Hearing And Other Factors Influencing Memory Performance In Remote Assessment

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HEARING AND OTHER FACTORS INFLUENCING MEMORY PERFORMANCE IN REMOTE ASSESSMENT

by

ERIKA SQUIRES

DISSERTATION

Submitted to the Graduate School
of Wayne State University,
Detroit, Michigan
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

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MAJOR: COMMUNICATION SCIENCES AND DISORDERS

Approved By:

________________________________________
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CHAPTER 1: INTRODUCTION

Evidence of an independent association between hearing loss and accelerated cognitive decline has revitalized the field of aural rehabilitation (AR; Lin et al., 2013). Researchers are working to explore whether interventions, including the use of hearing technology and aural rehabilitation, can prevent or slow the progression of cognitive decline. Typically, language comprehension is facilitated by successful speech perception and recognition processes; however, people with hearing loss may rely on higher-level cognitive processes to compensate for degraded auditory input (Wingfield & Lash, 2016). In this case, a person may be able to successfully understand a spoken message, despite reductions in early-stage auditory processes such as speech perception and recognition. While some individuals are able to rely on higher-level cognitive processes to support language comprehension, age-related changes in cognition including reductions in processing speed, working memory, and inhibition make compensating for impoverished auditory input particularly challenging for older adults with hearing loss.

In addition to being associated with an accelerated rate of cognitive decline, hearing loss is associated with a variety of negative health outcomes including frailty and reductions in quality of life; therefore, implementing timely and evidence-based interventions to address a person’s difficulty hearing and understanding spoken language is imperative (Kamil et al., 2016; Lin et al., 2013). Traditional approaches to AR have primarily focused on auditory-based tasks such as phoneme discrimination; however, in the past two decades a number of computerized AR programs have been developed that integrate cognitive activities into training. There is a need for more research exploring the effectiveness of auditory-cognitive training programs, and currently there is an urgent need for research into remote assessment to support telepractice. Therefore, this investigation will allow comparison of older adults’ speech discrimination performance in live
voice versus recorded voice presentation modalities in telephone assessment. The current study also will include an evaluation of how older adults’ self-reported hearing acuity may influence auditory verbal memory performance in videoconferencing assessment.
CHAPTER 2: REVIEW OF THE LITERATURE

Given the recent increase in the use of telepractice for aural rehabilitation, this dissertation will explore hearing and other factors that influence performance in remote assessment. Specifically, older adults’ speech discrimination performance in live voice and recorded voice presentation modalities will be compared in telephone assessment. Also, this investigation will explore how older adults’ self-reported hearing ability may influence auditory verbal memory performance in videoconferencing assessment. This chapter is focused on age-related hearing loss and changes in cognition, cognitive models of spoken language comprehension, neurocognitive substrates of spoken language comprehension, and the evolution of auditory training including current auditory-cognitive training programs.

Age-related hearing loss

The global population is aging at an unprecedented rate. In 2015, approximately 8.5% of the population was over the age 65; however, by 2050, this demographic will comprise a projected 16.7% of the global population (He et al., 2016). As the average lifespan increases, the number of people living with age-related conditions, including hearing loss, will also increase. This is problematic because hearing loss is associated with poorer physical health outcomes, reduced quality of life, social withdrawal, reduced vocational stability and productivity, and cognitive decline including memory impairment (Amieva et al., 2015; Dawes et al., 2015; Goman et al., 2017; Gopinath et al., 2012; Kramer et al., 2006). Age-related hearing loss (ARHL) currently affects approximately two-thirds of adults over the age of 70 in the United States and most commonly presents as a gradual and progressive bilateral loss of hearing that initially impedes the ability to hear high frequency sounds (Tu & Friedman, 2018; Yang et al., 2015). Although hearing
loss is typically classified as either peripheral or central in nature, the clinical presentation of ARHL is commonly accompanied by both components (Gates, 2012; Panza et al., 2015).

**Self-perceived hearing loss**

Self-perceived hearing loss refers to one’s subjective perception of hearing difficulty and has been associated with a wide variety of psychosocial consequences including depression, social and emotional loneliness, and reduced quality of life (Hawthrone, 2008; Pronk et al., 2013). The most common complaint among people who self-report hearing deficits despite normal or near-normal audiograms is difficulty understanding speech in noise. Given the impact that self-perceived hearing difficulties have on a person’s social and emotional well-being, it has been suggested that measuring self-perceived hearing loss may be more appropriate than using pure tone audiometry to determine whether hearing difficulties are affecting a person’s quality of life (Gopinath et al., 2012; Hickson et al., 2008).

Self-perceived hearing loss is defined variably across studies and is typically measured using self-report scales or validated questionnaires, such as the Hearing Handicap Inventory for the Elderly Screening Version (HHIE-S; Ventry & Weinstein, 1982). Choi et al. (2016) indicate that widely accepted cutoffs have been used to define self-perceived hearing loss using binary variables (“excellent or good hearing” and “any trouble hearing”), such that any self-reported hearing difficulty (i.e., any response other than excellent or good) classifies an individual as having self-reported hearing loss, regardless of audiometric findings (Hannula et al., 2011; Kamil et al., 2015; Kiely et al., 2012; Marrone et al., 2019; Mikkola et al., 2016). Thus, an individual can be diagnosed with both self-perceived hearing loss based on subjective self-report and hearing loss based on objective audiometric findings. Some individuals with self-perceived hearing loss are not diagnosed with objective hearing loss based on results from pure tone audiometry. For example,
people with central auditory nervous system pathology, central auditory processing disorder (CAPD), or cochlear damage can present with normal or near-normal pure tone thresholds despite self-reported difficulty understanding speech in adverse acoustic conditions, such as in the presence of background noise. In contrast, there are individuals with hearing loss diagnosed using objective audiometric measures who do not have self-perceived hearing loss. Despite the variety of clinical presentations of hearing loss, those individuals with objectively diagnosed hearing deficits are most likely to receive recommendations for treatment and management.

**Unrecognized hearing loss**

In contrast to individuals who self-report hearing loss, there is another group of people with unrecognized hearing loss (URHL) who do not self-report hearing loss. When asked about their hearing acuity, these individuals deny having hearing difficulties; however, when hearing acuity is assessed, people in this population do in fact have meaningful and measurable hearing loss. Individuals in this group are unlikely to seek professional help for their hearing concerns, which places them at higher risk for a wide variety of negative health outcomes that are associated with unmanaged hearing loss (Gopinath et al., 2012).

Research exploring characteristics of this population has revealed that men and people who are older are more likely to have URHL; however, “education, general intelligence, physical health, cognitive function, and living alone were not meaningfully related to URHL” (De Iorio et al., 2019, p. 387). While most individuals in this group are unaware of their hearing loss, people who are in denial of their hearing difficulties are also typically categorized as having URHL (Di Iorio et al., 2019). There are a variety of reasons why hearing loss may go unrecognized. First, because the onset of age-related hearing loss (ARHL) is gradual, many individuals with ARHL are unaware of the severity of their hearing impairment (Saunders, 2018). Hearing loss may go
unrecognized if a person engages in unconscious lifestyle modifications and compensatory activities (e.g., turning up the volume on their television, walking out of a room with background noise to speak on the phone, etc.) over time because of their hearing difficulties. Additionally, it has been proposed that reductions in cognition may result in reduced awareness of deficits among people with URHL (De Iorio et al., 2019).

Based on this information and the information about self-perceived hearing loss reported above, all individuals can be classified into one of four groups based on their measured hearing acuity and self-reported hearing abilities (Table 2.1). Among individuals with measurable hearing loss, there are two sub-populations, individuals who self-report hearing deficits and those who do not. The first group (Group A) demonstrates awareness of their hearing difficulties; however, the second group (Group B) is comprised of individuals with URHL. Alternatively, among individuals who have audiometrically normal hearing, there are two sub-populations, individuals who self-report hearing deficits and those who do not. The first sub-population is a group of people (Group C) with what is often referred to as “self-perceived hearing loss” and the second group of people (Group D) is comprised of people with typical hearing who have accurate awareness of their hearing abilities.

**Table 2.1**

*Patterns of hearing loss: Self-reported and audiometrically defined*

<table>
<thead>
<tr>
<th>Group A: People with hearing loss: Aware Group</th>
<th>Group B: People with unrecognized hearing loss</th>
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<tbody>
<tr>
<td>Measurable hearing loss (+)</td>
<td>Measurable hearing loss (+)</td>
</tr>
<tr>
<td>Self-reported hearing loss (+)</td>
<td>No self-reported hearing loss (-)</td>
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<th>Group C: People with self-perceived hearing loss</th>
<th>Group D: People with typical hearing: Aware Group</th>
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<tbody>
<tr>
<td>No measurable hearing loss (-)</td>
<td>No measurable hearing loss (-)</td>
</tr>
<tr>
<td>Self-reported hearing loss (+)</td>
<td>No self-reported hearing loss (-)</td>
</tr>
</tbody>
</table>
In a recent nationally representative sample of older adults, approximately 35-50% of participants self-reported hearing loss, with rates of positive self-report increasing with increasing age (Goman et al., 2020). Tremblay et al. (2016) reported that from a sample of 682 adults, 12% of individuals self-reported hearing difficulty despite having normal audiometric thresholds (i.e., Group C). Regarding unrecognized hearing loss (Group B), it is well established that most older adults who have hearing loss do not receive treatment (Chien & Lin, 2012). In a recent study, De Iorio et al. (2019) found that approximately 23% of their sample of adults ranging in age from 55-85 years old had unrecognized hearing loss.

Age-related changes in cognition

Age-related changes in cognition are believed to be influenced by a variety of factors including genetics, physical health, vision and hearing acuity, social interaction, and the environment. Changes in cognition associated with increasing age tend to follow a typical pattern with gradual onset and most older adults maintain an ability to compensate for and adjust to these changes. However, individuals with hearing loss may be doubly disadvantaged because they experience concomitant age-related changes in hearing and cognition. If an individual begins to demonstrate difficulty participating in activities of daily living as a result of cognitive changes, there is reason for concern because their independence and ability to age in place (i.e., stay in the residence of their choice for as long as possible) may become compromised.

Physicians and other health care providers may screen a person’s cognition using a standardized screening tool such as the Montreal Cognitive Assessment (MoCA) or the Mini-Mental State Examination (MMSE). Those who do not pass the screening should be referred for a comprehensive diagnostic evaluation for dementia. A comprehensive evaluation should include a battery of cognitive and neuropsychological tests to evaluate a person’s complex attention,
executive functioning, learning and memory, language, math, visuospatial, and social cognition skills (DSM-5, 2013).

Certain patterns of age-related changes in cognition are considered typical, but dementia is not part of typical healthy aging (Harada et al., 2013). Scientists studying neurocognitive changes associated with aging have discovered that crystallized intelligence, which refers to knowledge and skills that are well-practiced and very familiar, tends to remain fairly stable across the lifespan. Examples of crystallized intelligence include vocabulary knowledge and procedural memory. Alternatively, fluid intelligence, which refers to a person’s ability to process new information for problem solving and reasoning, typically declines over time. Tasks of fluid intelligence require cognitive processes such as attention, processing speed, executive function, and working memory for completion. While mild and gradual changes in cognition are considered a typical part of aging, significant changes in cognition (i.e., those that impede a person’s ability to completely activities of daily living) are not.

Behavioral mechanisms for cognitive decline in aging

Resource models of aging attribute age-related changes in cognition to a decrease in cognitive resources, which refers to “the quantity of mental processing power or mental energy that a given individual has available to use when performing a cognitive task” (Park, 2012, p. 4). These resources are important for the completion of daily tasks and limitations in processing capacity and capabilities contribute to age-related declines in sensory function and cognitive processing. While older adults demonstrate reductions in many cognitive domains as a natural consequence of senescence, these effects typically appear in cognitive domains that require self-initiated processing. However, knowledge, vocabulary, world experience, and non-declarative memory are generally maintained with advanced age, which can help older adults compensate for
age-related changes in other cognitive processes. Age-related changes in cognition may or may not be noticeable because many older adults adapt to senescence by modifying their daily routines to accommodate changes in cognition (e.g., avoiding driving on the highway or during rush hour) and relying on knowledge and experience to support problem solving. Additionally, individual factors such as motivation and personality are known to influence a person’s ability to successfully complete functional activities of daily living (Salthouse, 2004).

Four primary mechanisms have been proposed to account for age-related changes in cognition including reductions in processing speed (Salthouse 1991, 1996), working memory (Craik & Byrd, 1982), inhibition (Hasher & Zacks, 1988), and sensory function (i.e., vision and hearing acuity) (Lindenberger & Baltes, 1994). Reductions in processing speed refer to a decrease in the speed of mental operations and there is evidence that reductions in processing speed account for the majority of age-related variance on almost any type of cognitive task (Salthouse, 1996). A second explanatory mechanism for age-related declines in cognition is decreased working memory capacity, which has been well-documented among older adults (Craik & Byrd, 1982). Working memory refers to the amount of online cognitive resources available for storing, retrieving, and transferring information (Park, 2012). Evidence suggests that environmental supports, such as memory cues at the time of encoding and retrieval, multimodal input, and external memory aids can ameliorate the negative effects that arise from age-related reductions in working memory (Park et al., 1990; Park et al., 2012).

Inhibition has also been implicated as an explanatory mechanism and theory of cognitive aging. Older adults have greater difficulty inhibiting irrelevant stimuli compared to their younger counterparts, which suggests that older adults allocate attention to both relevant and irrelevant information (Hasher & Zacks, 1988). An inability to inhibit irrelevant information is problematic
because irrelevant information is then encoded and maintained in working memory, which reduces the working memory system’s capacity and ability to efficiently encode, store, and retrieve relevant information from memory. Zacks and Hasher (1997) have argued that poor inhibitory function is particularly problematic for online cognitive processes, such as spoken language comprehension because oral discourse is presented at a fast rate and listeners must identify key information as discourse unfolds in real time to comprehend the meaning of the spoken utterance and formulate an appropriate response. If older adults have difficulty inhibiting irrelevant information when processing spoken language, their comprehension skills are likely to be compromised.

Finally, sensory function is an important construct in the cognitive aging literature. Lindenberger and Baltes (1994) provided evidence to suggest that the majority of age-related variance in fourteen measures of cognitive ability was mediated by vision and hearing acuity, which suggests that sensory function is “a crude measure of brain integrity” (Park, 2012, p. 17). In a follow up study, Lindenberger and Baltes (1997) demonstrated that the relationship between sensory function and cognitive decline did not vary as a function of sociobiographical variables (i.e., socioeconomic status, education, income), which provides further evidence of the powerful mediating effect that sensory acuity has on age-related cognitive decline.

Memory decline is the cognitive process most often associated with clinically significant cognitive decline and the most common cognitive change recognized and reported on by older adults (Harada et al., 2013). While certain aspects of memory remain fairly stable across the lifespan, reductions in episodic, prospective, and working memory are typically observed in relation to aging.
Theoretical models of human memory

Memory is a complex, non-unitary construct made up of multiple systems. Atkinson and Shiffrin (1968) proposed an influential modal model of memory that suggests information passes through sensory memory systems into a limited capacity short-term memory (STM) store, which is capable of sending information to and retrieving information from a long-term memory (LTM) store. Atkinson and Shiffrin’s (1968) model receives support from the serial position effect, which is a well-documented phenomenon first described by Ebbinghaus (1913). The serial position effect refers to the finding that people are more likely to recall the first (i.e., a primacy effect) and last items (i.e., a recency effect) in a series best. This effect can account for a distinction between STM and LTM. However, the modal model presented by Atkinson and Shiffrin (1968) appeared to be oversimplified because evidence has revealed that STM and LTM dynamically interact in a more complex manner than originally proposed and that STM is not a unitary system (Baddeley, 2002).

In response, Baddeley and colleagues proposed a multistore model of working memory that in its current revision includes a central executive, two unimodal storage systems (i.e., a phonological loop and visuospatial sketchpad), and an episodic buffer (Baddeley, 2000; Baddeley & Hitch, 1974; Repovs & Baddeley, 2006). The central executive is a limited-capacity source of attentional control that also controls information transmission to and from the other subsystems. The phonological loop is a limited span system that contains two components, a phonological store that holds acoustic or phonological information and an articulatory rehearsal process that retrieves and rearticulates the information via subvocal rehearsal in order to refresh the memory trace being held in the phonological store. The phonological similarity effect influences the phonological loop and refers to the finding that sequences of similar sounds (i.e., words that are phonologically similar) are more difficult to remember than dissimilar sounds (Baddeley, 1966). The phonological
loop is also affected by the word length effect, which refers to the finding that immediate recall of word sequences decreases as spoken word length increases (Baddeley et al., 1975). The visuospatial sketchpad is comprised of two distinct and independent storage systems, a visual and a spatial subcomponent, which have unique mechanisms of maintenance and manipulation (Repvos & Baddeley, 2006).

The episodic buffer was added to Baddeley’s working memory model most recently and has the ability to integrate information from multiple domains (i.e., verbal, visual, and spatial information) into unitary representations (Baddeley, 2000). In addition to serving as a buffer between the phonological loop and visuospatial sketchpad, the episodic buffer also connects working memory with LTM and semantic knowledge (Baddeley, 2000).

Aspects of long-term memory can be classified as implicit or explicit. Implicit memory refers to unconscious, data driven memory processes that can be expressed unintentionally including procedural memory (i.e., skills and habits), primed and conditioned responses, and non-associative learning. Explicit, or declarative memory refers to conscious aspects of memory that depend on conceptually driven processing and includes two subtypes, semantic and episodic memory. Semantic memory refers to a person’s knowledge about the world, objects, and concepts. Measures of semantic memory include vocabulary, category fluency, and picture naming tests, such as the Boston Naming Test. Episodic memory refers to a person’s personal and autobiographical memories for personally experienced events. Common measures of episodic memory include list learning tests such as the California Verbal Learning Test (CVLT) and the Rey Auditory Verbal Learning Test (RAVLT) and tasks that measure memory for paired associates, prose passages, and design patterns. Free, cued, and spatial recall tasks are among the most common measures of episodic memory. Free recall is typically viewed as the most effortful
of these tasks, followed by cued recall and then spatial recall (Hasher & Zacks, 1979). Free recall is considerably more complex than the other two recall tasks, because there is little contextual support provided at the time of encoding or retrieval (Craik & Jennings, 1992).

Assessing a person’s memory in a variety of domains is one important component that assists with differentiating typical aging from major neurocognitive disorder, or dementia. The profile of memory deficits identified through testing can be compared to the pattern of decline observed among those with typical age-related cognitive decline. The findings from this assessment should also be compared to the individual’s previous level of function to determine whether there has been a decline.

**Major neurocognitive disorder: The dementias**

Dementia is not an inevitable consequence of aging. While recent evidence obtained from the Health and Retirement Study revealed that the prevalence of dementia decreased significantly in the United States from 2000 to 2012, the absolute number of people living with dementia increased (Langa et al., 2017). Dementia continues to be a public health priority because the global prevalence is increasing, especially in low- and middle-income countries (Livingston et al., 2017). In fact, the World Health Organization (WHO) anticipates that the number of older adults with dementia will more than triple in the next several decades, affecting approximately 152 million people by the year 2050 (WHO, 2012, 2019). The risk of developing cognitive impairment doubles every five years after the age of 65 and as many as 25-35% of people over the age of 85 experience some degree of cognitive impairment (Sarant et al., 2019).

There are distinctions in the way that dementia is defined clinically versus how it is defined in research frameworks. Clinical descriptions of dementia describe the condition as a syndrome comprised of a constellation of signs and symptoms that can be caused from a variety of disease
processes, such as Alzheimer’s disease (AD). Clinical descriptions of dementia are based on a clinical phenotype which can be used to classify the type and stage of dementia. The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5; American Psychiatric Association [APA], 2013) replaced the term ‘dementia’ with ‘major neurocognitive disorder’; however, organizations like the Alzheimer’s Association continue to use the term ‘dementia.’ Clinically defined dementia is based on the following criteria: significant cognitive decline from a previous level of performance in one or more cognitive domains, interference with ability to independently complete activities of daily living, deficits that do not appear only during delirium, and symptoms that are not better explained by another disorder (APA, 2013). Unlike previous versions of the DSM-5, new diagnostic criteria emphasize a decline rather than a deficit in function and highlight the importance of assessing cognitive skills using a variety of neuropsychological measures. As a result of their condition, people with dementia eventually rely on assistance with activities of daily living, which requires a considerable amount social, health, and economic resources.

As an alternative to defining dementia as a syndrome, the National Institute on Aging and Alzheimer’s Association (NIA-AA) has created a research framework in which dementia is defined as a biological construct (Jack et al., 2018). This framework is not intended to be used in routine clinical care and instead focuses on efforts to identify, diagnose, and stage Alzheimer’s disease (AD) using biomarkers including β amyloid deposition, pathologic tau, and neurodegeneration. Based on these biomarkers, individuals can be classified as having normal AD biomarkers, being on the Alzheimer’s continuum, or having non-AD pathologic change based on their biomarker profile. Based on this framework, AD is defined by the presence of β amyloid and
pathological tau and evidence of neuronal injury and cognitive symptoms are used to stage severity.

There are many different subtypes of dementia; however, the most common types include Alzheimer’s Disease, vascular dementia, dementia with Lewy bodies, and frontotemporal dementia. Each subtype of dementia has a characteristic profile of deficits that may be identified through a wide variety of behavioral and imaging-based diagnostic techniques. For example, imaging techniques such as structural imaging (e.g., magnetic resonance imaging (MRI)) can be used to identify regions of brain atrophy and positron emission tomography (PET) scans can be used to measure brain metabolism in various regions. Additionally, there is emerging evidence that biomarkers in a person’s cerebrospinal fluid (CSF) or blood may serve as useful markers of disease progression; however, the use of biomarkers is not currently recommended for diagnostic purposes and routine clinical practice (Livingston et al., 2017).

**Hearing loss and cognitive health among older adults**

There is evidence to support an independent association between hearing loss and dementia (Lin et al., 2013; Loughrey et al., 2018). Interestingly, a prospective population-based study revealed self-perceived hearing loss was also independently associated with accelerated cognitive decline (Amieva et al., 2015). The distinction between peripheral hearing loss and central (auditory processing) deficits is critical to fully understand the relationship between hearing impairment and cognitive decline because both systems are required for the “recognition and interpretation of sound signal” (Nixon et al., 2019, p. 6; Schneider & Pichora-Fuller, 2000). While research on this association has primarily focused on measures of peripheral hearing acuity, there is evidence to support an association between central auditory processing deficits and dementia (Gates et al., 2002; Gates et al., 2011). However, research evaluating the respective influences of peripheral and
central hearing deficits on cognitive processing remains limited (Lin & Albert, 2014; Stahl, 2017; Whitson et al., 2018).

