7485	5.429	20.713	1.1174	0.20555	5.3661	2.5013	7.1114	1.0879
0.13344	0.97302	10.377	0.90644	0.38281	0.33465	0.90754	24.791	1.0413	0.30843
0.22	2.8511	1.5886	3.6831	0.58655	0.25646	1.6644	2.0668	4.5968	0.57914
0.68103	66.737	23.694	10.271	2.8866	0.6482	32.076	6.6423	6.5362	1.8818
0.14286	3.4106	6.1286	11.65	0.80155	0.15694	5.1919	12.011	19.239	1.2344
0.27683	3.1786	0.66007	1.561	0.32581	0.19487	2.3306	0.56172	1.372	0.34291
0.065861	3.3843	1.7555	4.7127	1.016	0.17522	2.8296	1.433	4.0636	0.70713
X	X	X	X	X	X	X	X	X	X

REC O2 G	REC P8 D	REC P8 T	REC P8 A	REC P8 B	REC P8 G	REC T8 D	REC T8 T	REC T8 A	REC T8 B
0.15201	7.5233	14.247	39.959	1.8232	0.24409	2.5425	3.7202	7.7996	0.79257
0.20283	5.362	1.6509	2.504	1.1875	0.43147	7.715	0.84845	1.7735	1.2968
0.16536	3.6664	1.0567	5.6849	0.70155	0.19836	8.384	3.312	9.3841	2.216
0.15767	3.3415	3.2055	6.8362	0.78064	0.40973	4.1911	2.9824	6.6046	2.7313
0.24647	10.803	1.175	1.2681	1.5439	1.0516	12.288	1.1883	0.50479	0.33556
0.15949	2.3077	0.61986	0.52505	0.32206	0.17333	3.2602	0.68365	0.6873	0.36456
X	X	X	X	X	X	X	X	X	X
0.14822	4.4285	0.84763	2.0346	0.86057	0.15269	7.2179	1.2628	2.775	0.9516
0.43265	3.5633	1.0067	1.8128	0.82868	0.73473	8.7533	1.5744	3.0236	0.63298
0.33079	9.7422	11.691	16.651	3.1408	0.37951	3.7701	5.1573	6.4126	2.1445
0.23855	5.9558	12.266	11.676	0.90968	0.51855	3.3601	3.7352	3.8024	0.32317
0.19464	2.255	0.99099	1.3386	0.84873	0.15491	0.95458	0.38182	0.36138	0.24274
0.13101	2.3051	1.508	5.7525	1.0353	0.16074	2.1008	0.31007	0.43733	0.25276
X	X	X	X	X	X	X	X	X	X
0.15543	2.0993	0.75093	0.65097	0.27921	0.14643	2.7735	0.74196	0.52909	0.24956
0.18651	10.147	4.0394	15.537	1.2299	0.23051	15.828	2.7484	6.1725	1.1232
0.33079	9.7422	11.691	16.651	3.1408	0.37951	3.7701	5.1573	6.4126	2.1445
0.14867	4.5485	1.855	3.0504	0.67561	0.2231	2.4005	0.54594	0.57187	0.29333
0.2834	47685	10.697	23.675	1.7336	0.27154	3.0899	1.8753	3.4424	0.99928
0.20571	2.4144	1.0896	2.0802	1.7491	0.2803	11.298	2.0799	2.6758	1.9911
0.22055	2.9513	2.0494	5.3692	0.89295	0.32013	7.0252	1.8477	4.0024	1.3345
0.18154	0.37423	10.789	0.64353	0.21715	0.12606	1.313	47.47	3.1942	0.97874
0.23374	1.5773	1.6871	3.418	0.63661	0.29465	1.3559	1.0742	2.2359	1.9167
0.33937	16.825	4.8549	3.8288	1.2539	0.36032	25.001	4.699	2.7407	1.0324
0.20507	4.4003	19.761	26.232	1.3066	0.24763	4.5517	8.9279	9.7553	0.98335
0.22246	3.033	0.68481	1.1475	0.48691	0.42992	2.8686	0.65511	0.82641	0.96556
0.1573	4.0933	1.8732	3.1031	0.79917	0.32823	2.2877	0.88851	1.3994	0.35217
X	X	X	X	X	X	X	X	X	X