Exploring the association between dementia and its modifiable risk factors has important implications for preventing or slowing the progression of cognitive decline, which would ultimately be expected to improve the quality of life of affected individuals and lessen the burden of disease. People with hearing loss have two to five times the risk of developing dementia compared to those without hearing loss (Lin et al., 2011). Evidence for the association between hearing loss and cognitive decline comes from a recent meta-analysis of 33 studies, which revealed that people with treated hearing loss (i.e., those who use hearing technology) and untreated hearing loss demonstrate reductions in short term memory, attention, and executive functioning compared to adults with typical hearing (Taljaard et al., 2016).

Given the established association between hearing loss and cognitive decline in aging, it is important for clinicians who evaluate cognition to consider whether their findings may be contaminated by auditory factors such as a noisy testing environment or the presence of hearing loss. Many cognitive assessments are conducted auditorily; therefore, hearing loss or the presence of background noise during testing may lead to inaccurate results and overestimated rates of cognitive impairment. Additionally, it has been suggested that audiologists should screen older adults’ cognition and make referrals as needed given the high co-occurrence of hearing loss and cognitive decline. If a person is identified as having cognitive impairment after a comprehensive neuropsychological evaluation, this finding will allow providers to better address the patient’s needs.

While there has been a recent increase in research exploring the relationship between hearing loss and cognitive health, there is much research that is still needed. Specifically, there is
a need for more sensitive measures to assess the integrity of the auditory system past the cochlea. Additionally, there is a need for further research exploring the efficacy of auditory and cognitive interventions. Given that intraindividual variability in cognitive processing performance is a hallmark of aging, and particularly common among individuals with neurological disorders including dementia, it is important for researchers to consider how performance fluctuations affect auditory or cognitive training outcomes and how to monitor and accommodate such variability (Hultsch & MacDonald, 2004).

**Cognitive processes involved in spoken language comprehension**

Successful language understanding is facilitated by perception, recognition, and comprehension subprocesses that interact in a bottom-up and top-down fashion. Lissauer (1890) delineated how perception and recognition support comprehension. He conceptualized recognition as a two-part process with both perceptual and associative components. Using Lissauer’s framework (1890), perception is the conscious awareness of sensory information collected from the environment. In contrast, recognition is the process by which a precept is associated with information stores, allowing the stimulus to be recognized as familiar. Spoken word recognition occurs when acoustic information is mapped onto stored phonological representations of words. One can recognize a stimulus as familiar without attributing meaning to that stimuli, which distinguishes recognition from comprehension (e.g., Apfelbaum et al., 2011; Gaskell & Marslen-Wilson, 1997; Greenwald, 2017; Lissauer, 1890). Finally, comprehension is achieved when meaning is attributed to incoming stimuli, a process that requires the activation of specific semantic features associated with a given concept. Because perception, recognition, and comprehension are distinct mechanisms, an individual can demonstrate differential impairment of these processes
(e.g., intact perception but impaired comprehension or impaired perception in conjunction with functional comprehension skills).

A schematic organization of the cognitive processes involved in normal, single word comprehension (Figure 2.1), is based on evidence from both healthy and brain-injured adults (e.g., Davis & Johnsrude, 2003; Greenwald, 2017; Hillis et al., 1999; Hillis et al., 1990). Based on this framework, individuals with typical semantic processing skills perceive of stimuli, recognize it as familiar, and subsequently attribute meaning to the stimuli. Through interactive activation these cognitive mechanisms interact in bottom-up and top-down fashion. The sensory system, which includes sensory receptions and the neural pathways and brain regions involved in sensory perception, underlies perception and analysis of fundamental stimulus properties and transmits this information to cognitive systems, which encode, store, manipulate, and use this information to guide behavior. However, cognitive systems also provide feedback via attention, expectation, contextual information, and memory, which influences sensory and perceptual processing (Mahncke et al., 2006). Thus, a person with impaired perception, but spared comprehension may show an ability to use intact semantic knowledge to process and attribute meaning to perceptually degraded stimuli.

**Figure 2.1**

*A schematic of single word spoken word comprehension (modified from Greenwald, 2017)*
Performance on perceptual, recognition, and comprehension tasks can be influenced by a variety of factors including task demands, stimulus difficulty, the amount of processing time given, and the provision of cues. Stimulus difficulty for verbal tasks can be adjusted by manipulating acoustic factors, such as phoneme frequency, lexical factors, such as word frequency, and semantic factors such as imageability and concreteness. For example, if a person has high-frequency hearing loss, words containing high frequency speech sounds, such as “f” “s” and “th,” will be more difficult for this person to perceive and recognize, which could affect comprehension. Similarly, lexical factors such as word frequency (i.e., how commonly a word form occurs in a language) and semantic factors such as imageability (i.e., how easy it is to generate a mental image that is associated with a word’s meaning) and concreteness (i.e., degree of reference to a tangible or material object that we know through our senses) can influence speech perception, word recognition, and comprehension (Boulenger et al., 2010; Cortese & Schock, 2013; Helfer & Jesse, 2015; Revill & Spieler, 2012).

Vigilance tasks are commonly used to measure perception and require a person to stay aroused and sustain attention over a period of time. An individual is instructed to indicate (e.g., press a button) when they perceive of a change in a repeated stimulus. In vigilance tasks, difficulty can be increased by decreasing signal salience, increasing the frequency of target event rate (i.e., the number of times the target stimuli is presented per minute), increasing the source complexity (i.e., the number of signals to be monitored), and by requiring symbolic processing of stimuli (Szalma et al., 2004; Teo & Szalma, 2011). Evidence has revealed that performance on non-symbolic (i.e., sensory) vigilance tasks decreases as stimulus complexity increases (See et al., 1995; Teo & Szalma, 2011). Stimulus complexity can be manipulated by making the target stimuli more or less similar to the non-target stimuli. For example, during an auditory vigilance task in
which a person is instructed to identify a perceptual change in frequency, presenting tones that are closer in frequency to one another would make it more difficult for the listener to perceive of a change in frequency.

Similar to perceptual tasks, the similarity of stimuli to the target can affect performance on recognition tasks (LoCasto et al., 2007). Lexical decision tasks commonly used to measure spoken word recognition. Lexical decision tasks require an individual to decide if a spoken stimulus is a real word or not (i.e., a non-word). This task can be made more if the target stimuli are legal non-words, as compared to illegal non-words. Legal non-words are those that have orthographic and phonological overlap with real words, as opposed to illegal non-words, which do not. In auditory tasks, legal non-words (i.e., pseudowords) are often derived by changing one or more phonemes in a real word; however, non-derived or illegal non-words are those that cannot be “easily linked to any real word” (Cheng et al., 2014). Therefore, recognizing a legal non-word that is presented with in a series of real words is more difficult than recognizing an illegal non-word.

Manipulations in task demands and stimulus similarity can also affect the difficulty of spoken language comprehension tasks. There is an inverse relationship between linguistic complexity and language comprehension (Goodglass et al., 1970; Schuell et al., 1961). Category tasks are one type of comprehension task in which individuals are presented with a series of items and are prompted to reject items that do fit within the given category. Semantic relatedness which is defined as “human judgements of the degree to which a given pair of concepts is related” is known to affect performance on category tasks (Blaxton & Neely, 1983; Grose-Fifer & Deacon, 2004; Pedersen et al., 2007, p. 288). Specifically, it is more difficult for a person to reject a closely related semantic distractor than it is to reject a more distantly related semantic distractor during a categorization task. For example, if “food” was the category for a task, it would be more difficult
for a person to reject a closely related semantic distractor such as “spoon” than it would be for them to reject an unrelated semantic distractor such as “chair.”

As stated earlier, the amount of processing time given for task completion is another factor that can influence performance on speech perception, recognition, and comprehension tasks. The effect of processing time is particularly salient among older adults because increasing age is associated with reductions in processing speed (Salthouse 1991, 1996). Research has revealed that linguistic and non-linguistic auditory perception and spoken word recognition are improved when listeners are given an increased amount of processing time (Massaro, 1972; Massaro, 1974, Massaro & Idson, 1978). While recognition can be influenced by changes to the acoustic-phonetic input, there is evidence that modifications to processing time independently affects recognition such that spoken word recognition improves as processing time increases (LoCasto et al., 2007; Mattys, 1997). Finally, evidence supporting the influence that processing time has on comprehension comes from evidence of that increased processing time improves spoken language comprehension accuracy (Caplan et al., 2011). Pichora-Fuller (2003) explains how processing time is particularly influential in spoken language comprehension because spoken language is transient, and the listener cannot readily control the speaker’s rate of speech.

The provision of auditory and visual cues can also support speech perception, word recognition, and spoken language comprehension. Many language interventions use semantic and phonemic cueing, depending on the nature of a person’s deficits, to support language comprehension and production. Additionally, evidence suggests that visual cues including real and pictured objects, gestures, written words, and visual access to a speaker’s mouth can also support comprehension (Beattie & Shovelton, 1999; Chen & Rao, 1998; Skipper et al., 2009; Spivey et al., 2002; Venezia et al., 2019; Yorkston et al., 1977). Research has revealed that the presentation of
a visual cue can enhance performance on an auditory-based task and vice versa when the cross-modal cue is temporally or spatially synchronized or semantically related to the stimuli that is presented in the other modality (Diaconescu et al., 2011). However, cross-modal conflicts, which occur when a cross-modal cue is not temporally or spatially synchronized or semantically related to the target, can impair performance. Evidence suggests that listeners benefit from within- and cross-modal cues during auditory-based tasks; however, visual dominance tends to occur when there is a cross-modal conflict (Diaconescu et al., 2011; Oever et al., 2014). There is a need for further research exploring the influence of within- and cross-modal cues on semantic tasks.

The factors of stimulus difficulty, time given to complete a task, and cueing also have a relationship with memory. Evidence has revealed that stimuli difficulty can be adjusted through manipulations in linguistic complexity, as discussed above. While the relationship between lexical and semantic properties of words and various memory tasks (e.g., free recall versus recognition) are not well understood at this time, there is emerging evidence that recall can be affected by these properties (Lau et al., 2018). Additionally, there is evidence of a relationship between processing speed and free and cued recall performance (Bryan & Luszcz, 1996; Perrotin et al., 2006; Salthouse, 1996). Finally, the encoding principle of memory (Tulving & Thomson, 1973) indicates that memory is superior when the same cues are available at the time of encoding and retrieval. This principle has been observed using both visual and verbal cues (Puglisi et al., 1988) and suggests that cueing impacts memory processes.

While stimulus difficulty, processing speed, and the provision of cues are among the factors that can influence speech perception, word recognition, and spoken language comprehension, it is not feasible to strictly control acoustic, phonetic, and temporal aspects of tasks within and across all measures because doing so would significantly limit the number of available stimuli. The
potential influence of these factors on performance can be examined by administering multiple tasks, each well-controlled for specific factors. Additionally, there has been increasing focus on exploring factors that influence speech perception, recognition, and comprehension of discourse since most communication is conducted at the conversational level. While using stimuli at the discourse-level increases the ecological validity of the task, researchers must achieve a balance between control over stimuli and task demands while maintaining applicability to everyday life.

A cognitive model of normal spoken language comprehension at the sentence and discourse levels was developed by Wingfield and Tun (2007; Figure 2.2). This model is based on evidence that cognitive processing is capacity limited and that these limitations affect the sensory, perceptual, and cognitive systems. This model also suggests that in normal spoken language comprehension, information flows dynamically between sensory, perceptual, and cognitive systems in bottom-up and top-down fashion.

The framework developed by Wingfield and Tun (2007) is presented within the context of competing speakers and includes “source discrimination” as an important function of the sensory system. Successful spoken language comprehension often requires a listener to perceive and selectively attend to a speech signal among multiple competing signals (e.g., background noise, multiple people talking). Source discrimination involves auditory object formation, which is the process by which a listener uses spectrotemporal cues to segregate an auditory signal from multiple, competing signals (Anderson & Kraus, 2010; Bizley & Cohen, 2013). An auditory object is a discrete object that is distinct from other incoming auditory stimuli and serves as the basic perceptual unit in hearing. Successful auditory object formation is influenced by bottom-up factors such as the clarity and characteristics of the speech signal such as vocal pitch and timbre, as well
as top-down cognitive processes including attention, inhibition, and working memory (Johnson & Zatorre, 2005).

Based on the cognitive model of normal spoken language comprehension proposed by Wingfield and Tun (2007), once auditory object formation has occurred, the auditory signal passes through an attentional filter before the signal undergoes “initial-stage operations” including perceptual analysis and lexical identification. These initial operations feedforward to “linguistic/comprehension operations” which include syntactic resolution thematic role assignment, coherence structure, and discourse comprehension. Importantly, later-stage comprehension processes can also support phonological analysis and lexical identification through a feedback loop (as indicated on the model). During syntactic resolution, grammatical elements are identified, and grammatical structure is assigned and subsequently related to the theme of the sentence (i.e., thematic assignment). Discourse level comprehension is facilitated by the determination of coherence structure, which is achieved through the identification and integration of the propositional content of the message within and across sentences. Although not depicted in the schematic, this semantically meaningful representation must be encoded and held in working memory as a conversation unfolds in real time to allow the listener to prepare and formulate an appropriate response.
Behaviorally, older adults balance concomitant declines in hearing and cognition by relying on preserved linguistic knowledge including knowledge of phonotactic and lexical constraints, semantic context, and syntactic structure, which can be used to support comprehension. Therefore, the relative preservation of speech perception and spoken language comprehension skills among older adults can be accounted for when researchers consider the bidirectional manner in which auditory and cognitive processes interact. However, neural and behavioral compensatory processes that support speech perception limit the availability of resources for other cognitive operations, such as encoding what was heard into memory (Tun et al., 2009). Additionally, while older adults demonstrate relative preservation of their speech perception skills, understanding spoken language in the presence of background noise is particularly difficult for this population (Anderson & Kraus, 2010).

**Lexical and semantic effects in word recognition**

As noted above, it is well-established that lexical factors can influence spoken word recognition (Bierer et al., 2016; Dirks et al., 2001; Luce, 1986; Revill & Spieler, 2012). The Neighborhood Activation Model (NAM) was developed to account for these effects (Luce, 1986).
This model proposes that “words in the mental lexicon are organized into similarity neighborhoods” and that words are recognized relationally (Dirks et al., 2001, p. 234). Based on the NAM, word frequency, neighborhood density, and neighborhood frequency influence the speed and accuracy of spoken word recognition. Word frequency refers to how commonly a word form occurs in a language. Neighborhood density refers to the number of words that are phonemically similar to a particular word and neighborhood frequency refers to the average frequency of words in a lexical neighborhood. The NAM suggests that high frequency words with low neighborhood density and neighborhood frequency (i.e., lexically “easy” words) are recognized more accurately than low frequency words with high neighborhood density and frequency (i.e., lexically “hard” words; Dirks et al., 2001; Luce, 1986).

Research examining lexical effects in spoken word recognition is complicated by variability in the criteria used to classify words as lexically “easy” versus “hard” across studies. For example, some investigators have focused exclusively on word frequency and neighborhood density when classifying words as lexically “easy” or “hard” (Kirk et al., 1997), while others have controlled word frequency and defined lexical difficulty based on neighborhood density and neighborhood frequency (Carter et al., 2001; Dirks et al., 2001; Sommers et al., 1997). Despite this variability, support for the NAM’s prediction that lexically easy words will be recognized more accurately than lexically hard words has come from investigations with people with typical hearing and people with acquired hearing loss (Dirks et al., 2001; Kirk et al., 1997; Sommers et al., 1997). Overall, results from these investigations have revealed that word frequency is the strongest contributor to word recognition; however, there is also evidence that neighborhood density and neighbor frequency significantly influence word recognition (Bierer et al., 2016; Dirks et al. 2001).
Auditory lexical decision is a paradigm that has been used to explore processes influencing spoken word recognition. In an auditory lexical decision task, spoken words and non-words are presented in random order to a listener who is instructed to indicate whether the target is a real word (as opposed to a non-word). Typically, reaction time and accuracy data are collected during the task. Non-words are typically derived by changing one or more phonemes in real words and an equal number of real words and non-words are presented during the task. It is important to note that not all studies carefully control for the legality of non-words, which can influence the speed and accuracy in which a person is able to reject a non-word in a lexical decision task. As described above, illegal non-words are easier to reject than legal non-words; therefore, researchers should control for the legality of non-words when possible, as this factor can impact performance. Researchers have used the auditory lexical decision paradigm to explore how lexical characteristics (i.e., word frequency), non-word characteristics (e.g., how similar a non-word is to a real word), and contextual characteristics (i.e., semantic or word form priming) influence spoken word recognition (Goldinger, 1996; Hudson & Bergman, 1985). Research has revealed that real words are likely to be recognized more quickly and accurately than non-words and that non-words that deviate minimally from real words (e.g., a non-word that differs from a real word by a single phoneme) take longer to reject than non-words that are less similar to real words (Taft & Hambly, 1986). While the criteria used to classify a word as lexically “easy” versus “hard” has varied across studies, evidence suggests that the lexical factors of word frequency, neighborhood density, and neighborhood frequency each have a significant influence on spoken word recognition among people with and without hearing loss (Dirks et al., 2001; Kirk et al., 1997).

When examining lexical effects in spoken word recognition, researchers have used various stimuli including consonant-nucleus-consonant (CNC) word lists (Bierer et al., 2016), the
Northwestern University Auditory Test #6 (NU-6; Shi, 2014, 2015) and word lists created using lexical databases (Dirks et al., 2001; Carter & Wilson, 2001). Recently Bierer et al. (2016) explored the relationship between performance variability resulting from the use of CNC word for word recognition assessment and the lexical characteristics of items included on these lists. These researchers attempted to re-distribute items within the CNC word lists to reduce variability among items, increase test-retest reliability, and increase the sensitivity of the assessment. Lists were re-distributed via two sampling methods, first with respect to lexical frequency and also by selecting words with equal phonemic probability; however, neither of these sampling techniques significantly reduced performance variability. While Bierer et al. (2016) explain that more research is needed to examine whether sampling techniques can improve the test-retest reliability of word recognition testing using CNC word lists, it is important to note that the sampling methodology used by these authors discarded phonemic balancing across lists.

This limitation in methodology is important because it highlights the difficulties that researchers and clinicians encounter when attempting to developed well-balanced stimuli for word recognition and speech discrimination tasks. Achieving careful control over one aspect of stimuli often compromises the balance of other factors. For example, if balance among acoustic factors, such as sound frequency, is prioritized in stimulus develop, the balance among lexical factors, such as word frequency, and semantic factors, such as imageability, may be compromised. Alternatively, it is very difficult to carefully control lexical and semantic factors without reducing the balance of acoustic factors. This difficulty with stimulus development is especially relevant when researchers or clinicians are attempting to use meaningful spoken words. Depending on a professional’s background, he or she may prioritize control over one factor more than others. For example, an audiologist is more likely to prioritize control over acoustic factors, compared to a
speech-language pathologist who is more likely to carefully consider how lexical and semantic factors influence performance on word recognition and speech discrimination tasks. As noted above, this difficulty with stimulus specificity can be overcome by administering multiple tasks, each well-controlled for factors of interest.

Related to this, research has also revealed that semantic factors, such as word imageability and concreteness can influence word recognition. Specifically, higher imageability words and more concrete words are recognized more quickly and with greater accuracy compared to lower imageability words and words that are more abstract (Boles et al., 1983; Fliessbach et al., 2006; Klaver et al., 2005). Therefore, when developing or selecting stimuli for assessment and intervention purposes, it is important to consider the effect that acoustic, lexical, and semantic factors have on word recognition.

**The Ease of Language Understanding (ELU) model**

The Ease of Language Understanding (ELU) model is a meaning prediction model that attempts to explain how perceptual, linguistic, and cognitive factors interact to affect spoken language and visually-based language comprehension (Rönnberg et al., 2013; Figure 2.3). This model is useful for describing the potential consequences that hearing loss has on spoken language comprehension and the mechanisms through which reduced hearing acuity can affect higher level cognitive processes, such as language comprehension. The ELU was developed based on a model of working memory, which is defined as “a limited capacity system for temporarily storing and processing the info required to carry out complex cognitive tasks such as comprehension, learning, and reasoning” (p. 2). Based on the ELU framework, working memory is involved in the selective attention, maintenance, and inhibition of auditory information. The theoretical position of the ELU
model is that explicit task characteristics that affect perception interact with an individual’s implicit working memory capacity to influence performance (Rönnberg et al., 2010).

Based on this model, speech information is Rapidly, Automatically, and Multimodally Bound into a PHOnological representation (a process referred to as RAMBPHO). RAMBPHO proceeds in an implicit and effortless manner when the phonological information obtained from the speech signal matches lexical targets stored in semantic long-term memory. However, sub-lexical information may not have a matching phonological representation in semantic memory when the acoustic signal is degraded or the linguistic signal is poorly perceived. In this case, speech understanding becomes effortful and explicit and top-down processes that depend on working memory are invoked to compensate for the mismatch that caused a delay in lexical access (Rönnberg et al., 2013). This model suggests that the relative contribution of implicit and explicit processing fluctuates as a person listens; however, unlike RAMBPHO processing, explicit processing tends to occur at a slower rate. Recent evidence also suggests that semantic mismatches can occur in which case working memory resources are recruited to support inhibition of irrelevant semantic cues in order to help identify the semantic target. Therefore, both phonological and semantic mismatches require working memory resources to support speech perception in noise (Rönnberg et al., 2013).

The ELU model predicts that individuals with a high level of cognitive storage, as indicated by a high working memory capacity (WMC), are better equipped to compensate for and accommodate a degraded acoustic signal, which results in superior speech recognition skills compared to people with low WMC. In this way, the ELU framework provides an explanation for the finding that pure-tone audiometry is not predictive of speech-in-noise perception and suggests
that cognitive factors, specifically an individual’s working memory capacity, exert a strong influence on their speech perception skills.

RAMBPHO processing can be influenced by automatic top-down processes such as selective auditory attention (Rönnberg et al., 2013). Early attentional processing is dependent on working memory and there is evidence that individuals with high working memory capacity demonstrate superior “neural fine-tuning” that supports speech perception during early stages of language processing. The important role that attention plays in speech perception receives support from Heald and Nusbaum (2014) who suggest that even in the earliest stages of processing, speech perception is actively guided by automatic attentional processes and that “information-contingent changes in early encoding can occur as a function of context and experience” (p. 1). Traditionally, speech perception and recognition have been modeled as relatively passive processes; however, researchers have begun to recognize the role that active, cognitively-based processes such as attention have on early stages of speech perception (Heald & Nusbaum, 2014; Rönnberg et al., 2013). The influence that top-down processing has on RAMBPHO is not visually depicted in the updated schematic of the ELU framework provided by Rönnberg et al. (2013).

Rönnberg and colleagues (2013) also explain that the most recent version of the ELU model suggests that a post-dictive, explicit feedback loop influences predictive RAMBPHO processing (Rönnberg et al., 2013). This theoretical assumption was adapted from Poeppel and Monahan’s (2011) analysis by synthesis model, which proposes that top-down processes such as knowledge of language, prior experience, and semantic expectations influence the perceptual analysis of speech through a feedback mechanism. Similar to the ELU model, the analysis by synthesis model predicts that feedforward and feedback mechanisms are involved in speech perception and recognition (Poeppel & Monahan, 2011).
The influence of top-down processing on speech perception is so powerful that the ELU model suggests that linguistic knowledge and semantic cues can be sufficiently predictive so that minimal information from RAMBPFO is needed for successful recognition (Rönnberg et al., 2013). Because spoken language is transient, often underarticulated, and typically conveyed at a rapid rate of 140-180 words per minute, researchers suggest that listeners often settle for the “gist” of a spoken message without attending carefully to every spoken word and instead accept that some details may go unresolved (Pichora-Fuller et al., 1998; Rönnberg et al., 2013; Wingfield et al., 2015). According to the ELU framework, the use of “WMC-dependent executive mechanisms such as inhibition, focusing of attention, and retrieval of contextual and semantic information” can support gist-level processing (Rönnberg et al., 2013, p. 10; Wingfield et al., 2015). The mechanisms through which executive functioning and inhibition are incorporated into the ELU framework are not well-defined at this time (Wingfield et al., 2015). However, age-related declines in these domains, as well as working memory, are common among older adults and this model predicts that such declines would affect spoken language processing.

The ELU framework also offers a mechanistic explanation for the relationship between hearing loss and cognitive decline, specifically long-term memory impairment. Based on this model, when implicit and explicit processes are unable to work in conjunction to facilitate lexical access, fewer items are encoded and retrieved from episodic long-term memory. As a result, the efficiency of the long-term memory system decreases and suffers from a “disuse effect.” Rönnberg and colleagues (2013) do not suggest that people with hearing loss have a complete lack of automatic, implicit encoding of speech, but instead imply that these automatic processing mechanisms decrease in efficiency when a person has hearing loss. As a result, working memory-
dependent explicit processing is engaged more often than it is among those without hearing loss due the degradation of the acoustic signal.

The prediction that prolonged auditory input degradation negatively affects long-term memory is supported by evidence that despite long-term hearing aid use, people with hearing loss display long-term, but not short-term, memory deficits for auditory and non-auditory stimuli (Rönnberg et al., 2011). The finding that people with hearing loss demonstrate reduced long-term memory for non-auditory stimuli indicates that information degradation (i.e., poor auditory input to the brain) alone cannot explain decreased memory performance and suggests that long-term deprivation of intelligible auditory signals affects memory processes in multiple domains (i.e., visual tactile, and auditory; Rönnberg et al., 2013). However, longitudinal studies exploring the effects of hearing aid use on memory are needed to draw more definite conclusions about the long-term impact that hearing loss has on various domains of memory.

Figure 2.3

*The Ease of Language Understanding model (Rönnberg et al., 2013)*

*Hypotheses regarding the association between hearing loss and dementia*

Mechanisms underlying the association between hearing loss and dementia are complex and likely multifactorial; two such mechanisms that have received considerable support in the
literature are changes in brain structure and function, as well as changes in cognitive load (Lin & Albert, 2014; Uchida et al., 2019; Wayne & Johnsrude, 2015; Whitson et al., 2018). However, differences in conceptualizing and measuring hearing loss (e.g., self-report versus pure-tone average testing versus central auditory processing assessment) and differences in adjustment for potential confounding factors have yielded inconsistent evidence about hypotheses regarding the mechanisms underlying the association between hearing loss and dementia (Panza et al., 2019).

The “common cause” hypothesis is correlational and the most parsimonious explanation for the association between hearing loss and dementia. It reflects the prediction that a shared, age-related, physiological factor causes hearing loss and dementia (Fulton et al., 2015; Nixon et al., 2019, Wayne & Johnsrude, 2015). Proposed etiologies include generalized brain atrophy, vascular changes, inflammation, and oxidative stress, among others. This hypothesis is supported by evidence of significant correlations between global sensory function and performance on various cognitive measures (Humes et al., 2013). Some conceptual models assert that a causal or directional association exists, such that hearing loss contributes to the development of dementia while also acknowledging that an underlying age-related “common cause” could provide an independent contribution (Lin & Albert, 2014; Stahl, 2017; Whitson et al., 2018).

Other researchers suggest directional hypotheses including the sensory deprivation, resource allocation, and cognitive load theories. The sensory deprivation theory predicts that prolonged periods of reduced sensory input to the brain (i.e., from hearing loss) change brain structure and function and cause cognitive decline (Nixon et al., 2019). The finding that people with hearing loss have reduced gray matter volume in the auditory cortex suggests that hearing loss causes structural changes to the cortex (Eckert et al., 2012; Lin et al., 2014; Peelle & Wingfield, 2016). This evidence supports the sensory deprivation hypothesis that prolonged
deprivation causes structural changes within the brain. However, the common cause hypothesis could also be used to explain this finding because it suggests that a common factor contributes to age-related decline at the peripheral and central levels. The resource allocation hypothesis proposes that people with hearing loss reallocate cognitive resources (e.g., working memory, attention) to compensate for hearing loss, allowing for improved speech perception. However, the reallocation of cognitive resources results in fewer resources for the completion of higher-level cognitive processes, such as recalling information that was presented auditorily (Lindenberger & Baltes, 1994; Nixon et al., 2019; Tun et al., 2009). The resource allocation and sensory deprivation hypotheses are similar because both predict that hearing loss may cause cognitive decline; however, the resource allocation hypothesis predicts that declines in cognition are transient and occur as a direct result of compensation for reduced sensory input. In contrast, the cognitive load on perception theory suggests that cognitive decline precedes hearing loss (Lindenberger & Baltes, 1994).

Regardless of hypothesis directionality, there is considerable support from behavioral and neural studies that limitations in cognitive capacity underlie the association between hearing loss and dementia. Resource capacity models such as those from Kahneman (1973), Lavie (1995), and Sweller et al. (2011) suggest that different cognitive processes draw on the same pool of limited resources; therefore, when one cognitive process requires more resources, fewer resources are available for other cognitive processes. Researchers often use the term “cascading cognitive effects” to describe the finding that when resources are reallocated to support perceptual processing, downstream cognitive processes, such as memory, are negatively affected (Peelle & Wingfield, 2016; Stahl, 2017; Wayne & Johnsrude, 2015).
Compensation for chronic resource reallocation can result in structural and functional changes to the brain including brain atrophy and maladaptive changes in neural network connectivity. This reallocation is hypothesized to be a mechanism through which prolonged sensory deprivation from hearing loss contributes to cognitive decline (Peelle & Wingfield, 2016; Rutherford et al., 2018). If cognitive resources are reallocated to support speech perception, recognition, and comprehension as a result of hearing loss, changes in neural network connectivity and organizations may result. Thus, there is significant overlap in the evidence supporting changes in brain function and changes in cognitive load as mechanisms that explain the relationship between hearing loss and dementia. Given this connection between cognitive load and its ability to influence brain functionality, it appears likely that multiple mechanisms interact to contribute to the relationship between hearing loss and dementia “at various ratios for each individual” (Uchida et al., 2019, p. 7).

**Neurocognitive substrates of spoken language comprehension**

Hearing and listening are different processes, hearing refers to accessing acoustic information and involves the ear; however, listening is “hearing with attention and intention” and is a brain-based activity (Sweetow & Sabes, 2006). The detection of an auditory signal begins when sound waves travel through the ear canal and induce vibration in the tympanic membrane, which passes the vibrations along to the ossicles in the middle ear. Movement of the ossicular chain produces motion in the oval window, a membrane separating the middle and inner ear. Vibration in the oval window causes the fluid within the cochlea to move. Located in cochlea, the basilar membrane contains hair cells that are capable of transducing the mechanical energy into electrical energy which can then be transmitted to the brain via the auditory nerve. The auditory nerve connects with the vestibular nerve, which is responsible for transmitting balance information.
to the brain, to form the vestibulocochlear nerve (CN VIII). While connections with the central auditory system are complex, the signal passes from the cochlea and through the brainstem before reaching the auditory cortex for higher-level processing.

Poeppel and colleagues (Hickok & Poeppel, 2007; Poeppel et al., 2008; Poeppel & Monahan, 2008) have developed a dual-stream neuroanatomical model of speech processing (Figure 2.4). Based on this model, frontal, temporal, and parietal networks are interconnected and mediate speech perception, recognition, and comprehension. This framework indicates that auditory input from the peripheral auditory system is initially processed in the primary auditory cortex. Next, higher-level processing occurs in the superior temporal gyrus (STG) and posterior superior temporal sulcus (STS; Hickock & Poeppel, 2007; Poeppel et al., 2008). This model suggests that the initial stages of speech processing, including speech perception, cause bilateral activation of the STG and surrounding areas, including the STS. The STG is largely responsible for spectrotemporal analysis, which provides auditory object information as well as spatial position information about the acoustic signal. Based on this model, spectrotemporal analysis can be influenced by word form representations stored in other regions of the brain (Gow, 2012). Regions of the middle to posterior STS are responsible for phonological level analysis and actively maintaining phonemic information in a temporary buffer for further processing (Hickok et al., 2003). Information is transmitted bidirectionally between the STG and STS during the early stages of speech perception and both regions play a role in transforming acoustic information into phonetic information (Binder et al., 2000).

After phonological analysis occurs, there is a divergence of the system into two separate pathways that operate in parallel. This dual-system model is similar to many models of visual processing in which stimuli is processed via a ventral (‘what’) stream as well as a dorsal
(`where`/`how`) stream (Poeppel et al., 2008). In Hickok and Poeppel’s (2007) model of speech processing, the dorsal stream is strongly lateralized to the left-hemisphere and is associated with the posterior inferior frontal gyrus (pIFG), the premotor cortex, the anterior insula, and the Sylvian parietotemporal region (Spt). It is responsible for translating sensory or phonological representations into articulatory motor representations. This system plays an important role in speech production but is also hypothesized to contribute to speech perception (Hickok & Poeppel, 2007). The mechanism(s) through which the dorsal stream contributes to speech perception remain poorly understood; however, this perspective receives support from motor theories of speech perception, which are based on neuroimaging evidence that there is overlap in perception and production systems, specifically that regions of the inferior frontal gyrus are implicated in both processes (Burton, 2001; Hickok et al., 2003; Poeppel et al., 2008).

Similar to the dorsal stream, the ventral stream also receives information derived from spectrotemporal analysis of the signal as well as the phonological network. The ventral stream is bilaterally organized with a left-hemisphere bias. It is responsible for mapping “phonological representations onto lexical conceptual representations” (i.e., mapping ‘sound to meaning’) and supports speech recognition and comprehension processes (Hickok & Poeppel, 2007, p. 395; Gow, 2012). Anatomical regions associated with the ventral stream include the posterior middle temporal gyrus (pMTG) and posterior inferior frontal sulcus (pITS), the anterior middle temporal gyrus (aMTG), and anterior inferior temporal sulcus (aITS). The pMTG and pITS support lexical access and serve as the lexical interface where phonological information is linked to lexical semantic information (Hickok & Poeppel, 2007). The lexical interface houses word form representations, which link acoustic-phonetic representations to semantic representations. Based on this model, the more anterior regions of the temporal lobe are involved in accessing word
meaning, syntactic processing, and semantic and syntactic integration (Hickok & Poeppel, 2007; Scott & Johnsrude, 2003). Additionally, neuroimaging evidence has revealed that anterior temporal regions interact with the inferior temporal cortex when a grammatical representation is constructed.

This framework is supported by findings from Patterson et al. (2007) who suggest that more posterior regions of the temporal lobe appear to be involved in accessing semantic information from auditory input, compared to anterior temporal regions which have been implicated in integrating semantic information across modalities. Both the dorsal and ventral streams of the speech processing model developed by Poeppel and colleagues (Hickok & Poeppel, 2007; Poeppel et al., 2008; Poeppel & Monahan, 2008) send and receive information from conceptual networks that are widely distributed throughout the temporal, frontal, and parietal cortices (Binder et al., 2009).

The dual-stream model proposed by Poeppel and colleagues incorporates the frontal lobes in speech perception, recognition, and comprehension. While the model indicates that the posterior inferior frontal gyrus (pIFG) is an important aspect of the articulatory network, additional frontal regions are presumed to play a role in providing top-down support for spoken language processing. Other models of spoken language processing also suggest that various regions in the left frontal lobe play an important role in semantic and syntactic processing (Friederici & Gierhan, 2013; Obleser et al., 2007). Obleser et al. (2007) suggest that frontal regions are influenced by semantic processing, based on their finding that activity in the medial and lateral prefrontal cortices increases as the semantic predictability of words in sentences increases. Additionally, these researchers provided evidence that regardless of semantic predictability, activation in the left inferior frontal gyrus (LIFG) correlates with the amount of spectral detail provided by a speech
signal. This finding is supported by Peelle and Wingfield (2016) who suggest that domain general executive systems are recruited to support speech comprehension when an auditory signal is degraded. Related to this is the findings that the prefrontal cortex plays an important role in executive functioning and directing selective attention to relevant speech signals.

**Figure 2.4**

*A neuroanatomical model of speech processing (Hickok & Poeppel, 2007)*

Based on the neuroanatomical model of speech processing presented by Poeppel and colleagues, the brain regions and processes associated with auditory perception, recognition, and comprehension interact bidirectionally, such that processing in one neural network can influence or be influenced by related networks. Because this interaction is dynamic, processes that interrupt this connectivity, such as hearing loss, cause a change at one or more levels and this change has the potential to influence the other levels of processing.

**Neuroplasticity: The rationale for auditory training**

Scientists long believed that the capacity for learning and brain plasticity decreased substantially across the lifespan; however, behavioral and neuroimaging research has provided
convincing evidence of neuroplasticity in brains of older adults (Pauwels et al., 2018; Pichora-Fuller & Levitt, 2012; Sweetow & Palmer, 2005). The majority of auditory training programs are based on the principle of neuroplasticity and evidence that the auditory cortex is capable of reorganization in response to sensory experience (Bronus et al., 2011; Stecker et al., 2006; Sweetow & Palmer, 2005; Tremblay & Kraus, 2002; Woods & Yund, 2007).

Neuroplasticity refers to brain-based structural or functional changes that occur in response to frequent and intensive engagement in specialized tasks (Musiek et al., 2013; Zelinski et al., 2011). Alternations in brain structure and function are associated with changes at the behavioral level, such as an improvement in memory or speech-in-noise perception. Progressive learning facilitates neuroplasticity and repeated activation of the neural networks needed to successfully complete a task increases the “fidelity, reliability, and power of cortical representations” (Mahncke et al., 2006, p. 81). Importantly, neuroplasticity is a function of the central auditory nervous system; however, the peripheral auditory system is not plastic (Musiek et al., 2013).

While neuroplasticity has the potential to strengthen neural networks that support desired behaviors, it can also be a maladaptive mechanism by which cognitive domains that do not receive sufficient processing resources suffer from a “disuse effect” (Rönnberg et al., 2013, p. 7). It has been hypothesized that age-related changes in cognition are a result of negative neuroplasticity that results from a variety of interrelated factors including reductions in cognitive activity and weakened processing machinery (Mahncke et al., 2006). Based on this viewpoint, neuroplasticity underlies all learning, and the brain is as capable of positive neuroplasticity as well as negative neuroplasticity, which, along with evidence of neuroplasticity in the brains of aging adults, provides a rationale for auditory-cognitive training programs.
Long-term potentiation (LTP) is the cellular mechanism thought to underlie learning and memory (Hebb, 1949). LTP refers to activity-dependent increases in synaptic strength that become stronger as the frequency of activation increases. Mahncke et al. (2006) explain how progressive learning alters neural connectivity, stating that “the adult brain continuously adapts to disproportionately represent relevant sensory stimuli and behavioral outputs with well-coordinated populations of neurons” (p. 84). Based on evidence of LTP, plasticity-based training programs emphasize the importance of frequent and intensive practice using tasks specifically designed to engage the neural networks needed to accomplish a behavioral goal. In the case of auditory-cognitive training programs, tasks should be designed to engage the central auditory nervous system and surrounding neural networks.

Because learning facilitates neuroplasticity, many auditory-cognitive training programs depend on principles of learning. Learning occurs when the signal-to-noise ratio of cortical activity is strengthened so that an individual can engage cortical systems needed to accomplish a behavioral task or goal, while reducing the impact of internal “noise” that comes from spontaneous cortical activity (Mahncke et al., 2006). One important principle of learning is the importance of regular feedback. Feedback helps the learner determine whether they are making progress towards a goal and adjust their behavior accordingly to reduce the gap between their current level of performance and the goal; therefore, most auditory-cognitive training programs provide regular feedback after each trial or activity to help trainees monitor their progress. Additionally, feedback and reward are important aspects of plasticity-based training programs because it is believed that regular reinforcement can help improve neuromodulatory systems that support learning and memory and that the release of various neurotransmitters can help stimulate neuroplasticity (Gu, 2002; Mahncke et al., 2006). For example, positive reinforcement is believed to engage the
dopamine system, which is one neuromodulatory system believed to be involved in neuroplasticity.

**Changes in cortical network activation patterns in response to hearing loss**

Neural evidence suggests that age-related changes in hearing and cognition are supported by compensatory processes that involve changes in cortical network activation patterns. Imaging studies indicate that neural network connectivity is affected by a degraded auditory signal, resulting in measurable changes in performance on various tasks of speech perception and spoken language comprehension. Specifically, there is increased engagement of the cingulo-opercular, premotor, and frontoparietal regions of the brain in response to degraded acoustic stimuli (Campbell & Sharma, 2013; Du et al., 2016; Erb & Obleser, 2013; Peelle, 2018; Peelle et al., 2010; Vaden et al., 2013). These brain regions are respectively associated with performance monitoring, verbal memory, and attention (Peelle, 2018). While the core speech network remains active when presented with degraded auditory stimuli, additional neural networks outside of the traditional speech processing network are recruited to compensate and support auditory perception of acoustically degraded speech (Peelle, 2018). These findings suggest that neural network activation patterns change to compensate for a degraded auditory signal and support the hypothesis that changes in brain structure and function occur as a result of hearing loss.

**Aural rehabilitation and auditory training**

Because hearing loss is associated with adverse physical, cognitive, and psychological outcomes, it is critical that researchers and clinicians develop high-quality, evidence-based aural rehabilitation programs for people with hearing loss. Ideally, AR is recommended as a supplemental intervention for people fit with hearing technology as well as for individuals with self-reported hearing loss; however, the provision of AR services is limited and fewer than 10%
of audiologists offer comprehensive rehabilitation to their patients (Pallarito, 2011). This is problematic because aural rehabilitation (AR) aims to reduce the negative effects of hearing loss on an individual’s “function, activity, participation, and quality of life through sensory management, instruction, perceptual training, and counseling” (Boothroyd, 2007, p. 63). Interventions may include the use of hearing technology (e.g., cochlear implantation, hearing aids) as well as auditory and cognitive training. Auditory training can be defined as “a set of (acoustic) conditions and or tasks that are designed to activate auditory and related systems in such a manner that their neural base and associated auditory behavior is altered in a positive way (Musiek et al., 2013, p. 157). The purpose of this type of intervention is to increase person’s ability to compensate for impoverished auditory input by improving their perception, recognition, and comprehension of spoken language, especially in adverse listening conditions (Chisolm & Arnold, 2012; Pallarito, 2011).

Several investigations have explored whether differences in treatment outcomes exist between new and experienced hearing aid (HA) and cochlear implant (CI) users to determine the optimal timeframe in which AT should be initiated. In general, research has revealed that experienced users can derive significant benefits from auditory training programs, which suggests that the specific timeframe in which treatment is initiated is not crucial (Kricos & Holmes, 1996; Saunders et al., 2016; Stecker et al., 2006). However, this finding is not conclusive across studies. For example, Olson et al. (2013) reported that based on effect size data, new HA users (<6 months of device use) derived greater benefits from the Listening and Communication Enhancement (LACE™) program than experienced HA users (>2 years of use). Interestingly, this finding was not replicated in a study by Saunders et al. (2016) who also used LACE™ for training purposes;
however, these researchers considered experienced HA users to be those who had used their device(s) for at least one year.

Because different timeframes have been used to classify individuals as “new” versus “experienced” users of hearing technology, it is difficult to draw definitive conclusions about the timeframe in which therapy should be implemented to maximize benefits from intervention. For example, in a study by Stecker et al. (2006), the average duration of HA use for experienced users was 16 months, compared to a study by Kricos and Holmes (1996) whose experienced users had an average of 8 years of experience using HAs. Research with CI recipients has also revealed considerable variability in the degree and timeframe in which benefits from therapy were obtained by new and experienced users and suggest that individual factors such as the duration of hearing loss influence treatment outcomes (Fu et al., 2005).

The evolution of auditory training

Auditory training formally began in the early 1800s with the work of Itard whose approach focused on consonant, vowel, and pitch discrimination (Musiek et al., 2013). However, in the United States the field of audiology was established after World War II in response to the number of military members with service-related hearing loss. At this time, audiology was primarily a rehabilitative profession and providers offered speechreading training, auditory training, and psychosocial counseling as well as hearing aid fittings (Binzer, 2002; Chisolm & Arnold, 2012). Over subsequent decades, audiology became a primarily diagnostic profession as the number of hearing health providers offering aural rehabilitation services declined due to lack of high-quality evidence, a lack of reimbursement, and limited time to provide services. However, in the past two decades there has been a resurgence of research on auditory training and many hearing health professionals have suggested that audiologists should increase their focus on rehabilitation
(Binzer, 2002; Kricos & McCarthy, 2007; Miller, 2015; Tye-Murray, 2018). It is also important to note that the provision of AR services also falls within the scope of practice of speech-language pathologists (SLPs); therefore, many SLPs may be receiving increased referrals for patients with listening deficits due to hearing loss.

Renewed interest in AT has resulted in part from the evidence that hearing loss is independently associated with accelerated cognitive decline (Lin et al., 2013). Technological advancement is another factor contributing to the renewed interest in auditory training. Traditionally, AT was delivered verbally in a face-to-face setting (Appendix A); however, services can now be administered via computerized programs which offer numerous advantages to patients and providers, including the provision of training in patients’ homes, flexible training schedules, the ability of hearing health providers to track and monitor progress remotely, and reductions in cost and time needed to provide services (Appendices B and C).