REC T8 G	REC FC6 D	REC FC6 T	REC FC6 A	REC FC6 B	REC FC6 G	REC F4 D	REC F4 T	REC F4 A	REC F4 B
0.23792	1.6147	1.2488	2.36	0.31584	0.12247	2.3187	1.428	2.5952	0.34556
0.36366	8.3124	0.56854	0.59153	0.27214	0.17282	4.843	1.5212	0.88831	0.78705
0.75254	5.1677	1.2976	7.5927	1.5417	0.18879	5.4009	1.6193	7.0837	0.84131
1.2429	1.5944	1.0659	2.3757	0.34086	0.14805	1.828	2.0235	2.8808	0.37215
0.22441	9.7268	1.1653	0.57348	0.39423	0.29355	79.293	2.0183	0.50968	0.25691
0.14561	3.1137	0.4549	0.35576	0.18465	0.12254	2.3654	0.8362	0.41774	0.20816
X	X	X	X	X	X	X	X	X	X
0.1569	3.8338	0.36177	0.88145	0.26517	0.055708	3.5813	0.48957	0.5394	0.26839
0.45882	3.8941	0.66845	1.1295	0.29721	0.23264	3.7336	0.47783	0.81316	0.19154
0.40743	3.1744	3.5301	6.0948	1.9204	0.25277	3.4683	2.7683	6.0615	1.7438
0.17558	6.2806	3.1405	3.6729	0.48312	0.52626	3.162	4.2224	4.7404	0.36379
0.085273	1.1446	0.67799	0.62231	0.45942	0.23851	1.3639	0.71188	0.49262	0.28601
0.14767	2.8885	0.70457	2.6363	0.29267	0.10111	2.1879	0.95273	3.8866	0.55318
X	X	X	X	X	X	X	X	X	X
0.14422	2.1472	0.5253	0.27608	0.17966	0.12074	3.0665	0.51907	0.28481	0.10677
0.3953	1.0722	1.8877	3.5592	0.59389	0.2351	35.265	2.248	3.1509	0.38338
0.40743	3.1744	3.5301	6.0948	1.9204	0.25277	3.4683	2.7683	6.0615	1.7438
0.10494	3.4826	0.6046	0.68501	0.55357	0.25438	1.6349	0.58672	0.6821	0.20893
0.30786	1.8772	1.1224	2.4625	0.51208	0.18141	5.3979	2.4205	5.3576	0.52777
0.63407	4376	0.51173	0.43373	0.31672	0.14138	2.7079	0.43066	0.40269	0.42053
0.83431	8.0826	2.3876	4.8476	0.86161	0.39075	4.5479	1.5572	3.0365	0.37905
0.61112	1.1072	50.901	2.0836	0.9972	0.2675	0.90782	5.4795	0.92028	0.32313
2.2677	4.1398	0.80152	3.1512	3.2166	3.7026	1.5339	0.94012	1.7623	0.69346
	0.45685	18.02	3.0313	1.992	0.80685	0.25832	54.05	7.2854	3.411
0.19719	2.7414	2.1043	2.9441	0.55086	0.19176	66.117	24.33	11.25	1.7022
0.9835	0.82793	0.26295	0.31249	0.19322	0.18143	1.0983	0.36213	0.47725	0.23948
0.14885	3.2445	0.99077	1.2716	0.41847	0.18896	1.7489	0.92384	1.0765	0.37874
X	X	X	X	X	X	X	X	X	X