A review of the history of auditory training would be incomplete without a discussion about musical training for people with hearing difficulties because this topic has gained increased attention in recent years (Musiek et al., 2013). Compared to non-musicians, experienced musicians have superior auditory perception of spectro-temporal changes, neural representations of harmonic differences, auditory working memory, and speech perception in noise (Parbery-Clark et al., 2011; Parbery-Clark et al., 2012; Pichora-Fuller & Levitt, 2012). While individuals who learn to play an instrument at a young age and continue to engage in musical practice throughout their lives (i.e., experienced musicians) have demonstrated advantages in auditory processing, recent research has revealed that short-term musical training can improve a person’s speech perception in noise (Dubinsky et al., 2019) as well as auditory attention during speech encoding (Zendel et al., 2019). While the research on musical training for adults with auditory processing deficits is promising,
further work on the effectiveness of musical training to improve the auditory processing skills of older adults is needed to determine the optimal features of such programs.

**Analytic, synthetic, and auditory brain training programs**

Auditory training programs are typically classified as analytic, synthetic, or a combination of both approaches. Analytic AT is a “bottom-up” approach in which speech is broken down into component elements and training focuses on improving perception, discrimination, and recognition of constituent parts. Typically, analytic approaches involve perceptual training at the sound-level and consonant recognition training has been the primary focus of most analytic AT approaches (Sweetow & Palmer, 2005). Consonant recognition training for adults is based on the rationale that age-related hearing loss is characterized by a loss of auditory access to high-frequency speech cues, including many fricative and plosive sounds, which are essential for accurate speech perception in noise (Woods & Yund, 2007). It has been suggested that adaptive perceptual training focused on consonant recognition will cause neuroplastic change in the auditory cortex and improve speech discrimination for higher-level auditory tasks such as word identification and sentence recognition (Stecker et al., 2006; Woods & Yund, 2007).

Synthetic training is considered “top-down” because it focuses on improving a person’s ability to use contextual information, linguistic knowledge, cognitive skills, and communication strategies to improve his or her auditory processing skills (Sweetow & Sabes, 2006). Many synthetic AT tasks, such as auditory closure, attempt to improve a person’s ability to use context cues and linguistic knowledge to understand the gist of a message. In auditory closure tasks, a target word is either masked (i.e., inaudible) or omitted from a sentence and the listener must use context cues to predict the target word.
Adaptive auditory training programs

Typically, AT programs have participants complete training tasks in varying levels of background noise to simulate the situation in which most people with hearing loss have difficulty understanding speech. Many AT programs are adaptive, meaning that activities increase or decrease in difficulty, depending on a person’s level of success. Adaptive AT programs can increase or decrease task difficulty by modifying the signal-to-noise ratio (SNR), the rate of time compressed speech, the complexity of linguistic stimuli (i.e., lexical frequency, imageability, syntactic complexity), the array size, or by inserting or removing distractors or visual cues. The use of an adaptive paradigm is based on the rationale that this approach should facilitate neuroplasticity and enhance motivation because people are more inclined to continue to participate in training when they feel sufficiently challenged, yet successful (Stecker et al., 2006; Sweetow & Sabes, 2006; Woods & Yund, 2007).

The definition of ‘success’ varies among AT programs. The customized learning: Exercises for Aural Rehabilitation (cCLEAR™) program adapts the signal-to-babble ratio of the signal to ensure that users perform at 80% accuracy during training (Barcroft et al., 2011b). In contrast, Henshaw and Ferguson (2013b) developed an adaptive working memory program that aimed to improve speech perception and cognition and the number of items to be remembered was adjusted accordingly to ensure that participants performed at approximately 60% accuracy (Henshaw & Ferguson, 2013b). These are two examples of programs that differ in their target accuracy and approach to adaptivity; however, numerous other programs exist that use different approaches than those listed above. Further research is needed to determine the accuracy rate that should auditory-cognitive training programs should use to optimize outcomes while also encouraging trainee motivation and adherence to the program.
The efficacy of auditory training

Evidence-based reviews of AT programs have concluded that the evidence is not robust to draw firm conclusions about the efficacy of auditory training for adults (Henshaw & Ferguson, 2013a; Sweetow & Palmer, 2005). Several studies fail to report effect sizes and when reported, effect sizes are typically small. Also, none of the studies included in the Sweetow and Palmer (2005) review specifically explored whether skills acquired in AT generalized to other materials and contexts. Related to this, in a review conducted by Henshaw and Ferguson (2013a), the majority of studies investigated generalization; however, outcomes measures were often not described in adequate detail and there were inconsistencies in the administration of outcome measures because participants in some studies were not asked to complete all of the outcome measures. Henshaw and Ferguson (2013a) also noted that only one of thirteen studies (Sweetow and Sabes; 2006) included cognitive outcome measures, which included behavioral assessments of attention and working memory. Given the relationship between hearing loss and cognition, it is important to explore whether auditory training influences cognitive outcomes; however, few studies include these measures. Related to this, few AT studies comprehensively assess and describe participants’ baseline level of cognition, which is also problematic because of the codependent relationship between cognition and audition.

Based on the results of their evidence-based review, Sweetow and Palmer (2005) concluded that synthetic AT programs are capable of improving trainees’ speech recognition in noise; however, these authors determine that there was less evidence about the effectiveness of analytic training. Sweetow and Palmer (2005) predict that the optimal parameters for analytic AT are yet to be realized, which may account for the lack of evidence supporting this approach. Findings in support of synthetic training, in contrast to analytic training, come from a study in
which the two approaches were compared (Rubinstein & Boothroyd, 1987). This study divided participants into two groups: one group received synthetic sentence-level perception training and the second group received a combination of synthetic and analytic training. Results of this investigation revealed that both groups showed significant improvements in speech-in-noise perception and led researchers to conclude that synthetic training alone provided all of the benefits that a combination of synthetic and analytic training offered. However, this study did not compare combined analytic-synthetic training to analytic training alone, which is a limitation of the investigation. Kricos and Holmes (1996) directly compared an analytic AT program to a synthetic program and found that the synthetic training resulted in significantly greater improvement on the Communication Profile for the Hearing Impaired, which is a self-report tool used to measure a person’s communication performance, environment, strategies, and adjustment (Demorest & Erdman, 1987). A recent review of computerized, home-based AT programs for CI recipients showed that all computerized programs used either a purely synthetic approach or a combination of analytic and synthetic approaches, providing further evidence for the increased emphasis on synthetic training (Zhang et al., 2014).

While research has generally supported the use of synthetic auditory training as an approach to improve the auditory processing skills of people with hearing loss, the potential benefits of cognitive training for people with hearing loss have also received increased attention in recent years. In a 2018 interview, Tye-Murray explained that she refers to her program, clEAR™ as an ‘auditory brain training’ program because it combines analytic and synthetic training techniques as well as cognitive activities to target skills such as auditory attention, processing speed, and working memory, which are factors that affect speech perception, recognition, and comprehension. Ferguson and Henshaw (2015) also advocate for auditory-cognitive or auditory
brain training programs such as cLEAR™, LACE™, and Brain Fitness™ based on their evidence that cognitive training may result in greater auditory benefits than focusing exclusively on the sensory refinement of one’s auditory skills.

**Customized learning: Exercises for Aural Rehabilitation (cLEAR™).** Customized learning: Exercises for Aural Rehabilitation (cLEAR™) is a 12-session computerized auditory training program, formerly called ‘I Hear What You Mean’ that was developed by Tye-Murray and colleagues. This program is interactive and meaning-based. Barcroft et al. (2011a) define a meaningful task as one that requires semantic processing and explain that form-based tasks such as sentence repetition can be completed without semantic processing. Meaning-based AT is advocated for based on the rationale that communication is meaningful and requires semantic processing; therefore, using stimuli that require the activation of semantics will facilitate generalization and reduce the degree of transfer needed to realize functional benefits of training. Barcroft et al. (2011) developed a model of AT that depicts comprehension as the central focus of training and indicates that levels of linguistic analysis (i.e., word, sentence, and discourse) do not need to be targeted in a hierarchical manner (Figure 2.5).

This model suggests that improvements in auditory processing made at one level will positively affect skills at other levels, as long as tasks are meaning-oriented and require semantic processing.

**Figure 2.5**

*A schematic of meaning-based auditory training (Barcroft et al., 2011)*
The cLEAR™ program has typically been administered via one-hour sessions, twice per week for a total of six weeks, resulting in a total of 12-hours of training. Each training session focuses on a general theme, such as health and well-being. Studies that have explored the efficacy of cLEAR™ have used five activities in which stimuli are presented auditorily only in the presence of adaptive four-talker (Barcroft et al., 2011a; Sommers et al., 2015; Tye-Murray et al., 2012) or six-talker babble (Barcroft et al., 2016; Tye-Murray et al., 2016, 2017). The signal-to-noise ratio (SNR) adjusts via a two-down, one-up procedure to ensure that participants’ accuracy is approximately 80% for all activities. In these studies, after an incorrect response the trial was repeated at a SNR that was +2 dB easier. Alternatively, after a correct response, the subsequent trial was presented at a SNR -1 dB harder (i.e., decreasing the level of signal relative to noise).

The first activity in cLEAR™ is an analytic task in which participants identify the position of a target phoneme in consonant-vowel-consonant words. A study by Tye-Murray et al. (2016) used an alternative first activity, which was a four-item word identification task in which participants were auditorily presented with a word and prompted to identify the spoken word by choosing from four pictures on the screen. The second cLEAR™ activity is an analytic four-choice phoneme discrimination task. In this task, participants are presented with two words (e.g., /cat/-/bat/) that differ by a single phoneme and are prompted to identify which picture, from a field of four, matches the pair of words that they heard (e.g., /cat-cat/, /cat-bat/, /bat-cat/, /bat-bat/). The third activity is an analytic-synthetic sentence completion task in which the trainee is auditorily presented with a sentence and is then prompted to identify which word would be most appropriate to complete the sentence from a field of four choices presented in writing on the screen. The fourth cLEAR™ task is an analytic-synthetic sentence comprehension activity during which a participant is auditorily presented with a sentence and then selects the most appropriate sentence that would
follow the target from a field of three written sentences presented on the screen. Finally, the fifth cLEAR™ activity is a synthetic paragraph comprehension task in which trainees hear a short paragraph (approximately five sentences) and respond to two comprehension questions. In their 2016 study, Tye-Murray et al. also modified the fifth activity to be a paragraph comprehension task that required participants to arrange five sentences in the correct order to form a cohesive paragraph after hearing each of the five sentences auditorily.

The auditory skills trained in cLEAR™ include consonant discrimination, recognition of frequently used words, bound morpheme identification, and discourse comprehension, and cLEAR™ also attempts to target cognitive processes including auditory attention, working memory, and processing speed through the use of tasks that require a trainee to rely on these processes for successful completion of the training activities. For example, auditory working memory is required to the paragraph comprehension task, because the trainee must encode and retain the spoken information in working memory to retrieve it and respond accurately to the comprehension questions.

The cLEAR™ program is based on the theory of “transfer appropriate processing” (TAP), which suggests that learning increases as the degree of overlap between training tasks and desired outcomes increases (Morris et al., 1977). This theory has important implications for AT and suggests that training programs should use ecologically valid training tasks that simulate situations in which people with hearing loss have greatest difficulty, so people are engaging the same auditory and cognitive processes needed for successful functional communication during the completion of training (Barcroft et al., 2011b). Evidence has revealed that improvements in task-specific learning typically occur in response to AT and that training benefits increase with an increasing degree of overlap between stimuli, talker (i.e., single versus multi-talkers), and task
demands used in training and outcome measure testing (Barcroft et al., 2016; Figure 2.6). For example, research has shown that training programs that use stimuli recorded by a single-talker result in greater gains in a single-talker speech discrimination compared to multi-talker focused AT programs, which yield significantly greater gains in multi-talker discrimination (Barcroft et al., 2011b). This suggests that AT activities and stimuli should incorporate similar skills as those skills hoping to be improved upon and supports the viewpoint that meaning-based training programs are “more transfer appropriate for communicative situations that involve meaning in the real world…” (Barcroft et al., 2016, p. 807). For this reason, cLEAR™ offers users the option to have their close communication partners record stimuli to be used in training to facilitate talker-specific gains.

**Figure 2.6**

*A schematic of overlapping factors that affect AT outcomes (Barcroft et al., 2016)*

Evidence from studies exploring the efficacy of cLEAR™ have revealed improvements in speech recognition skills among trainees (Barcroft et al., 2011b; Barcroft et al., 2016; Tye-Murray et al., 2017). However, others have suggested that the evidence in support of this program is limited due to limitations such as the lack of a power calculation, limited information about the control group, blinding processes, follow-up outcome testing, training feedback, ecological validity, compliance rates, and outcome measure selection and reporting (Henshaw & Ferguson, 2013).
**Listening and Communication Enhancement (LACE™).** LACE™ is an auditory-cognitive training program that incorporates analytic, synthetic, and cognitive activities to enhance a person’s listening abilities. This program is based on an interactive framework of communication created by Kiessling et al. (2003; Figure 2.7). This model includes positive and negative feedback loops, which indicate that successful comprehension and communication can further facilitate listening skills, but also that poor comprehension and communication skills may negatively affect listening.

**Figure 2.7**

*An interactive framework of communication (Kiessling et al., 2003)*

The goal of LACE™ is to teach people how to incorporate acoustic, linguistic, and environmental cues to support language comprehension and successful communication. This approach is based on the assumption that people are capable of using residual auditory information to support comprehension. Because auditory perception, recognition, and comprehension rely on cognitive processes including auditory working memory and processing speed, LACE™ also attempts to directly improve these processes. Sweetow and Sabes (2004) explain that their
treatment approach is based on the principle of neuroplasticity and evidence that cortical reorganization can occur as a result of auditory training.

LACE™ is typically administered 30 minutes per day, five days per week for a total of 4 weeks, resulting in a total of 10 hours of training. LACE™ includes three categories of tasks: comprehension of degraded speech (~70% of training), enhancement of cognitive skills (~15% of training), and the use of communication strategies (~15% of training). At the beginning of each training session, the trainee gets to select from a variety of themes, such as health or finances, which helps to reinforce the importance of using context cues to support comprehension (Sweetow & Sabes, 2006).

Three exercises are included in the portion of the training that attempts to improve a person’s ability to understand degraded speech including understanding speech in babble, time compressed speech, and the speech of competing talkers. In the speech in babble task, sentences are presented auditorily only in the presence of multi-talker babble. The trainee is prompted to repeat (either aloud or silently) as much of the sentence as possible, after which a written sentence is presented on the screen and the subject is asked to determine whether he or she has understood the sentence correctly and select “yes” or “no” to report their accuracy. Initially the SNR is +10 dB. When the trainee responds correctly, the SNR is made -4 dB harder (i.e., decreasing the amount of signal relative to noise); alternatively, if the trainee responds incorrectly, the SNR is made +4 dB easier. This four-up, four-down adaptive SNR procedure is used for the first five trials; however, after five trials the SNR is adjusted by ±2 dB at a time depending on response accuracy. The second task in this portion of training is a time compressed speech task, which follows the same paradigm used for the speech in babble task; however, the adaptive variable in this task is the compression ratio (CR) of the speech signal. During this task, trainees hear a sentence and is
prompted to repeat it aloud or silently. Next, the written sentence is displayed on a screen and the participant reports whether he or she understood the sentence correctly. The CR begins at 0.85 (i.e., stimuli are time compressed to 85% of the normal rate of speech). After each trial, the CR increases or decreases by 0.075 depending on the accuracy of the trainee’s response for the first five trials and increases or decreases in increments of 0.025 for the remaining trials. Finally, the competing speaker task also uses the same sentence repetition paradigm from the speech in babble activity; however, the background noise is single-talker babble and the participant is instructed to listen to a male, female, or child’s voice and repeat the sentence spoken by that talker.

The cognitive activities included in LACE™ are the target and missing words tasks. The target word task aims to improve trainees’ auditory working memory skills. During this task, the trainee sees a target word written on the screen. Next, the subject is auditorily presented with a sentence that contains the target word. After the presentation, the trainee is presented with four written words on the screen and is asked to identify the word that occurred just prior to the target word presented at the beginning of the task. Finally, the written sentence is presented on the screen and the trainee is prompted to report their accuracy. This task is adaptive; two correct responses result in increasing difficulty and two incorrect responses result in decreasing difficulty (Figure 2.8). The missing word task was designed to target auditory processing speed and the use of contextual cues. This is an auditory closure task in which trainees are presented with a sentence in quiet; however, the target word is completely masked by an environmental sound. Next, the subject is prompted to predict the masked word and say it audibly or silently. After doing so, the trainee is presented with four written words on the screen and is asked to identify the word that would best complete the sentence as quickly as possible. Unlike the understanding degraded speech tasks
and the target word activity, the missing word task is not adaptive; however, the accuracy and speed or responses are recorded.

**Figure 2.8**

Adaptive levels of the Target Word task from LACE™ (Sweetow & Sabes, 2006)

- Level 1: TW presented *before* the patient hears the sentence.
- Level 2: TW presented *after* the patient hears the sentence.
- Level 3: 2 TWs presented *before* the patient hears 2 sentences.
- Level 4: 2 TWs presented *after* the patient hears 2 sentences.
- Level 5: 3 TWs presented *before* the patient hears 3 sentences.
- Level 6: 3 TWs presented *after* the patient hears 3 sentences.

*Note: When the trainee correctly identifies two consecutive stimuli, the program progresses to the next level; if the trainee incorrectly identifies two consecutive stimuli, the program reverts one level.*

The third component of LACE™ is one that aims to improve trainees’ understanding and use of communication strategies. This module provides education about a variety of interactive communication strategies that can improve a person’s ability to manage communication situations and breakdowns, provides information about how to properly maintain hearing technology, and information about how to modify the environment to support comprehension and communication needs.

A 2006 study conducted by Sweetow and Sabes (2006), the developers of LACE™, revealed significant improvement on all outcome measures except one among trained subjects. Objective outcome measures included a speech-in-noise test (the QuickSIN), the Hearing in Noise Test (HINT), which measures sentence recognition, and a subset of participants completed a listening span test (to assess auditory working memory) as well as a visual Stroop task (to assess speed of processing). The experimental group demonstrated significant improvement compared to the control group for all objective outcome measures, except for the HINT test. Subjective outcome measures included two self-report scales that assessed hearing handicap as well as strategies and
attitudes about hearing loss. Effect size calculations revealed small but significant effects for all outcome measures except the HINT and the self-report scale used to measure strategy use and attitudes toward hearing loss. Sweetow and Sabes (2006) hypothesize that limitations in outcome measure sensitivity may explain the small effect sizes for these measures. These authors highlight that the limitations of their study include an inability to determine whether the observed improvements occurred in response to changes within the central auditory regions of the brain, or whether these improvements reflect “behavioral adaptations” and also acknowledge that this study did not evaluate long-term effects of training.

The findings from Sweetow and Sabes (2006) study exploring the efficacy of LACE™ receive support from two other studies that used LACE™ (Olson et al., 2013; Song et al., 2012). Olson et al. (2013) used a prospective, repeated-measure group design in which participants were randomly assigned to an intervention or control group, and participants were further separated into a new HA user training group, an experienced HA user training group, and a control group. Results from this investigation revealed significant improvements in speech in noise perception, understanding competing speech at the sentence level, and overall communication function post-training. Song et al. (2012) explored whether auditory-cognitive training via LACE™ resulted in neural plasticity and improved speech-in-noise perception. The results of this investigation revealed improvements in speech-in-noise perception that were retained at six-month follow-up testing as well as evidence of training-related improvements in neural encoding of pitch cues. Specifically, their findings suggested that LACE™ improved subcortical speech representation, making it less susceptible to degradation from competing background noise (Song et al., 2012). While this study provided evidence in support of LACE™ and demonstrated strengthened neural encoding of acoustic stimuli in response to training, it is important to note that the participants in
this investigation were younger adults with typical hearing and no history of neurological disorders (Song et al., 2012). Therefore, conclusions cannot be made as to whether these results would generalize to a population with older adults with hearing loss or cognitive impairment.

While findings from the previously mentioned studies using LACE™ were largely positive, Saunders et al. (2016) provided discrepant evidence. Saunders et al. (2016) conducted a randomized control trial that compared LACE™ plus hearing aid use to standard-of-care hearing aid intervention alone. Outcome measures for this investigation included a variety of speech perception tasks as well as measures of auditory memory and use of linguistic context. Results revealed that supplementing standard of care hearing aid intervention with LACE™ did not significantly improve performance on any of the outcome measures compared to the standard of care control group. One factor that likely contributed to these contradictory findings was variability in participant characteristics, specifically related to participant age and hearing acuity.

**Brain Fitness™.** BrainHQ™, formerly marketed as Brain Fitness™, is an adaptive, computerized auditory-cognitive training program created by Posit Science that aims to strengthen users’ memory and attention skills and increase processing speed. Brain Fitness™ is based on evidence of neuroplasticity in adults and this program was designed to “improve the function of the auditory system through intensive brain plasticity-based learning” (Smith et al., 2009, p. 595). This auditory-cognitive training program is based on the rationale that intensive practice and learning facilitates changes in neural responsivity and connectivity across networks in the central nervous system and that these changes will mediate improvements in sensory function. The activities included in Brain Fitness™ require a high level of attentional control and increase in difficulty as the program progresses, while ensuring that trainees maintain a level of accuracy
sufficiently high enough to be rewarding and encourage continued participation (Mahncke et al., 2006).

A large scale randomized controlled double-blind study using Brain Fitness™ was conducted by Smith et al. (2009). In this investigation, trainees were randomized to a treatment group who participated in 40, one-hour training sessions over the course of eight weeks. The active control group participated in the same number of hours of training, which involved watching educational videos. Participants were individuals over the age of 65 without a history of neurological or communicative disorders; however, 16.6% of the total sample were hearing aid users.

Brain Fitness™ includes six auditory-based cognitive training activities and each hour-long session includes four activities trained for 15 minutes each. Activities are randomized at the beginning of each treatment session, allowing for a large degree of overlap among the activities trained. In the first activity, trainees hear modulated sounds that sweep from either low to high or high to low pitch and participants indicate whether the direction of the sweep was upward or downward. The second activity is a syllable discrimination task in which a person is presented with two written syllables on the screen, next the trainee hears a syllable aloud and is prompted to select which syllable was heard. The third activity is a memory-based matching activity in which participants are prompted to match items based on syllables spoken aloud. The participant clicks on an item and hears a syllable, he or she must click on other items to locate the matching syllable. The fourth activity is also a memory-based task that presents two or more syllables. The participant is then instructed to click buttons depicting each syllable in the same order that they were presented auditorily. The fifth activity is a following directions activity in which a person is auditorily presented with a set of instructions and must follow the directions to manipulate items on the
screen. Finally, the sixth activity is a paragraph comprehension activity that requires participants to answer multiple choice questions about short stories that are presented auditorily. Similar to cLEAR™ and LACE™, Brain Fitness™ is adaptive and modifies various factors including the signal-to-noise ratio (SNR), speech rate via time compressed speech, and the array size to ensure that the participant achieves 75-85% accuracy during each task (Zelinski et al., 2011).

The study conducted by Smith et al. (2009) measured on-task outcome measures for two of the six trained activities as well as transfer tasks, which included measures of attention, a visual recall task, and various auditory-based recall tasks including list learning, discourse, and working memory assessments. Results from this investigation indicated that the training group demonstrated significantly greater improvements in auditory memory and attention compared to the active control group on all on-task and untrained, transfer tasks except for on the visual memory task and one of the story recall tasks (Smith et al., 2009). Effect size calculations revealed a small but clinically significant overall effect from treatment and gains observed immediately following treatment were maintained at three-month follow-up testing.

Further evidence supporting Brain Fitness™ comes from a study that revealed significantly improved speech-in-noise perception, memory, and speed of processing among older adults with hearing loss who completed this training program (Anderson et al., 2013). This study also demonstrated that behavioral improvements were associated with cognitive changes. Specifically, participants who benefited from the intervention demonstrated improved brainstem timing as evidenced by earlier peak latencies. This finding suggests that the effects of noise on auditory brainstem response were reduced. The findings from Anderson et al. (2013) provide evidence that auditory-cognitive training has the potential to influence neural timing in a manner that enhances audition and cognition. Importantly, Brain Fitness™ was developed based on principles of
neuroplasticity and included intensive, active engagement in behaviorally relevant activities with regular feedback as well as an adaptive protocol that adjusted the difficulty of tasks according to participants’ accuracy.

**Summary**

The field of audiology has evolved considerably since its inception and has more recently begun to transition back towards being a rehabilitative profession, focusing more heavily on aural rehabilitation and auditory training, rather than strictly focusing on diagnostics. This transition is due in part to evidence of a relationship between cognition and audition (Lin et al., 2013). Within the past two decades AR programs have increasingly focused on synthetic training activities that use meaning-based activities and stimuli based on the rationale that doing so will allow for the greatest transference of skill and knowledge to real-world contexts, thereby maximizing functional outcomes (Barcroft et al., 2011a). Similar to the type of tasks incorporated into training, other factors such as individual differences in personality and motivation, type, configuration, and severity of hearing loss, and baseline cognitive status can influence treatment outcomes and warrant further investigation. Advancements in technology have made telepractice and computerized AR training programs increasingly popular in recent years; however, this is also a need for research exploring the effectiveness of aural rehabilitation telepractice for older adults to ensure that evidence-based services are being provided to those affected by hearing loss (Saunders & Chisolm, 2015).

There are many plasticity-based computerized training programs, such as LACE™, cLEAR™, and Brain Fitness™, which use auditory and cognitive training activities to enhance the signal-to-noise ratio of desired cortical activity, correct negative learning, and increase overall brain stimulation in order to improve speech perception and spoken language comprehension.
Generally, evidence regarding plasticity-based computerized training programs is mixed and the majority of research in support of these programs has been conducted by those who developed the interventions, which represents a conflict of interest and indicates that there is a need for further investigations into the efficacy of these treatment programs. Additionally, while developers of the three auditory-brain training programs reviewed above explain that their approaches were based on principles of neuroplasticity, none of the articles reviewing these programs provide specific detail or hypotheses about the cognitive and linguistic mechanisms underlying success with different tasks and stimuli. That is, those who develop these training programs have provided a limited explanation to describe how each activity in the training program is expected to modify cognitive processing or brain structure and function.

Given that interindividual variability is a hallmark of aging, it is important to determine why auditory-cognitive training programs facilitate improved auditory and cognitive skills among some individuals, but not others. Differential improvement across individuals who participate in the same auditory-cognitive training program is likely influenced by interindividual differences that include factors such as a person’s baseline level of cognition performance (including working memory capacity, processing speed, attentional control, and inhibition), the type, severity, configuration, and age of onset of hearing loss, the type of hearing technology used (if any), the timeframe in which treatment is initiated, the duration and intensity of treatment, and factors such as personality and motivation that are known to affect a person’s adherence to an intervention program. It is important to understand the influence that interindividual factors have on treatment outcomes so programs can be customized based on a person’s unique needs, strengths, and weaknesses.
In order to identify treatment targets that will lead to the greatest improvement in functional outcomes, it is important to determine whether a person is a strong candidate for telepractice services and computerized training. This determination should be based on a variety of demographic, cognitive, and attitudinal factors, including an assessment of a person’s proficiency using technology. A comprehensive assessment should also include using a variety of measures to assess a person’s cognitive and perceptual skills. Experts in the field of AR have suggested that the lack of robust findings for computerized AR training programs may be related to the limited amount of information about which diagnostic measures are most useful in identifying who would benefit from telepractice services (Saunders & Chisolm, 2015).

**Factors Affecting Telepractice in Aural Rehabilitation**

Telepractice is advantageous because it is time and cost effective; however, factors including age, software security, cognitive abilities, and attitudes toward technology (Czaja et al., 2006; Saunders & Chisolm, 2015) impact a person’s willingness to adopt and ability to use technology. All of these factors can influence whether an individual is capable of receiving the same quality of services as those provided in person. Clinicians, including audiologists and speech-language pathologists, have a responsibility to assess whether a client is a candidate for telepractice services and must take these factors into account when making the decision to recommend these services.

**Telepractice for older adults**

An older adult’s ability to adopt and proficiently use technology is becoming “increasingly important for functional independence” (Czaja et al., 2006, p. 333). This relates to the concept of aging in place, which is defined as “the ability to live in one’s own home and community safely, independently, and comfortably, regardless of age, income, or ability level” (Centers for Disease
Control and Prevention, 2009). The majority of older adults express a desire to age in place; however, functional and cognitive difficulties often limit a person’s ability to do so. Technology is one potential solution to reduce barriers that older adults encounter in their attempt to age in place. For example, the use of technology can now be applied to banking and shopping, socially connecting with others, and accessing health care; however, to engage in these activities, internet access and a willingness and ability to use technology are required. The number of older adults with access to technology has increased considerably in recent years. As of 2017, 67% of adults aged 65 and older reported using the internet, a 53% increase from 2000 (Pew Research Center, 2017). While technology access and adoption are increasing among older adults, a number of ‘digital divides’ persist. For example, older adults, people with less education, and individuals from lower socioeconomic backgrounds are less likely to have internet access compared to younger adults, people with higher education, and those from higher socioeconomic backgrounds.

An effort has been made to develop a valid method of screening individuals’ hearing via telephone. This approach is advantageous because remote screening is efficient, does not require scheduling or transportation, and is typically easy to use. One highly researched hearing screening was developed by Watson et al. (2012) and can be administered via telephone and uses spoken three-digit sequences. The participant is prompted to type the three digits presented into the phone using the keypad after each trial. Participants must pay a small fee to receive this hearing screening; however, research has supported its validity. In addition to being efficient, convenient, and inexpensive compared to traditional service models, telehealth may be particularly advantageous for older adults who rely on assistance with transportation, among other various logistical aspects involved in receiving health care. However, it is important to have a better understanding of which
individuals have enough confidence, comfort, and proficiency with technology to understand how telehealth can be modified to be more accessible and useable for various populations.

**Cognitive demands of telepractice**

When exploring how to maximize the benefits of telepractice, it is imperative to consider how cognitive load affects performance. This is especially true during diagnostic sessions because the goal is to obtain accurate information about a client’s skills on various measures in order to set appropriate treatment goals. As discussed previously in this review, research suggests that people with hearing difficulties must allocate additional cognitive resources to early-stage perceptual processing, which limits the availability of resources for other cognitive processes such as encoding and retrieving information from working memory (Peelle & Wingfield, 2016; Stahl, 2017; Wayne & Johnsrude, 2015). Related to this is evidence that information processing requires a higher cognitive load when the information is presented via videoconferencing compared to face-to-face interaction (Ferran & Watts, 2008). Given that people with hearing difficulties experience an increase in cognitive load associated with listening at baseline, the additional cognitive load that videoconferencing creates compounds their difficulties, making telepractice particularly challenging for these individuals.

The finding that videoconferencing is associated with increased cognitive demands is corroborated by evidence that higher levels of working memory capacity and processing speed are associated with successful performance on computerized tasks (Czaja et al., 2006). These authors suggest that because cognitive abilities are predictive of successful computer use, software programs should be designed to place minimal demands on cognitive processes, such as working memory. Therefore, when developing assessment and treatment materials for telepractice services, it is important for clinicians to remain mindful that videoconferencing and computerized tasks are
associated with increased cognitive demands and that people with hearing loss already experience increased cognitive load due to the nature of their hearing difficulties.

**Practical challenges of telepractice**

The provision of telepractice services, which includes telephone and videoconferencing sessions, presents unique challenges to clinicians. The use of telecommunication devices introduces a great deal of variation into the telepractice session that is often unknown or unmeasured (Phillips et al., 2020). Specifically related to auditory factors, there is concern regarding the examiner’s inability to control the intensity level, variability in sound fidelity attributable to types of devices used by the clinician and the client (i.e., landline versus smartphone), and the client’s listening approach, which may range from holding the device, using speakerphone, or using wired or wireless headphones. All of these factors potentially influence the quality of the auditory signal received by the client, which can influence performance in assessment and treatment. This is especially problematic, given evidence that degraded auditory input is associated with reductions in cognitive performance among adults with age-appropriate cognition; therefore, those with auditory or cognitive deficits at baseline are even more likely to be negatively affected by poor-quality auditory input (Phillips et al., 2020; Wong et al., 2019). These same issues apply to assessment and intervention procedures that require visual presentation. Visual materials must be presented via videoconferencing, which involves the same auditory challenges presented during telephone sessions, but also includes variability in visual factors, such as camera resolution and visual display size.

An additional consideration for telepractice services is the use of standardized assessments. While many standardized assessments and screening tools are auditory-verbal in nature, few studies have been conducted to collect normative data in standardized, remote administration
conditions. Therefore, when conducting remote assessment, clinicians must be cognizant of the fact that test administration is non-standardized due to variation in the devices and modality used to administer the assessment, as well as potential alterations in the response modality used by the client (Phillips et al., 2020). Additionally, given that remote assessment procedures are non-standardized (with the rare exception being when remote standardized procedures and normative data have been published for a particular assessment), variation in telecommunication limits a clinician’s ability to compare clients’ performance to normative data collected via traditional, in-person test administration. A related factor that must be considered when interpreting the results of assessments administered via telepractice is the impact that hearing and vision acuity have on performance. Phillips and colleagues (2020) encourage clinicians to ask clients about their self-perceived vision and hearing acuity, as well as their use of assistive devices for sensory impairment.

Another auditory-based concern in telepractice services is the decision to use live voice or audio-recording to present stimuli. The decision to use live voice versus recorded voice presentation is also an issue in face-to-face assessment. While a number of studies have investigated performance variability across presentation modalities in face-to-face assessment (Mendel & Owen, 2011; Roeser & Clark, 2008; Uhler et al., 2016), there is a paucity of research exploring the use of live versus recorded voice presentation in remote assessment. Typically, in a face-to-face setting, recorded voice presentation is preferable because live voice presentation introduces variability into an assessment due to natural fluctuations in the speaker’s voice (i.e., vocal intensity) and the rate of stimulus presentation. Whereas the use of audio-recordings allows for greater reliability of the results obtained from assessment (Mueller & Hornsby, 2020).
The decision to use live versus recorded voice presentation in telepractice assessment is an important topic that warrants investigation because there are numerous practical challenges associated with using audio-recordings in telepractice. Presentation modality is especially relevant to word recognition or speech discrimination assessment and considerations for telepractice are described below.

**Word recognition assessment: Considerations for telepractice.** Word recognition (WR) testing, also referred to as speech discrimination, is used to measure a person’s ability to understand speech under controlled conditions and also to determine if word recognition scores are consistent with the type and configuration of hearing loss derived from pure-tone audiometry. While WR cannot be used to estimate a person’s ability to understand speech in real-world settings, word recognition and speech discrimination tasks have continued to be used by audiologists and speech-language pathologists (SLPs) as a way to measure and track a person’s ability to understand speech in controlled conditions.

While it is widely agreed upon that WR testing should be conducted using audio-recorded stimuli (Carhart, 1946; Mueller & Hornsby, 2020; Roeser & Clark, 2008; Wilson & McArdle, 2008), many audiologists continue to use live voice presentation based on the belief that it is faster, more convenient, and provides the clinician with greater control over stimulus presentation (Mendel & Owen, 2011). However, the use of live voice presentation also introduces significant variability into the assessment, which reduces the reliability of the measure. Variability can come from the speaker’s voice and rate of stimulus presentation, as examples.

Mendel and Owen (2011) explain that while early research reported no significant difference in the advantages offered by recorded presentation as compared to live voice presentation, more recent research has revealed that WR testing using recorded stimuli is
preferable because of the stability that this method of presentation provides. However, these authors also explain that there are few recent studies comparing live voice and recorded presentations. Although limited, recent investigations comparing recorded and live voice WR testing have generally found that among children and adults, WR scores are typically higher when the assessment is administered using live voice presentation (Roeser & Clark, 2008; Uhler et al., 2016). These researchers have concluded that recorded administration is superior due to the reduced variability provided by this method and because live voice presentation may overestimate an individual’s ability to understand speech. Interestingly, Mendel and Owen (2011) conducted a study to compare the time of administration for WR testing via live voice versus audio-recording using the Northwestern University Auditory Test #6 (NU-6; Tillman & Carhart, 1966). Although comparing performance accuracy across presentation mode was not the primary focus of this investigation, these researchers found no significant difference in participants’ mean WR scores based on the presentation method used.

As described above, audiologists and SLPs use WR in assessment and rehabilitation. For example, an SLP who is providing services to a person who uses hearing technology may conduct a brief speech discrimination task at the beginning of a therapy session to ensure that the client has auditory access to speech sounds across the range of speech frequencies. If a client demonstrates a reduction in speech discrimination compared to his or her usual performance, best practice guidelines for SLP indicate contacting the client’s audiologist and encouraging the client to schedule an appointment with the audiologist to ensure that their hearing technology is functioning and programmed properly. Additionally, an SLP might assess speech discrimination in language assessment to assess the integrity of perception in a person with impaired auditory comprehension.
If a clinician is providing teletherapy via the telephone or videoconferencing platform and wishes to use recorded stimuli for a word recognition task, the clinician would need to present the stimuli directly through the telephone line or videoconferencing platform, which requires advanced technology, likely unavailable to most clinicians. Alternatively, the clinician could transmit the audio-recording indirectly, from the speaker of a separate device (i.e., a tablet or computer) through his or her computer microphone or telephone to the client. However, indirect transmission through multiple devices compromises sound fidelity. While live voice presentation is not standardized and reduces the reliability of results, the consensus among audiologists has been that live voice presentation is preferred over recorded presentation in telepractice because the use of recorded stimuli can exacerbate problems with sound fidelity (Taylor et al., 2015). Therefore, it is of interest to explore whether there is a difference in speech discrimination performance when tasks are administered via live voice compared to recorded voice in remote assessment.

**Memory assessment: Considerations for telepractice.** The issue of live voice versus recorded presentation is also highly relevant to memory assessment. Efforts to validate a variety of memory tools across computer technologies are ongoing, including both remote and in-person computer administration (Canini et al., 2014). Assessing memory using recorded stimuli offers distinct advantages to live voice, such as a reduction in the variability associated with stimulus presentation and a high degree of “validity and reliability due to...greater objectivity, precision, and standardization” (Canini et al., 2014, p. 2). Temporal factors such as the rate (i.e., the number of stimuli presented per minute) and duration of stimulus presentation (i.e., the length of time each stimulus is presented) are particularly important to consider when assessing memory because these factors can influence the rate at which a memory trace decays (Craik & Rabinowitz, 1985; Frensch
& Miner, 1994; Laughery & Pinkus, 1966; Ricker et al., 2016). When using recorded stimuli in memory assessment, presentation rate and duration is fixed and standardized, which reduces the variability associated with stimulus presentation. To address this issue when using face-to-face live voice presentation of stimuli in memory assessment, validated tools typically provide explicit instructions to the examiner regarding the rate and duration of stimulus presentation to reduce variability as much as possible. Given the variability associated with live voice presentation of stimuli, neuropsychologists, speech-language pathologists, and other cognitive-linguistic researchers typically use recorded stimuli during memory assessment (Christensen & Wright, 2010; Schlegel & Gilliland, 2007; Wong et al., 2019). Similar to the research on speech discrimination, there is a considerable amount of evidence supporting the use of recorded stimuli in face-to-face memory assessment; however, research exploring the use of recorded stimuli in telepractice assessment is limited.

Related to memory assessment in telepractice, the examiner must consider procedural aspects of the assessment to determine whether it could be delivered via the telephone or videoconferencing. For example, n-back tasks are commonly used to assess working memory capacity. In an n-back task, participants are presented with a series of stimuli and asked whether each stimulus matches a stimulus n trials before. The timing of stimulus presentation must be carefully controlled in n-back tasks and the examiner must be able to confirm that participants have visual or auditory access to the stimuli being presented. Due to concerns about audio quality and the examiner’s inability to ensure that stimuli are visually or auditorily accessible to the participant, currently it is not feasible to administer n-back tasks via telepractice. For similar reasons many span tasks, such as the word span task included in the Temple Assessment of Language and Short-term Memory in Aphasia (Martin et al., 2018), cannot be administered via
telepractice because the stimuli in these assessments are typically word or digit sequences that are presented a single time to a participant; therefore, the examiner cannot determine whether the participant was able to hear the stimuli presented in each trial.

An alternative paradigm to assess memory via telepractice is the use of list learning tasks such as the California Verbal Learning Test (Delis et al., 2017) and the Hopkins Verbal Learning Test (Benedict et al., 1998). The use of auditory-verbal list learning tasks in telepractice is promising because these assessments involve multiple learning trials. During the learning phase of the assessment, participants are presented multiple times with the list of stimuli to be remembered. In this paradigm, if an individual can repeat and learn the words across multiple trials, the examiner can be confident that the participant was able to hear the stimuli prior to the recall phase. It is important to note that results obtained from a list learning task would be compromised if the examinee were to write down items to be remembered as they were presented. The act of writing the items down would provide the examinee with a second opportunity to encode the information into his or her memory. Also, the examinee could then reference the written list of items during the recall period of the task, which could have a significant effect on performance. Therefore, it is not feasible to administer auditory-verbal list learning tasks via telephone. Videoconferencing administration of a list learning memory assessment is preferable over telephone administration because the examiner could arrange to see the examinee’s hands and ensure that he or she is not typing or writing any information during the assessment.

Experience, attitudes, and proficiency with technology

In addition to the increased cognitive demands associated with computerized activities, factors such as a person’s experience, attitude, and proficiency with technology can also affect their ability to successfully use computers and participate in telepractice. Specifically, evidence
suggests that people with more experience using computers and more positive attitudes about technology are more likely to use technology (Czaja et al., 2006). Additionally, individuals with higher levels of computer proficiency are more likely to use other advanced technologies, such as smart phones (Czaja et al., 2006). For these reasons, it is important for clinicians to assess a person’s experience, attitude, and proficiency regarding technology to determine whether they are a candidate for telepractice AR services. Those who are not ideal candidates for telepractice services due to limited computer experience may consider enrolling in a computer or Internet training program to increase their proficiency and familiarity using technology (Boot et al., 2015).

Because a variety of demographic, cognitive, and attitudinal factors can affect a person’s ability to access and use technology, more research is needed to identify assessment tools and procedures that effectively identify individuals who would benefit from telepractice services, including AR services (Saunders & Chisolm, 2015). The field of audiology is transitioning from a primarily diagnostic profession to one more heavily focused on rehabilitation while technology has simultaneously become increasingly advanced and accessible within individuals’ homes. This combination makes telepractice an optimal platform to provide time- and cost-effective services; therefore, it is imperative that clinicians obtain a better understanding of factors that facilitate successful engagement in telepractice.

**Summary**

The recent increase in telepractice services offers numerous advantages including, but not limited to, time- and cost-efficient service delivery and increased accessibility to care. However, there are limitations with this service delivery model. First, there is limited research exploring how individual factors such as a person’s age, cognitive abilities, sensory acuity, and access to and familiarity with technology impact his or her ability and willingness to participate in telepractice.
Practical concerns regarding sound fidelity, audio quality, and connection strength and security also serve as a barrier to telepractice services. Additionally, many standardized assessments have not been validated for remote assessment, which limits their use in telepractice. Finally, there is a need for additional research exploring how to administer measures of perception, recognition, comprehension, and other measures of cognition via telepractice to ensure that these tools are being administered in a valid and reliable manner.

Statement of the Problem

With the revitalization of aural rehabilitation (AR) and increased use of telepractice services, it is apparent that there is a paucity of research examining multiple factors that could affect remote assessment. An assessment of memory is commonly included in a comprehensive assessment for AR because recently developed auditory-cognitive training programs include auditory-based cognitive activities, such as auditory memory tasks. The following aspects of remote assessment of memory in older adults are identified as important to advancing the field:

1. Remote assessment of memory is limited by technological factors that affect the timing and clarity of stimulus presentation. Study of the adequacy of specific paradigms for remote assessment of memory is needed.

2. The relationship between hearing ability and cognitive health has not received sufficient examination through remote assessment. Study of the adequacy of specific remote assessments for memory and hearing is needed, particularly in older adults.

3. The effect of presentation modality (live voice versus recorded voice) on speech discrimination performance has been explored in face-to-face assessment. However, there is currently no available research exploring this effect in remote assessment.
These aspects of the current problem outline the dearth of research available regarding remote assessment of memory. The above issues will be addressed in this study with the following research questions.

**Research Questions**

1) In telephone assessment with older adults, is there a difference in performance for speech discrimination administered via live voice versus recorded voice?

2) Is there a relationship between performance in speech discrimination administered via live voice and self-reported hearing ability?

3) In videoconferencing assessment with older adults, is there a relationship between self-reported hearing ability and performance on the *California Verbal Learning Test—Third Edition (CVLT3)*?

4) Is there a relationship between performance in speech discrimination administered via live voice and performance on the *CVLT3*?

**Hypotheses**

1) It is hypothesized that in telephone assessment with older adults, speech discrimination performance will be significantly better in the live voice presentation condition compared to the recorded voice presentation condition.