RECF4G	RECF8D	RECF8T	RECF8A	RECF8B	RECF8G	RECAF4D	RECAF4T	RECAF4A	RECAF4B
0.10784	4.8346	2.5659	5.527	0.52565	0.20281	6.7919	2.2155	5.9033	0.82712
0.38183	25.98	3.0642	2.7215	0.90313	0.2588	9.1506	0.94174	0.89562	0.41406
0.13688	14.443	1.774	7.7353	1.4851	0.20061	15.036	1.8897	7.7931	1.0267
0.12879	4.765	1.3548	2.5107	0.32981	0.14263	4.9768	1.442	2.4997	0.33053
0.14135	32.14	3.4054	0.89867	0.41791	0.29567	427.54	25.555	3.1679	0.68985
0.10433	5.5153	0.99974	0.56382	0.28633	0.20816	12.982	1.0991	0.74334	0.24152
X	X	X	X	X	X	X	X	X	X
0.10569	16.391	0.91441	0.97849	0.43129	0.14836	1.4583	0.36969	0.54481	0.24472
0.11889	28.883	2.3877	3.999	0.7147	0.32848	5.4552	0.54075	0.94203	0.21955
0.17756	6.4016	5.4872	6.3603	2.0074	0.33259	6.2078	4.4436	7.7919	2.653
0.23372	12.002	4.3999	4.8431	0.54221	0.44877	9.1655	4.6918	5.2532	1.006
0.11298	8.6109	1.1178	0.97039	0.52111	0.25385	68601	1.0225	0.6696	0.42294
0.10792	6.7329	0.92643	3.0966	0.39145	0.1695	8.8286	1.156	3.19	0.054368
X	X	X	X	X	X	X	X	X	X
0.072723	18.138	1.1718	0.51273	0.24711	0.18774	6.3595	0.83131	0.29291	0.12681
0.13196	14.718	2.6281	4.3613	0.53374	0.21369	11.75	1.7893	3.0449	0.48745
0.17756	6.4016	5.4872	6.3603	2.0074	0.33259	6.2078	4.4436	7.7919	2.653
0.099132	12.667	1.1975	1.2471	0.89179	0.4252	4.4202	0.5921	0.85674	0.2364
0.11711	7.7183	2.1774	5.446	0.54132	0.15013	3.5679	2.5718	7.0079	0.54157
0.12375	13.09	0.98986	0.72428	0.5413	0.14683	3.1517	0.47624	0.47364	0.45229
0.13536	6.4444	2.426	5.0147	0.80206	0.45988	8.7127	2.0158	4.1698	0.5202
0.27586	0.29369	5.0181	0.30825	0.15882	0.096172	1.4266	9.406	1.2931	0.40493
0.14982	1.14	0.66344	1.4566	0.69035	0.62501	6.0483	1.6717	2.4167	1.453
1.1949	0.63288	32.274	5.0629	2.5948	1.007	0.43391			
0.3739	5.8393	3.5672	4.7172	0.64862	0.17631	5.0683	5.9961	7.3534	0.60522
0.19127	1.1276	0.27253	0.34727	0.20914	0.19395	5.083	0.54413	0.65544	0.3508
0.11353	3.5594	1.294	1.5845	0.46508	0.22977	3.0352	0.83394	1.1836	0.3361
X	X	X	X	X	X	X	X	X	X

REC AF4 G				
0.35584				
0.17171				
0.13535				
0.14582				
0.30087				
0.14904				
X				
0.1049				
0.11566				
1.0834				
0.72377				
0.2473				
0.1503				
X				
0.10945				
0.28252				
1.0834				
0.10361				
0.12676				
0.13676				
0.13921				
0.27945				
1.1603				
0.17689				
0.23262				
0.1102				
X				

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PROFESSIONAL EXPERIENCE

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University of Kentucky ▪ Lexington, KY
- August 2016 – May 2018
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- August 2017- November 2018
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Hazelwood Center▪ Lexington, KY
- March 2017 – August 2017
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PUBLICATIONS

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