   Null hypothesis: In telephone assessment with older adults, there is no significant difference in speech discrimination performance in live voice versus recorded voice presentation modalities.

2) It is hypothesized that for the majority of participants, performance on live voice speech discrimination and self-reported hearing ability will be positively correlated.
Null hypothesis: There is no relationship between performance on live voice speech discrimination and self-reported hearing ability.

3) It is hypothesized that in videoconferencing assessment with older adults, individuals with self-reported hearing loss will perform significantly worse on the CVLT3 compared to those who do not self-report hearing loss.

Null hypothesis: In videoconferencing assessment with older adults, there is no significant correlation between self-reported hearing ability and performance on the CVLT3.

4) It is hypothesized that performance on live voice speech discrimination and performance on the CVLT3 will be positively correlated.

Null hypothesis: There is no relationship between performance on live voice speech discrimination and performance on the CVLT3.
CHAPTER 3: METHODS

The purpose of this study was to explore a variety of factors that may influence remote memory assessment in older adults. Specifically, this investigation explored the influence of presentation modality (i.e., live voice versus recorded voice) on speech discrimination performance in remote assessment as well as factors influencing the timing and clarity of stimulus presentation. The relationship between hearing ability and memory was also investigated. The methods used for data collection and analysis are described in this chapter, including information about study participants, instrumentation, experimental procedures, research design, and data analysis procedures.

Participants

Sixty individuals participated in the telephone portion of this investigation and 46 of those individuals also participated in the follow-up Zoom session (see Table 3.1 for demographic information). The age of participants ranged from 55 to 79 years ($M = 62.47$, $SD = 6.06$). The mean age of males who participated in the study was 63.43 years ($SD = 6.82$) and the mean age of participating females was 61.95 ($SD = 5.63$).
Table 3.1

Demographic information

<table>
<thead>
<tr>
<th>Demographic Variable</th>
<th>N = 60</th>
<th>% of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>21</td>
<td>35.0%</td>
</tr>
<tr>
<td>Female</td>
<td>39</td>
<td>65.0%</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>3</td>
<td>5.0%</td>
</tr>
<tr>
<td>American Indian or Alaska Native</td>
<td>3</td>
<td>5.0%</td>
</tr>
<tr>
<td>Asian</td>
<td>2</td>
<td>3.3%</td>
</tr>
<tr>
<td>Native Hawaiian or Pacific Islander</td>
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<td>0%</td>
</tr>
<tr>
<td>White</td>
<td>52</td>
<td>86.7%</td>
</tr>
<tr>
<td>Ethnicity</td>
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<td></td>
</tr>
<tr>
<td>Hispanic or Latino</td>
<td>6</td>
<td>10%</td>
</tr>
<tr>
<td>Not Hispanic or Latino</td>
<td>54</td>
<td>90%</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High School</td>
<td>11</td>
<td>18.3%</td>
</tr>
<tr>
<td>Some College</td>
<td>8</td>
<td>13.3%</td>
</tr>
<tr>
<td>Associate degree</td>
<td>3</td>
<td>5.0%</td>
</tr>
<tr>
<td>Bachelor’s Degree</td>
<td>20</td>
<td>33.3%</td>
</tr>
<tr>
<td>Graduate Degree</td>
<td>18</td>
<td>30.0%</td>
</tr>
</tbody>
</table>

Participants were recruited via word of mouth and met the following inclusionary criteria:
a) 55-85 years of age; b) English as a primary language; c) high school education or greater; d) self-reported normal vision (with or without corrective devices); e) self-reported normal cognition; f) speech intelligibility within normal limits; g) access to Zoom on a device with internet access and a camera (if participating in the videoconferencing portion of the investigation), and h) access to a telephone that could be set to speaker and/or headphones that could be used with a telephone.

Exclusionary criteria included current hearing aid use, a history of cognitive or learning deficits, a history of injury or illness affecting the central nervous system, any medical condition that would limit the ability of the subject to participate in the study, failure of either cognitive screening, and/or failure of the vision screening. The selected age range for this investigation was based on recent studies that have used this age range to explore various factors affecting older adults with hearing loss (De Iorio et al., 2019; Lim & Loo, 2018; Wong et al., 2019).
Recruitment focused on sampling from a general population of cognitively healthy older adults without a specific focus on recruiting a particular number of individuals with any specific type of hearing profile. As explained above, all individuals can be categorized into one of four groups, depending on their audiometric profile and self-reported hearing status (Table 2.1). These groups include: (A) people with self-reported and measurable hearing loss, (B) people who do not self-report hearing loss despite having measurable hearing loss, (C) people with self-reported hearing loss and typical hearing when measured by pure tone audiometry and (D) people who do not self-report hearing loss and have typical hearing when measured by pure tone audiometry. Individuals in group B are described as having unrecognized hearing loss and individuals in group C are described as having self-perceived hearing loss.

**Materials**

*Telephone session*

At the beginning of the telephone session each participant completed an audibility and speech intelligibility check to confirm that he or she had auditory access to information being presented (Appendix D) and provided intake, demographic information (Appendix E). The experimental measures used in this session were administered via live voice or recorded voice presentation. Specific information about presentation modality for each measure is described below.

**Montreal Cognitive Assessment—Telephone Version (T-MoCA).** Cognitive assessment was conducted via the telephone using the T-MoCA (Pendlebury et al., 2013), which was adapted from the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The T-MoCA includes all auditory verbal tasks included on the full-length MoCA; however, because the tool was adapted for telephone use, visual tasks and those requiring paper and pencil are not included on this
measure. As a result, the **T-MoCA** has a maximum of 22 possible points, takes approximately 5-10 minutes to administer, and contains tasks in the following domains: attention, language, abstraction, immediate recall, delayed recall, and orientation (Appendix F). Based on studies to validate the tool, a cut-off score between 18 to 19 is thought to be optimal (Pendlebury et al., 2013; Zietemann et al., 2017). In telephone administration of the **T-MoCA**, an additional point for individuals with low education is not added to examinees’ scores. While the sensitivity and specificity of the **T-MoCA** varies across studies (Cohen & Alexander, 2017; Pendlebury et al., 2013), in general, the sensitivity of the tool is very high, which indicates that it has a high degree of accuracy in detecting people who may have MCI. However, it has demonstrated moderate specificity, which indicates that when using this tool, clinicians may potentially classify individuals as having MCI when they do not meet criteria. For this reason, research exploring the utility of this tool has emphasized the importance of using the tool for screening in research and to determine whether additional assessment is warranted when it is used in clinical settings (Cohen & Alexander, 2017; Zietemann et al., 2017). This cognitive measure was administered via live voice.

If a potential participant received a score <18 out of 22 points on the **T-MoCA**, the examiner explained that she had collected all information needed from the telephone session and the telephone session was terminated at that time. The examiner for this investigation was a certified speech-language pathologist with experience screening cognition and talking with people about their performance on these types of measures. Also, because the goal of this investigation was to recruit healthy older adults, this situation only occurred two times throughout the course of data collection. Of the 60 participants included in this investigation, all passed the **T-MoCA** and the mean score among participants was 20.12 (SD = 1.25).
**Speech discrimination.** Participants participated in a speech discrimination task designed to assess a person’s ability to discriminate between sounds across the range of speech frequencies. The purpose of this task was to compare participants’ performance in live voice versus recorded voice presentation modalities using telephone administration. The Northwestern University Auditory Test #6 (NU-6) Ordered by Difficulty (Version II), Short Interval word lists were used for this task (Tillman & Carhart, 1966; Hurley & Sells, 2003; Appendix G). Each word list contained 50 phonetically balanced monosyllabic words. This tool was selected because it is highly researched and commonly used in clinical audiology and research.

Each participant completed the speech discrimination task with two word lists; one list was presented via live voice and one list was presented via recorded voice. The decision to administer one list per presentation condition was based on procedures used by Mendel and Owen (2011) who used one NU-6 word list per condition to explore differences in NU-6 administration time across three presentation conditions. The presentation of word lists across participants was controlled to avoid a sequencing effect. Therefore, both lists were given the same number of times in the live and recorded voice presentation conditions and participants were assigned to one of four order blocks to control for order effects (Table 3.2). NU-6 list equivalency has been demonstrated when stimuli are presented in quiet (Hurley & Sells, 2003; Tillman & Carhart, 1966; Stockley & Green, 2000; Stuart et al., 1994). However, a study exploring list equivalency in broadband noise revealed significant differences in listener performance across NU-6 word lists (Stuart, 2004). Results from this investigation suggested that NU-6 word lists two and four were most similar. Therefore, to reduce the possibly that list variability would contribute to variability in participant performance, word lists two and four were used in this investigation.
Table 3.2

Forms to be used for the NU-6 task: List and presentation modality order

<table>
<thead>
<tr>
<th>Form A</th>
<th>Form B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NU-6 List 2—Live voice</td>
<td>1. NU-6 List 2—Recorded voice</td>
</tr>
<tr>
<td>2. NU-6 List 4—Recorded voice</td>
<td>2. NU-6 List 4—Live voice</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Form C</th>
<th>Form D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NU-6 List 4—Recorded voice</td>
<td>1. NU-6 List 4—Live voice</td>
</tr>
<tr>
<td>2. NU-6 List 2—Live voice</td>
<td>2. NU-6 List 2—Recorded voice</td>
</tr>
</tbody>
</table>

Regardless of the task condition (i.e., live versus recorded voice), participants were presented with a word auditorily and asked to immediately repeat the word that was presented. This procedure was repeated for every word on each word list (i.e., 100 total trials). An Auditec recording of the NU-6 Ordered by Difficulty (Version II), Short Interval word lists was used for the recorded voice presentation condition. Mueller and Hornsby (2020) explain that the test takes approximately three minutes per ear; however, in this investigation the assessment was not administered in a sound booth. Therefore, each word list was presented one time, binaurally to each participant. The speaker controlled the rate of live voice presentation with a visual cue timed the same as the recording for voice onset and practiced imitating the prosody and articulation of the speaker on the recorded version of the NU-6 to ensure that the presentation was as consistent as possible. Prior to each participant, the examiner listened to the NU-6 recording as a refresher for articulation and prosody. The NU-6 Ordered by Difficulty (Version II), Short Interval recordings use a male speaker’s voice. The examiner who presented stimuli in the live voice condition for this study was female. Using a female speaker for the live voice presentation condition increased the ecological validity of the live voice presentation condition since most professionals in the fields of speech-language pathologists and audiology are female.
Additionally, the developers of the NU-6 assessment explain that the NU-6 Ordered by Difficulty (Version II) Short Interval measure it not recommended for children or older adults. However, the developers do not provide a rationale or supporting research to justify this recommendation. Mendel and Owen (2011) compared live voice, long and short interval administration time for the NU-6. These authors included a group of older adults with hearing loss in their investigation. Results from this study revealed no significant difference in performance among older adults on the long and short interval versions of the NU-6 Ordered by Difficulty. Therefore, to reduce the administration time, the NU-6 Ordered by Difficulty (Version II) Short Interval measure was administered to participants in this investigation. Response accuracy for each word list was scored as the percentage of whole-words accurately repeated. Performance in live voice versus recorded voice conditions was compared within-subjects to determine whether presentation condition had a significant effect on performance.

Participants participated in a second speech discrimination task, the Phoneme Discrimination task from the preliminary version of the Temple Assessment of Language and Short-term Memory in Aphasia (TALSA; Appendix H; Martin et al., 2018). This task was designed to assess “early input phonological processing using an identity judgement task” (p. 10). Participants were presented with a pair of words or a pair of non-words and were asked to identify whether the pair was the same or different. Stimuli included 44 word trials and 44 non-word trials. Word stimuli were controlled so that all words were concrete and low in frequency; non-words were derived from real words by changing one to three phonemes (Martin et al., 2018). Words were presented in two sets of mixed lists in which each set had 22 word pairs with the same items and 22 word pairs with different items. Similarly, for the non-word stimuli, 22 non-word pairs were the same and 22 non-word pairs were different. Additionally, Martin et al. (2018) designed
this measure so that “non-word pairs will never be presented in the same set with the words pairs from which they were derived” (p. 11). Half of participants received the non-word list first (e.g., participant 1, 3, 5) and the other half of participants received the real word list first (e.g., participant 2, 4, 6). This measure was administered via the telephone using audio-recorded stimuli.

While the NU-6 is a word recognition measure commonly used by audiologists, the TALSA speech discrimination task is more similar to the types of assessment administered by speech-language pathologists. Therefore, both measures were included in this investigation. Most speech discrimination measures focus exclusively on real words; however, the TALSA speech discrimination task is unique because it includes words and non-words. Non-word discrimination adds a unique component to the assessment because it should be a more sensitive measure than word discrimination. Also, the decision to administer the TALSA speech discrimination task using recorded stimuli was based on the rationale that results from this measure would not be usable if administered via live voice because of the variability associated with presentation. It was planned that if a participant’s average speech discrimination score was <70% in the recorded voice condition, their responses on the TALSA speech discrimination task would not be included in data analysis because of their difficulty with recorded voice speech discrimination. One participant in this study received a score <70% on the NU-6 word list in the recorded condition; therefore, TALSA data from this individual met the criteria to be excluded from the analysis. Due to a decision made by the dissertation committee overseeing this project, the TALSA analyses were not included in the reported dissertation results.

Videoconferencing session

For session two, the videoconferencing platform Zoom was used for the following reasons:

1) Auditory-verbal list learning must be administered via videoconferencing rather than telephone
to allow the examiner to track participants’ hands to ensure that no writing or typing occurred; and, 2) For hearing questionnaires, videoconferencing offered an advantage over telephone administration by reducing demands on working memory and hearing acuity.

All materials used in this session were designed or adapted to allow for remote administration. Participants could use a computer, tablet, or telephone that supported Zoom, had internet access, and was equipped with a camera. All verbal stimuli in this session were presented via live voice. Because the cognitive measure included in the videoconferencing session required a sheet of paper, pencil, and eraser, individuals who participated in this session were asked to gather these items prior to the start of the session. The examiner notified the participant that he or she would need these items when scheduling the Zoom session.

**General questionnaire.** Participants completed a general questionnaire (Appendix I) that included questions regarding self-reported hearing, vision, and cognitive status and informal questions regarding familiarity and comfort using Zoom. A brief vision screening was conducted to ensure that visual problems were not the cause of errors on visual components of the cognitive measure and to provide an indication that participants could read. The font size used for the vision screening was the same size as the font used to present written questions for the self-reported comfort and familiarity with Zoom survey as well as the self-reported hearing questionnaires, described below.

**Comfort and familiarity with Zoom.** Participants’ comfort and familiarity with Zoom was assessed via questions adapted from two questionnaires. A total of four questions regarding Zoom were included on the general questionnaire that was administered during the videoconferencing session. Two questions regarding self-efficacy and affect were selected from a technology questionnaire developed by Rothpletz et al. (2016), who designed a tool to assess a
person’s acceptance of internet-based hearing health care. Additionally, Indiana University Information Technology Services developed a questionnaire to explore the usability and usefulness of a videoconferencing platform (Abaci & Goodrum, 2016). Two questions aimed at obtaining information regarding participants’ experience and comfort using videoconferencing were adapted from this tool for use in this investigation. The four items used to assess participants’ familiarity and comfort with Zoom were modified and converted to statements in order to use the same five item Likert scale (response options range from strongly disagree to strongly agree) for all questions. The examiner read each of the statements aloud while presenting the statement and possible response options in writing via screenshare. Participants were prompted to respond to each statement by providing a number from one to five with one indicating “strongly disagree” and five indicating “strongly agree.” Due to a decision made by the dissertation committee for this project, these results are not reported in this document. However, preliminary data from the 46 participants who completed this portion of the project (i.e., those who completed the Zoom session) revealed that the average number of hours per week spent on the computer was 30.96 (SD = 23.39). Additionally, 86.9% of participants ‘agreed’ or ‘strongly agreed’ that they had experience using Zoom and 82.6% of respondents indicated that they ‘agreed’ or ‘strongly agreed’ that they felt comfortable using Zoom.

**Self-reported hearing status.** Participants’ self-reported hearing status was assessed using a single item self-report survey as well as two questionnaires. For the single item hearing loss screener, participants were asked “which statement best describes your hearing (without a hearing aid or other listening device)?” This question was selected because it is the self-reported hearing status question used by the National Health and Nutrition Examination Survey and the National Health Interview Survey (Marrone et al., 2019). Response choices included: “excellent,” “good,”
“a little trouble,” “moderate trouble,” “a lot of trouble,” and “deaf.” Participant responses were categorized into a binary variable “excellent or good hearing” and “any trouble hearing”, such that any self-reported hearing difficulty (i.e., any response other than excellent or good) classified an individual as having self-reported hearing loss (Hannula et al., 2011; Kamil et al., 2015; Kiely et al., 2012; Marrone et al., 2019; Mikkola et al., 2016).

Participants also completed the Hearing Handicap Inventory—Screening Questionnaire (Ventry & Weinstein, 1982; Appendix J) and the Hearing Self-Assessment Questionnaire (HSAQ; Bonetti et al., 2018; Appendix K). The Hearing Handicap Inventory for the Elderly—Screening (HHIE-S; Ventry & Weinstein, 1982) or the Hearing Handicap Inventory for Adults—Screening (HHIA-S; Newman et al., 1990) was used, depending on a participant’s age. The HHIE-S was developed for individuals ≥60 years old and the HHIE-A was developed for people <60 years old. These tools were developed to assess an individual’s self-perceived psychosocial difficulties resulting from their hearing and were selected because they are the most used self-report questionnaires to screen for hearing loss (Yueh et al., 2010). The HHIE-S and HHIE-A each include a total of ten questions and participants were prompted to indicate whether their hearing caused them to feel frustrated, embarrassed, handicapped, or to have other problems in a variety of communicative settings. Participants were instructed to respond ‘no,’ ‘sometimes,’ or ‘yes’ to each item. Based on a participant’s responses, he or she is typically classified as having ‘no handicap,’ ‘mild-moderate handicap,’ or ‘severe handicap’ regarding their hearing (see Appendix J for detailed scoring procedures). However, for the purposes of this investigation, participants’ responses were classified into a dichotomy. One group included individuals with ‘no handicap’ and the other group included individuals with any level of hearing handicap (i.e., ‘mild-moderate handicap’ or ‘severe handicap’). The use of a dichotomous variable was similar to the approach
used in the Hearing Self-Assessment Questionnaire (HSAQ), described below. The HHIE-S and HHIA-S took approximately two to five minutes to administer.

The Hearing Self-Assessment Questionnaire (HSAQ) was developed to quantify the social-emotional consequences of hearing loss as well as to identify functional hearing loss, specifically with the goal of detecting mild to moderate hearing loss with high sensitivity and specificity. The HSAQ was developed in response to evidence that other self-report questionnaires, such as the HHIE-S, have high sensitivity and specificity for moderate and severe degrees of hearing loss; however, their detection of mild hearing loss is less accurate (Salonen et al., 2011). Additionally, the HSAQ was selected because it has been validated against audiometric assessment and results from this validation study revealed good screening properties as well as good construct, concurrent, and discriminant validity (Bonetti et al., 2018).

The HSAQ included ten questions related to the frequency in which a person’s hearing causes difficulty understanding spoken language, frustration, and avoidance. Participants were instructed to respond to each item by indicating ‘never,’ ‘rarely,’ ‘sometimes,’ ‘often,’ or ‘always.’ A total score was calculated based on participant responses (see Appendix K for detailed scoring procedures) and a cut-off score ≥ 15 was used to identify hearing loss. This measure took approximately five minutes to administer (Bonetti et al., 2018).

The HHIE/HHIA-S and the HSAQ were administered via videoconferencing based on the rationale that the items from these questionnaires are lengthy (i.e., up to 25 words). Presenting items via the telephone in an auditory-only presentation modality may have placed high demands on participants’ working memory, which could reduce response accuracy. Therefore, these questionnaires were administered in an auditory-verbal format and the examiner read each item aloud to the examinee while simultaneously showing the typed question and response options for
each question using the screenshare feature on Zoom. This approach allowed participants to read along with each item as it was verbally presented. While the HHIE/HHIA-S and the HSAQ have typically been administered using pencil and paper in a face-to-face setting, because this investigation exclusively used remote assessment, it was determined that auditory-visual presentation via videoconferencing most closely replicated the typical method of administration. While the single-item hearing loss screener was given via videoconferencing for individuals who participated in both sessions, those who did not participate in the Zoom session were asked the single-item hearing screening question via the telephone based on the rationale that national surveys administer this screener via a telephone interview (Marrone et al., 2019).

**California Verbal Learning Test-Third Edition (CVLT3).** The California Verbal Learning Test—Third Edition (CVLT3; Delis et al., 2017; Appendix L) is a test of explicit memory designed to comprehensively assess the strategies and processes involved in recognizing, learning, and recalling verbal information. This test was developed for use with individuals between the ages of 16 and 90-years-old. The CVTL3 is a list learning task in which participants are auditorily presented with a nine-word list and are asked to recognize and recall items across a series of trials. The CVLT3 Brief Form was selected because it is recommended for individuals for whom fatigue is a concern (Farrer & Drozdick, 2020). Administration of the CVLT3 Brief Form takes approximately 30 minutes (Appendix L). This version also includes an optional forced-choice recognition task that follows a five-minute delay. All trials except the forced-choice recognition task are required to derive the primary scores for this assessment. Given concerns regarding participant fatigue, the forced choice recognition task was excluded from this investigation to reduce the total time needed to administer the CVLT3 Brief Form; therefore, the task took participants approximately 30 minutes to complete.
During administration of the **CVLT3**, participants were asked to imitate specific hand postures so that the examiner could track their hands. During the 10-minute delay, participants were engaged in a task in which they were prompted to imitate a series of relaxing gestures presented by the examiner. Participants’ performance on this delay task was not scored. This delay task was selected because the publishers of the **CVLT3** explain that the participant should not complete other types of verbal assessment during this delay period, because verbal tasks could “tax or interfere with the verbal encoding and recall of the CVLT word list” (Farrer & Drozdick, 2020, p. 28). Therefore, a gesture imitation task was used to fill the 10-minute delay period because it was non-verbal nor cognitively demanding. This task was also selected because it allowed the examiner to ensure that participants were not writing or typing list items to be remembered for the assessment. Classical music without words was played during the ten minute delay and if participants initiated conversation with the examiner, he or she received a brief comment and redirection to the gesture activity.

Given the auditory-verbal nature of the **CVLT3**, the publishers of this tool explain that it can be administered via videoconferencing. The publishers of this test also caution that this test was not standardized using telepractice administration; however, in a recent investigation, the California Verbal Learning Test—Second Edition (**CVLT-II**; Delis et al., 2000) was administered to people with Multiple Sclerosis in person and via the telephone and results revealed no significant difference in performance in the two administration conditions, suggesting that it is feasible to administer the assessment via telepractice (Barcellos et al., 2018). Additionally, systematic reviews and meta-analyses have been conducted to explore remote neuropsychological assessment and these studies have generally found that performance on list learning tasks, such as the **CVLT3**, is not affected by videoconferencing administration (Brearly et al., 2017; Cullum et al., 2014).
Based on these findings, participants were administered the CVLT3 Brief Form via videoconferencing in this investigation. Although this assessment was auditory-verbal in nature, results obtained from telephone administration of the CVLT3 would have been compromised if participants wrote down the list of words to be recalled. Using videoconferencing, the examiner was able to see participants to ensure that they were not writing during the test, making this Zoom preferable to telephone administration.

The CVLT3 was specifically selected for this investigation because the four list learning trials included in the assessment helped identify participants whose hearing acuity could have influenced their performance significantly. Unlike measures of verbal memory that only require the examiner to present stimuli one time, the multiple learning trials included in the CVLT3 made it a suitable measure of verbal memory for the purposes of this investigation. If a person repeated the list items during the learning phase, the examiner knew the participant heard the stimuli. However, if a participant was unable to repeat and learn the list items after the four learning trials, the examiner was unable to determine whether the participant’s hearing acuity, device, or memory (or some combination) prevented them from learning and repeating the words. Therefore, individuals who did not learn the words after the four learning trials did not participate in the short and long delay recall tasks or the yes/no recognition task. However, these individuals did complete the remainder of the videoconferencing session, which included the Quick Mild Cognitive Impairment screen (Qmci; O’Caoimh et al., 2012; O’Caoimh & Molloy, 2017; Appendix M), a cognitive measure described below.

Finally, when using the CVLT3, examiners must determine whether they wish to use a traditional paper or digital administration format. The publishers of the CVLT present the option of using the Q-interactive® platform to administer the CVLT. There is emerging evidence that
performance on cognitive tests is equivalent when digital and paper administration are compared (Daniel, 2012). However, attempting to transmit recorded stimuli through multiple devices raises concerns regarding sound fidelity (as described above). Therefore, for the purposes of this investigation, the CVLT3 Brief Form was administered via live voice.

Due to the challenges of videoconferencing for clarity of auditory stimuli, one modification to the administration of the CVLT3 was made. During the learning trials, if the participant correctly repeated the list of words, the examiner provided brief feedback (i.e., gave them a thumbs up and said “correct”) so the participant knew their response was accurate. This modification to administration did not interfere with the timing of the test because the examiner used a visual cue for voice onset to control presentation rate so that it was consistent across participants. With that one exception, the CVLT3 Brief Form was administered and scored according to the guidelines provided in the test manual, which generated scaled scores for immediate and delayed recall tasks as well as the yes/no recognition task. Scaled scores from the immediate and delayed recall components of the assessment were combined to derive a total recall index score, which was used as the primary outcome measure for this experimental task. The yes/no recognition scaled score served as a secondary outcome measure.

**Quick Mild Cognitive Impairment screen (Qmci).** Cognitive assessment was conducted via videoconferencing using the Quick Mild Cognitive Impairment screen (Qmci; O’Caoimh et al., 2012; O’Caoimh & Molloy, 2017; Appendix M). Although the Qmci is relatively new compared to other widely used cognitive screeners such as the MoCA (Nasreddine et al., 2005) and the Standardised Mini Mental State Examination (SMMSE; Malloy et al., 1991), it has demonstrated greater sensitivity and specificity than these tools, providing a rationale for its use (Clamette et al., 2017; O’Caoimh et al., 2012). The Qmci was administered via videoconferencing
and took approximately 3-5 minutes to complete. The total score possible on the Qmci is 100
points and a score ≤62 is the cut-off score for mild cognitive impairment; therefore, participants
who received a score ≤62 were not included in the investigation. It is important to note that remote
administration of the Qmci has not been validated at this time. Therefore, this measure was given
in a non-standardized manner. Of the 46 individuals who participated in the videoconferencing
portion of the evaluation, all passed the Qmci cognitive screener and the mean score among
participants was 82.33 (SD = 5.30).

**General procedures**

This study was conducted using two remote data collection sessions (see Table 3.3 for
information regarding the order, modality, and estimated time of administration for all tasks).
When scheduling the telephone session, which was conducted prior to the videoconferencing
session, the examiner emailed potential participants a research information sheet and participants
were asked to email the examiner back to confirm receipt of the form. The research information
sheet explained that by completing the telephone and videoconferencing sessions, the individual
was agreeing to participate in the study. The telephone session took approximately 25 minutes to
complete. At the end of the telephone session, participants were asked if they were willing to
participate in the videoconferencing session, which took approximately 50 minutes. The examiner
confirmed that those who met the criteria to advance to the videoconferencing session (i.e., those
who met criteria on the T-MoCA) and expressed willingness to participate in the follow-up session
had a computer, tablet, or telephone that supported Zoom, had internet access, and a camera. To
the extent possible, the examiner scheduled the videoconferencing session for approximately 15-
30 minutes after the telephone session to give participants a short break between sessions. On
average, time between telephone and videoconferencing sessions among participants who completed both sessions was 19.28 minutes ($SD = 6.57$).

**Table 3.3**

*Task type, order, and administration time for each administration modality*

<table>
<thead>
<tr>
<th>Approximate Time to Administer</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Telephone Session</strong></td>
<td></td>
</tr>
<tr>
<td>Audibility and speech intelligibility check</td>
<td>&lt;1 minute</td>
</tr>
<tr>
<td>Intake form</td>
<td>1 minute</td>
</tr>
<tr>
<td>T-MoCA (Pendlebury et al., 2013)</td>
<td>5-10 minutes</td>
</tr>
<tr>
<td>NU-6 Ordered by Difficulty (Version II) Short Interval (Tillman &amp; Carhart, 1966; Hurley &amp; Sells, 2003)</td>
<td>7 minutes</td>
</tr>
<tr>
<td>- Two lists will be administered</td>
<td></td>
</tr>
<tr>
<td>- One list will be presented via live voice</td>
<td></td>
</tr>
<tr>
<td>- One list will be presented via recorded voice</td>
<td></td>
</tr>
<tr>
<td>TALSA speech discrimination task (Martin et al., 2018)</td>
<td>7 minutes</td>
</tr>
<tr>
<td><strong>Videoconferencing (Zoom) Session</strong></td>
<td>~25 minutes</td>
</tr>
<tr>
<td>General questionnaire:</td>
<td>5 minutes</td>
</tr>
<tr>
<td>- Audibility and speech intelligibility check</td>
<td></td>
</tr>
<tr>
<td>- Vision screener</td>
<td></td>
</tr>
<tr>
<td>- Informal questions regarding comfort and familiarity with Zoom</td>
<td></td>
</tr>
<tr>
<td>- Single item-survey regarding self-reported hearing status</td>
<td></td>
</tr>
<tr>
<td>Hearing Handicap Inventory—Screening (Ventry &amp; Weinstein, 1982)</td>
<td>3-5 minutes</td>
</tr>
<tr>
<td>Hearing Self-Assessment Questionnaire (Bonetti et al., 2018)</td>
<td>5 minutes</td>
</tr>
<tr>
<td>California Verbal Learning Test—Third Edition (Delis et al., 2017)</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Qmci (O’Caoimh et al., 2012)</td>
<td>5 minutes</td>
</tr>
<tr>
<td><strong>Mission</strong></td>
<td>~50 minutes</td>
</tr>
</tbody>
</table>

An attempt was made to control the volume to the extent possible using remote administration. At the beginning of the telephone session, the examiner asked participants to use headphones or put their telephone on speaker, depending on which they were more comfortable. Of the participants, 32 chose to use speakerphone and 28 used headphones. Participants were also prompted to set their telephone to a comfortable listening level before completing the audibility
and speech intelligibility check. This check was also completed at the beginning of the videoconferencing session to ensure that participants had auditory access to information presented by the examiner (Appendix D). To complete the audibility and intelligibility check, participants were asked to repeat four words from the CID W-1 spondaic words (Cambron et al., 1991) and were prompted to adjust their volume until speech was audible and intelligible (i.e., when participants accurately repeated four of four words), at which point they were instructed not to adjust the volume for the duration of the telephone or videoconferencing session. While the majority of participants demonstrated an ability to hear and understand speech during telephone session without needing to adjust their device volume, four participants were initially unable to accurately repeat the four spondaic words. However, after an adjustment in device volume, these four participants demonstrated that speech was audible and intelligible. All participants demonstrated an ability to hear and understand the spondaic words during the initial presentation in the videoconferencing sessions. It was also recognized that lack of environmental control is a major limitation of telepractice and there is a need for additional research to explore strategies that can be used to ensure audibility of stimuli (Kruse et al., 2017; Wade et al., 2019). Therefore, participants were also asked to reduce environmental distractors (such as background noise from the television) to the extent possible to support their ability to participate in the study.

In a final effort to keep presentation volume as consistent as possible within and across participants, the examiner used a sound level meter smartphone application (app) to monitor volume when presenting stimuli via live-voice and audio-recording. Recently, a study was conducted to evaluate and compare the effectiveness of a variety of smartphone apps to accurately measure noise levels (Crossley et al., 2020). A calibrated pure tone sound field and sound booth were used to evaluate effectiveness. Based on the results of this investigation, the National Institute
for Occupational Safety and Health (NIOSH) Sound Level Meter was the most accurate app and had a goodness-of-fit coefficient (i.e., an $R^2$ value) of 0.97, which suggests that the app has a strong ability to detect true noise thresholds. Based on these findings, the NIOSH Sound Level Meter app was used for this investigation. The examiner used the app to ensure that her vocal intensity remained between 50 and 65 dB when administering tasks via live voice because this is the typical intensity range of conversational speech. Similarly, the examiner used the NIOSH Sound Level Meter app when presenting stimuli via recorded presentation to ensure that stimuli were presented between 50 and 65 dB.

**Equipment**

The examiner conducted all telephone calls using a smartphone (iPhone®). To present recorded speech discrimination stimuli during the telephone session, audio was played from the examiner’s laptop computer (MacBook Air®) and the examiner put her telephone on speakerphone so the audio could transmit from the computer speakers to the participant. To present live voice stimuli during the telephone session, the examiner kept her telephone on speakerphone. To maximize the consistency of administration, the examiner held her telephone approximately equal distance from the source of sound (i.e., the computer speakers and the examiner’s mouth) when presenting stimuli via live and recorded voice. For the NU-6 task, a digital recording from Auditec was used and for the TALSA speech discrimination task, stimuli were presented using E-Prime 3.0. The videoconferencing portion of the investigation was conducted via Zoom on a laptop computer (MacBook Air®) and all stimuli were presented via live voice.

Participants’ performance during the telephone and videoconferencing sessions was audio-recorded for later scoring. Recordings were captured via a digital voice recorder and were transcribed within one month of each session. Transcriptions were saved in a password protected
file on a laptop computer. Immediately after digital files were transcribed, audio-recordings were permanently deleted from the digital voice recorder to protect participant privacy.

**Scoring and data analysis**

To explore the effect of presentation modality on speech discrimination performance in telephone assessment (Research Question One), participants’ performance on both of the NU-6 word lists was scored as percentage of whole-words accurately repeated. Because each participant completed the NU-6 task in both conditions (i.e., live and recorded voice), a repeated measure, or paired samples t-test was used to test for a difference in means between the two conditions. Additionally, an analysis was conducted to determine whether one NU-6 list was significantly harder than the other list in either presentation modality. To do so, participants’ performance was averaged by list and presentation modality (i.e., participants’ performance was averaged across list two live voice presentation, list two recorded voice presentation, list four live voice presentation, and list four recorded voice presentation). Average participant performance on each list in each presentation modality was compared to the other list in the same presentation modality. For example, average participant performance on list two recorded presentation was compared to average participant performance on list four in the recorded presentation modality and average participant performance on list two live presentation was compared to average participant performance on list four in the live voice presentation modality. These comparisons were conducted using independent samples t-tests.

The relationships between performance in live voice speech discrimination and self-reported hearing ability on the Hearing Handicap Inventory—Screening (HHI-S), the Hearing Self-Assessment Questionnaire (HSAQ), and the single item hearing loss screener were explored (Research Question Two). To do so, responses on the HHI-S, the HSAQ, and the single item
hearing loss screening measures were correlated with participants’ percent accuracy performance in live voice speech discrimination. Participant responses on the HHI-S were categorized into a dichotomous variable, such that each participant was classified as having ‘no hearing handicap’ or a ‘hearing handicap.’ Similarly, responses on the HSAQ and single item hearing loss screener were scored and categorized into hearing loss and no hearing loss groups. Participants’ responses on the self-reported hearing measures served as dichotomous predictor variables and participants’ live voice speech discrimination scores served as a criterion variable. To analyze the relationship between measures of self-reported hearing ability and performance in live voice speech discrimination, point-biserial correlations were used. Additionally, three Mann-Whitney U tests were conducted to explore whether participants with or without hearing loss/handicap performed significantly differently in live voice speech discrimination.

To explore the relationship between self-reported hearing ability and memory performance in videoconferencing assessment (Research Question Three), participants’ responses on three self-reported measures of hearing ability were correlated with their total recall index scores on the California Verbal Learning Test—Third Edition (CVLT3). As described above, responses on the three self-reported hearing ability questionnaires (i.e., the HHI-S, HSAQ, and single item hearing screener) were categorized into dichotomous variables. Therefore, point-biserial correlation was used to explore the relationship between each of the dichotomous self-reported hearing measures and participants’ CVLT3 index scores, which served as the continuous criterion variable. Additionally, a series of Mann-Whitney U tests were conducted to explore whether there was a significant difference in CVLT3 index scores among people with and without hearing loss/handicap, as defined by each of the self-reported hearing measures.
The relationship between performance in live voice speech discrimination and CVLT3 index scores was explored (Research Question Four). To do so, participants’ average performance in live voice speech discrimination served as a continuous criterion variable and was correlated with their CVLT3 index scores, which served as a continuous predictor variable. While this analysis involved a correlation between two continuous variables, the relationship between the variables visually appeared non-linear; therefore, Spearman’s correlation coefficient was calculated to examine their relationship.

Additional analyses were conducted to examine whether there was a significant difference among responses on the three self-reported hearing questionnaires, the HHI-S, the HSAQ, and the single item hearing loss screener. Given that these analyses involved an exploration of the association between dichotomous variables, a phi coefficient was calculated to explore each association. To examine whether CVLT3 yes/no recognition scores differed among people with and without hearing loss/handicap, a Mann-Whitney U test was conducted for each self-reported hearing measure. Similarly, a Mann-Whitney U test was used to explore whether people with or without hearing loss/handicap, as defined by each of the self-reported hearing measures, performed significantly differently on the two cognitive screeners used in this study.

**Sample size calculation**

A sample size calculation was completed to ensure adequate power for this study, to diminish the likelihood of errors, and to avoid bias in interpreting results. To conduct this calculation, three main factors were considered: Type I error (α-error), power, and the estimated effect size. Type I error rate, or significance level, was set at 5%. Power is the probability that a test of significance will pick up a significant effect, if an effect exists. For this investigation, power was set at 80%. Finally, estimated effect size was based on literature exploring the relationship
between audition and cognition. Specifically, results from a meta-analysis exploring the relationship between hearing and cognitive function were used to make this estimate. Taljaard et al. (2016) report that “individuals with normal hearing had better general cognition than people with...untreated hearing loss (d = 0.54, medium effect)” (p. 722). Additional research has revealed a large effect size for the relationship between audition and cognition (Wong et al., 2019). These researchers found that when memory tasks were completed in a natural auditory condition (i.e., live voice presentation), people with hearing loss performed significantly worse than people with normal hearing on measures of auditory-verbal recall and recognition (d = 0.97-1.43, large effect size). Therefore, based on previous literature, a medium to large effect is predicted for this investigation.

Cohen’s (1988) approach to interpreting effect sizes for correlational studies was used for this study. According to this approach, the effect size is low if the value of $r$ varies around 0.1, medium if it varies around 0.3, and large if $r$ varies around 0.5 or higher. An estimated medium to large effect size (0.4) was used to calculate the sample size needed for this investigation, based on a review of the literature. Using a Type I error rate of 5% and an estimated effect size of 0.4, a sample of 46 participants was needed to achieve 80% power in this study. Therefore, the target sample size for the videoconferencing portion of this investigation was 46-50 participants. A slightly increased target sample size was used for the telephone portion of the investigation, as the primary goal of this session was to compare speech discrimination in live-voice and recorded presentation modalities in telephone assessment. Recently, Mendel and Owen (2011) used a sample of 60 participants to explore the effect of presentation modality on test administration time for the NU-6. Therefore, in accordance with the sample size used by these authors, the target sample size for the telephone portion of the investigation was 60 participants.
CHAPTER 4: RESULTS

This investigation used quantitative methods to explore factors that have the potential to influence remote memory assessment in older adults, including the impact of presentation modality (i.e., live voice versus recorded voice) on speech discrimination performance. The relationship between self-reported hearing ability and memory as well as factors influencing the timing and clarity of stimulus presentation in remote memory assessment were also explored. As described in Chapter Three, measures of speech discrimination, memory, and self-reported hearing status were adapted to allow for remote administration, which was conducted via the telephone and videoconferencing. A total of 60 individuals participated in the telephone portion of this investigation and 46 of these individuals also participated in the videoconferencing session (see Table 3.1 for detailed demographic information). The results from four primary research questions, along with additional analyses, are reported in this chapter.

Research questions

Research Question One: In telephone assessment with older adults, is there a difference in performance for speech discrimination administered via live voice versus recorded voice?

Out of a possible 50 points, the mean speech discrimination score in the live voice condition was 43.70 ($SD = 2.81$) and the mean speech discrimination score in the recorded voice condition was 43.42 ($SD = 3.15$). Prior to conducting the analysis to explore whether there was a significant difference in means between the two conditions, the assumption of normality for speech discrimination scores was examined. It was considered satisfied for live voice speech discrimination data based on a Shapiro-Wilk test, $W(60) = 0.965, p = .085$. Furthermore, live voice speech discrimination data was found to have a skewness of $-0.548 (SE = 0.309)$ and kurtosis of $0.353 (SE = 0.608)$, which provided further evidence that this variable was approximately normally
distributed. The assumption of normality was also considered satisfied for recorded voice speech discrimination data based on a Shapiro-Wilk test, $W(60) = 0.969, p = .128$. This variable was found to have a skewness of -0.403 ($SE = 0.309$) and kurtosis of 0.362 ($SE = 0.608$), which further suggested that it was approximately normally distributed. Based on these outcomes and after visual inspection of the histograms of live and recorded voice speech discrimination data and the Q-Q plots, the parametric paired samples t-test was selected to compare speech discrimination performance in live and recorded voice conditions. Prior to conducting the paired samples t-test, visual inspection of a scatterplot suggested a weak, positive, linear association between the two variables (Figure 4.1).

Based on the results of the paired samples t-test, there was not a significant difference in scores for live voice ($M = 43.70, SD = 2.81$) and recorded voice speech discrimination ($M = 43.42, SD = 3.15$); $t(59) = 0.675, p = .502$. On average, live voice speech discrimination performance was 0.28 points higher than recorded voice speech discrimination performance (95% CI [-0.557, 1.124]). However, there was insufficient evidence to reject the null hypothesis at $\alpha = 0.05$ and there was not a significant difference between live and recorded voice speech discrimination performance among participants in this investigation. It is important to note that one participant scored considerably lower than the remainder of participants in both live and recorded voice conditions (as seen in the scatterplot in Figure 4.1). The paired samples t-test was repeated without this outlier; however, the results of that test also indicated a non-significant relationship between live voice ($M = 43.85, SD = 2.59$) and recorded voice speech discrimination performance ($M = 43.58, SD = 2.92$); $t(58) = .635, p = .528$. 
Figure 4.1

Scatterplot of live versus recorded voice speech discrimination scores

Data was collapsed across the different test forms used so that average speech discrimination performance in each modality (i.e., live and recorded voice) could be compared among the two NU-6 word lists used. This analysis was conducted to explore whether one of the word lists was significantly harder than the other. As described above, live and recorded voice speech discrimination scores appeared to be normally distributed. Therefore, independent samples t-tests were used to make these comparisons.

An independent samples t-test was conducted to compare average live voice speech discrimination performance on NU-6 word list two to average live voice speech discrimination performance on NU-6 word list four. Inspection of Q-Q Plots revealed that live voice speech discrimination was approximately normally distributed and that there was homogeneity of variances, as assessed by Levene’s Test for Equality of Variances ($p = .207$). Results from the independent samples t-test revealed a non-significant difference in live voice speech discrimination scores for NU-6 word list two ($M = 43.33, SD = 3.14$) and NU-6 word list four ($M = 44.03, SD = 2.44$); $t(58) = -0.963, p = .340$. 
An independent samples t-test was also conducted to compare recorded voice speech discrimination performance on NU-6 word list two to recorded voice speech discrimination performance on NU-6 word list four. Similar to the live voice speech discrimination data, inspection of Q-Q Plots revealed that recorded voice speech discrimination was approximately normally distributed and there was homogeneity of variances, as assessed by Levene’s Test for Equality of Variances ($p = .391$). Results from the independent samples t-test revealed a non-significant difference in recorded voice speech discrimination scores for NU-6 word list two ($M = 43.70, SD = 3.28$) and NU-6 word list four ($M = 43.13, SD = 3.04$); $t(58) = -.694, p = .490$.

Finally, a series of analyses were conducted to explore whether participant gender, age, or education were associated with participant performance on live or recorded voice speech discrimination. First, point-biserial correlations were conducted to explore the associations between gender and live voice speech discrimination and gender and recorded voice speech discrimination. The assumption of homogeneity of variances appeared to be satisfied for the correlation between gender and live voice speech discrimination based on Levene’s Test for Equality of Variances ($p = .781$). Results from the point-biserial correlation revealed a non-significant relationship between gender and live voice speech discrimination performance ($r_{pb} = .046, p = .724$). The assumption of homogeneity of variances also appeared to be satisfied for the correlation between gender and recorded voice speech discrimination based on Levene’s Test for Equality of Variances ($p = .496$). Results from the point-biserial correlation revealed a non-significant relationship between gender and recorded voice speech discrimination performance ($r_{pb} = -.059, p = .656$).

Next, the relationship between age and speech discrimination performance was explored. The assumption of normality was not considered satisfied for age data based on a Shapiro-Wilk
test, $W(60) = 0.909, p < .001$. Therefore, the non-parametric Spearman’s correlation coefficient was calculated to explore the association between age and live voice speech discrimination ($r_s = -.347, p = .007$). This finding revealed a weak negative association between and age and live voice speech discrimination performance, such that as individuals’ ages increased, their live voice speech discrimination performance decreased. Spearman’s correlation coefficient was also calculated to explore the association between age and recorded voice speech discrimination ($r_s = -.036, p = .787$). This finding revealed a non-significant association between age and recorded voice speech discrimination scores. Finally, Spearman’s correlation coefficient was calculated to explore the relationship between speech discrimination performance and education, which was measured on an ordinal scale. Results of these analyses revealed that education and live voice speech discrimination were not significantly associated ($r_s = .092, p = .484$). However, education and recorded voice speech discrimination performance were significantly associated ($r_s = .297, p = .021$). This finding indicated that there was a weak positive relationship between recorded voice speech discrimination performance and education, such that as participants’ education levels increased, their recorded voice speech discrimination performance also increased.

**Research Question Two:** Is there a relationship between performance in speech discrimination administered via live voice and self-reported hearing ability as measured by the Hearing Handicap Inventory—Screening (HHI-S), the Hearing Self-Assessment Questionnaire (HSAQ), and the single item hearing loss screener?

As described above, all participants ($N = 60$) completed the single item hearing loss screener. Participants who completed the HHI-S and HSAQ were those who participated in the videoconferencing session ($n = 46$). After categorizing HHI-S scores into a dichotomous variable, 37 participants were classified as having ‘no hearing handicap’ and nine participants were
classified as having a ‘hearing handicap.’ Point-biserial correlation was used to explore the strength and direction of the association between these variables. Participants’ responses on the HHI-S served as a dichotomous predictor variable and participants’ live voice speech discrimination scores served as a continuous criterion variable. The assumption of homogeneity of variances appeared to be satisfied for the correlation based on Levene’s Test for Equality of Variances ($p = .907$). Results from the point-biserial correlation revealed a non-significant relationship between live voice speech discrimination performance and HHI-S score ($r_{pb} = .018, p = .908$).

Additionally, a Mann-Whitney U test was conducted to explore whether there was a significant difference in live voice speech discrimination performance among participants with and without hearing handicap, as classified by the HHI-S. This test was selected because the number of participants in the hearing handicap versus no hearing handicap groups differed considerably. Based on results from the Mann-Whitney U test, median live voice speech discrimination scores for people with hearing handicap ($Mdn = 44.00$) and without hearing handicap ($Mdn = 44.00$) were not significantly different ($U = 169.000, p = .957$). The results of this test supported findings obtained from the point-biserial correlation coefficient.

The relationship between live voice speech discrimination and HSAQ responses was also explored. Participants’ responses on the HSAQ were scored and categorized into a binary variable, such that participants were classified as having no self-reported hearing loss or self-reported hearing loss based on a cut-off score of 15 points. After categorizing participants’ responses, six participants were classified as having hearing loss and 40 participants were classified as not having hearing loss. It is important to note that the six individuals identified as having hearing loss by the HSAQ were six of the nine participants identified as having hearing loss using the HHI-S. To
explore the association between participants’ performance in live voice speech discrimination and their responses on the HSAQ, point-biserial correlation was used. The assumption of homogeneity of variances appeared to be satisfied for the correlation based on Levene’s Test for Equality of Variances ($p = .848$). Results from the point-biserial correlation revealed a non-significant relationship between live voice speech discrimination and HSAQ responses ($r_{pb} = .066, p = .665$).

A Mann-Whitney U test was also conducted to explore whether there was a significant difference in live voice speech discrimination performance among participants with and without self-reported hearing loss, as classified by the HSAQ. This test was selected because of the considerable difference in the number of participants in the hearing loss versus no hearing loss groups. Based on results from the Mann-Whitney U test, median live voice speech discrimination scores for people with hearing loss ($Mdn = 44.00$) and without hearing loss ($Mdn = 44.00$) were not significantly different ($U = 137.500, p = .577$). The results of this test supported findings obtained from the point-biserial correlation.

The relationship between live voice speech discrimination and responses on the single item hearing screener was also explored. Participants’ responses on the single item screener were categorized into a binary variable, such that participants were classified as having no self-reported hearing loss if they described their hearing as ‘excellent’ or ‘good’ or self-reported hearing loss if they reported any difficulty hearing (i.e., ‘a little trouble,’ ‘moderate trouble,’ ‘a lot of trouble,’ or ‘deaf’). After categorizing participants’ responses, 20 participants were classified as having hearing loss and 40 participants were classified as not having hearing loss. Point-biserial correlation was used to examine the strength and direction of the association between participants’ performance in live voice speech discrimination, which served as the continuous criterion variable, and their responses on the single item hearing loss screener, which served as the dichotomous
predictor variable. The assumption of homogeneity of variances appeared to be satisfied for the correlation based on Levene’s Test for Equality of Variances \((p = .565)\). Results from the point-biserial correlation revealed a non-significant relationship between live voice speech discrimination and responses on the single item hearing screener \((r_{pb} = -.191, p = .145)\). A point-biserial correlation analysis was repeated using only the single item hearing loss screening data collected from the individuals who participated in the Zoom session \((n = 46)\). The homogeneity of variances appeared to be satisfied for the correlation based on Levene’s Test for Equality of Variances \((p = .195)\). Results from the point-biserial correlation revealed a non-significant relationship between live voice speech discrimination and Zoom responses on the single item hearing screener \((r_{pb} = -.169, p = .261)\).

A Mann-Whitney U test was also conducted to explore whether there was a significant difference in live voice speech discrimination performance among participants with and without self-reported hearing loss, as classified by the single item screener. This test was selected because of the considerable difference in the number of participants in the hearing loss versus no hearing loss groups. Based on results from the Mann-Whitney U test, median live voice speech discrimination scores for people with hearing loss \((Mdn = 43.00)\) and without hearing loss \((Mdn = 44.00)\) were not significantly different \((U = 314.000, p = .174)\). The results of this test supported findings obtained from the point-biserial correlation. As indicated in Table 4.1, none of the self-reported hearing measures were significantly associated with live voice speech discrimination scores and as indicated in Table 4.2 there was not a significant difference in live voice speech discrimination among people with hearing loss/handicap and without hearing loss/handicap.
Table 4.1

Point-biserial correlation coefficients for self-reported hearing measures and live voice speech discrimination scores

<table>
<thead>
<tr>
<th></th>
<th>Live voice speech discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHI-S</td>
<td>$r_{pb} = .018, p = .908$</td>
</tr>
<tr>
<td>HSAQ</td>
<td>$r_{pb} = .066, p = .665$</td>
</tr>
<tr>
<td>Single item hearing screener</td>
<td>$r_{pb} = -.191, p = .145$</td>
</tr>
</tbody>
</table>

Table 4.2

Mann-Whitney U tests between hearing status and live voice speech discrimination scores

<table>
<thead>
<tr>
<th></th>
<th>Hearing loss/handicap</th>
<th>No hearing loss/handicap</th>
<th>Mann-Whitney U</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Mdn^a$</td>
<td>$Mdn^a$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHI-S</td>
<td>44.00</td>
<td>44.00</td>
<td>169.000</td>
<td>.957</td>
</tr>
<tr>
<td>HSAQ</td>
<td>44.00</td>
<td>44.00</td>
<td>137.500</td>
<td>.577</td>
</tr>
<tr>
<td>Single item hearing screener</td>
<td>43.00</td>
<td>44.00</td>
<td>314.000</td>
<td>.174</td>
</tr>
</tbody>
</table>

$^a$Represents median live voice speech discrimination scores

Finally, a series of analyses were conducted to explore the association between gender, age, and education and the three measures of self-reported hearing ability included in this investigation. First, three phi coefficients were calculated to explore the association between (1) the HHI-S and gender ($\varphi = -.031, p = .833$), (2) the HSAQ and gender ($\varphi = -.116, p = .432$), and (3) the single item hearing screener and gender ($\varphi = -.222, p = .085$). The results from the phi coefficients indicated that there was not a significant association between gender and the three measures of self-reported hearing ability. Next, age was correlated with the HHI-S, HSAQ, and single item hearing screener. Given that the age variable was not normally distributed, non-parametric Spearman’s correlation coefficients were computed to explore these associations. Based on the results of these tests, there was not a significant association between the HHI-S and age ($r_s = -.273, p = .066$), the HSAQ and age ($r_s = -.134, p = .375$), nor the single item hearing
screener and age \((r_s = -0.018, p = .889)\). Finally, the associations between education level and responses on the self-reported hearing measures were explored using rank-biserial correlations. Based on the results of these tests, there was not a significant association between the HHI-S and education \((r_{rb} = -0.095, p = .531)\), the HSAQ and education \((r_{rb} = -0.195, p = .193)\), nor the single item hearing screener and education \((r_{pb} = -0.016, p = .904)\). In summary, participant gender, age, and education did not appear to be significantly associated with participants’ responses on the three measures of self-reported hearing ability included in this investigation.

**Research Question Three:** In videoconferencing assessment with older adults, is there a relationship between self-reported hearing ability and performance on the California Verbal Learning Test—Third Edition (CVLT3)?

The three measures of self-reported hearing ability used in this investigation were correlated with participants’ CVLT3 index scores, which reflected overall recall performance. The mean CVLT3 index score among participants was 106.22 \((SD = 14.31)\). Because the self-reported hearing measures were dichotomous variables, point-biserial correlations were used to explore the strength and direction of the association between these measures and CVLT3 index scores. The assumption of normality was considered satisfied for CVLT3 index score data based on a Shapiro-Wilk test, \(W(46) = 0.953, p = .062\). Furthermore, the variable was found to have a skewness of -0.225 \((SE = 0.350)\) and kurtosis of -0.923 \((SE = 0.688)\), which also suggested that it was approximately normally distributed.

First, the relationship between participants’ CVLT3 and HHI-S scores was explored. The assumption of homogeneity of variances appeared satisfied based on Levene’s Test for Equality of Variances \((p = .262)\). Results from a point-biserial correlation revealed a non-significant relationship between CVLT3 scores and HHI-S responses \((r_{pb} = .147, p = .331)\). Next, the
relationship between CVLT3 scores and HSAQ responses was tested. The assumption of homogeneity of variances appeared satisfied based on Levene’s Test for Equality of Variances (p = .288). The results from this correlation revealed a non-significant relationship between CVLT3 scores and HSAQ responses ($r_{pb} = .217, p = .147$).

Finally, the relationship between CVLT3 scores and participants’ responses on the single item, self-reported hearing ability screener was explored. The assumption of homogeneity of variances appeared satisfied based on Levene’s Test for Equality of Variances (p = .490). Results from the point-biserial correlation revealed a non-significant relationship between CVLT3 scores and self-reported hearing status based on the single item screener ($r_{pb} = -.040, p = .791$). As indicated in Table 4.3, none of the self-reported hearing measures were significantly associated with CVLT3 index scores.

<table>
<thead>
<tr>
<th></th>
<th>CVLT3 Index Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHI-S</td>
<td>$r_{pb} = .147, p = .331$</td>
</tr>
<tr>
<td>HSAQ</td>
<td>$r_{pb} = .217, p = .147$</td>
</tr>
<tr>
<td>Single item hearing screener</td>
<td>$r_{pb} = -.040, p = .791$</td>
</tr>
</tbody>
</table>

In addition to conducting a series of point-biserial correlations to explore the relationships between CVLT3 index scores and self-reported hearing measures, a series of Mann-Whitney U tests were conducted (Table 4.4). These tests were used to explore whether there was a significant difference in CVLT3 index scores among people with and without hearing loss/handicap. A Mann-Whitney U test was selected because of the considerable difference in the number of participants in the hearing loss/handicap versus no hearing loss/handicap groups for each self-reported hearing measure. Based on results from the Mann-Whitney U test, median CVLT3 index scores for people with hearing handicap ($Mdn = 114.00$) and without hearing handicap ($Mdn = 103.00$), as classified
using the HHI-S, were not significantly different \((U = 202.000, p = .338)\). Similarly, median CVLT3 index scores for people with hearing loss \((Mdn = 117.00)\) and without hearing loss \((Mdn = 103.00)\), as classified using the HSAQ, were not significantly different \((U = 164.000, p = .160)\).

Finally, based on results from the Mann-Whitney U test, median CVLT3 index scores for people with self-reported hearing loss \((Mdn = 111.00)\) and without self-reported hearing loss \((Mdn = 103.50)\), as classified using the single item hearing screener, were not significantly different \((U = 212.000, p = .774)\).

**Table 4.4**

Mann-Whitney U tests between hearing status and CVLT3 index scores

<table>
<thead>
<tr>
<th>Hearing loss/handicap</th>
<th>No hearing loss/handicap</th>
<th>Mann-Whitney U</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHI-S</td>
<td>114.00</td>
<td>103.00</td>
<td>202.000</td>
</tr>
<tr>
<td>HSAQ</td>
<td>117.00</td>
<td>103.00</td>
<td>164.000</td>
</tr>
<tr>
<td>Single item hearing screener</td>
<td>111.00</td>
<td>103.50</td>
<td>212.000</td>
</tr>
</tbody>
</table>

*aRepresents median CVLT3 index scores

Finally, a series of analyses were conducted to explore the association between gender, age, and education and CVLT3 index scores. First, point-biserial correlation was used to explore the direction and strength of the association between gender and CVLT3 index scores. The assumption of homogeneity of variances appeared satisfied based on Levene’s Test for Equality of Variances \((p = .116)\). Results from this test revealed that gender and CVLT3 index scores were significantly correlated \((r_{pb} = .307, p = .038)\) at \(\alpha = .05\). Females \((M = 109.09, SD = 12.08)\) scored significantly higher than males \((M = 99.64, SD = 17.15); t(44) = -2.141, p = .038\). Next, age was correlated with CVLT3 index scores. Given that the age variable was not normally distributed, Spearman’s correlation coefficient was computed to explore this association. Based on the results
of this test, there was not a significant association between age and CVLT3 index scores ($r_s = .054$, $p = .720$). Finally, the association between education level and CVLT3 index scores was explored using Spearman’s correlation. Based on the results of this test, there was not a significant association between education level and CVLT3 index scores ($r_s = .159$, $p = .290$). In summary, participant age and education did not appear to be significantly associated with participants’ CVLT3 index scores; however, participant gender was significantly associated with these scores with females scoring significantly higher than males.

**Research Question Four:** Is there a relationship between performance in speech discrimination administered via live voice and performance on the CVLT3?

Given that CVLT3 data was collected via videoconferencing, data from a total of 46 participants was used in this analysis. Prior to analyzing the data, visual inspection of a scatterplot depicting live voice speech discrimination and CVLT3 index scores was conducted (Figure 4.2). This inspection revealed a non-linear relationship between the two variables. Given this violation in linearity, the non-parametric Spearman’s correlation coefficient was calculated to assess the relationship between these variables. There was a weak, positive correlation between the two variables, $r_s = .066$; however, the relationship was not significant ($p = .662$).

**Figure 4.2**

*Scatterplot of live voice speech discrimination vs CVLT3 index scores*
A series of non-parametric partial correlations were conducted to determine the relationship between an individual’s live voice speech discrimination performance and CVLT3 index scores while controlling for gender, age, and education. There was a weak positive partial correlation between live voice speech discrimination and CVLT3 index scores while controlling for gender; however, this partial correlation was not statistically significant; \( r = .059, p = .699 \).

There was also a weak positive partial correlation between live voice speech discrimination and CVLT3 index scores while controlling for age; however, this partial correlation was not statistically significant; \( r = .090, p = .556 \). Similarly, there was a weak positive partial correlation between live voice speech discrimination and CVLT3 index scores while controlling for education; however, this partial correlation was not statistically significant; \( r = .057, p = .709 \).

**Additional analyses**

A series of additional analyses were conducted to explore the relationship between participant responses on the self-reported hearing questionnaires and other measures included in the investigation. Other variables of interest included scores from the CVLT3 yes/no recognition task, the T-MoCA, and the Qmci.

**Associations among the self-reported hearing questionnaires**

First, a series of analyses were conducted to explore the relationship among the self-reported hearing questionnaires used in this study. These questionnaires included the single item hearing loss screener, the HHI-S, and the HSAQ. Because participant responses on these three measures were dichotomous, a phi coefficient was calculated to evaluate the strength of the association between each set of variables. First, a phi coefficient was calculated to explore the association between the HHI-S and the HSAQ. Based on the phi coefficient, the HHI-S and HSAQ were strongly associated \( (\varphi = .785, p < .001) \). Next, the phi coefficient was calculated to explore
the association between the HHI-S and single item hearing loss screener. This statistic indicated that these two measures were strongly associated with one another (φ = .507, p < .001). Finally, the association between participant responses on the HSAQ and the single item hearing loss screener was explored. Based on the results of a phi coefficient, participants’ responses on the HSAQ and single item hearing screener were moderately to strongly associated (φ = .445, p = .003). As indicated in Table 4.5, all three self-reported hearing measures were strongly associated.

**Table 4.5**

*Phi coefficients for the association among self-reported hearing questionnaires*

<table>
<thead>
<tr>
<th></th>
<th>HHI-S</th>
<th>HSAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HHI-S</strong></td>
<td>φ = .785</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>p &lt; .001</em></td>
<td></td>
</tr>
<tr>
<td><strong>HSAQ</strong></td>
<td>φ = .507</td>
<td>φ = .445</td>
</tr>
<tr>
<td><strong>Single item hearing screener</strong></td>
<td><em>p &lt; .001</em></td>
<td><em>p = .003</em></td>
</tr>
</tbody>
</table>

*Statistically significant at α = .05

**Exploring differences in CVLT3 recognition scores based on self-reported hearing ability**

A series of analyses were conducted to explore whether participants with and without hearing loss/handicap, as defined by their responses on the three measures of self-reported hearing ability, demonstrated a significant difference in performance on the CVLT3 yes/no recognition task. The average CVLT3 yes/no recognition scaled score among participants was a 10.17 (SD = 2.35). Scores from this task did not appear to be normally distributed based on a Shapiro-Wilk test, W(46) = 0.868, p < .001. Visual inspection of the data further supported this conclusion. Therefore, the non-parametric Mann-Whitney U test was used to compare differences in CVLT3 yes/no recognition scores between the two independent groups (i.e., hearing loss/handicap versus no hearing loss/handicap) for each measure of self-reported hearing ability (Table 4.6).

A Mann-Whitney U test indicated that CVLT3 yes/no recognition scores did not differ significantly among people with a ‘hearing handicap’ (Mdn = 11.00) and ‘no hearing handicap’
(\(Mdn = 11.00\)) based on classification using the HHI-S (\(U = 156.500, p = .786\)). Similarly, a Mann-Whitney U test indicated that CVLT3 yes/no recognition scores were not significantly different among people with hearing loss (\(Mdn = 11.50\)) and without hearing loss (\(Mdn = 11.00\)), based on classification from the HSAQ (\(U = 146.000, p = .415\)). Finally, CVLT3 yes/no recognition scores were not significantly different among people with hearing loss (\(Mdn = 11.00\)) and without hearing loss (\(Mdn = 11.00\)) based on classification from the single item hearing loss screener (\(U = 222.500, p = .971\)).

**Table 4.6**

*Mann-Whitney U tests between hearing status and CVLT3 yes/no recognition scores*

<table>
<thead>
<tr>
<th></th>
<th>Hearing loss/handicap</th>
<th>No hearing loss/handicap</th>
<th>Mann-Whitney U</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Mdn^a)</td>
<td>(Mdn^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHI-S</td>
<td>11.00</td>
<td>11.00</td>
<td>156.500</td>
<td>.786</td>
</tr>
<tr>
<td>HSAQ</td>
<td>11.50</td>
<td>11.00</td>
<td>146.000</td>
<td>.415</td>
</tr>
<tr>
<td>Single item</td>
<td>11.00</td>
<td>11.00</td>
<td>222.500</td>
<td>.971</td>
</tr>
</tbody>
</table>

\(^a\)Represents median CVLT3 yes/no recognition scores

**Exploring differences in cognitive screener scores based on self-reported hearing ability**

A series of analyses were conducted to explore whether participants with and without hearing loss/handicap, as defined by their responses on the three measures of self-reported hearing ability, demonstrated a significant difference in performance on the cognitive screeners included in this investigation, (i.e., the T-MoCA and Qmci). Before conducting these analyses, the relationship between the T-MoCA and Qmci was explored. Scores from the T-MoCA were not normally distributed based on a Shapiro-Wilk test, \(W(46) = 0.890, p < .001\). Visual inspection of the data further supported this conclusion. Alternatively, Qmci data appeared to be normally distributed based on a Shapiro-Wilk test, \(W(46) = 0.966, p = .203\). Because T-MoCA data was not
normally distributed, Spearman’s correlation coefficient was calculated to explore the relationship between these two variables. Based on the results of this correlation, the T-MoCA and Qmci appeared to have a strong, positive association ($r_s = .476, p < .001$).

Next, the non-parametric Mann-Whitney U test was used to compare differences in T-MoCA scores between the two independent groups (i.e., hearing loss/handicap versus no hearing loss/handicap) for each measure of self-reported hearing ability (Table 4.7). A Mann-Whitney U test indicated that T-MoCA scores were not significantly different among people with a hearing handicap ($Mdn = 20.00$) and no hearing handicap ($Mdn = 20.00$) based on classification using the HHI-S ($U = 143.500, p = .531$). Similarly, a Mann-Whitney U test indicated that T-MoCA scores were not significantly different among people with hearing loss ($Mdn = 19.50$) and without hearing loss ($Mdn = 20.00$) using the HSAQ ($U = 99.500, p = .513$). Finally, T-MoCA scores were not significantly different among people with hearing loss ($Mdn = 20.00$) and without hearing loss ($Mdn = 20.00$) based on classification using the single item hearing screener ($U = 422.500, p = .717$).

**Table 4.7**

Mann-Whitney U tests between hearing status and T-MoCA scores

<table>
<thead>
<tr>
<th>Hearing loss/handicap</th>
<th>No hearing loss/handicap</th>
<th>Mann-Whitney U</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mdn</strong></td>
<td><strong>Mdn</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHI-S</td>
<td>20.00</td>
<td>20.00</td>
<td>143.500</td>
</tr>
<tr>
<td>HSAQ</td>
<td>19.50</td>
<td>20.00</td>
<td>99.500</td>
</tr>
<tr>
<td>Single item hearing screener</td>
<td>20.00</td>
<td>20.00</td>
<td>422.500</td>
</tr>
</tbody>
</table>

*Represents median T-MoCA scores

Next, differences in Qmci performance were compared among people with and without hearing loss/handicap. Group sizes for the hearing loss/handicap and no hearing loss/handicap
groups differed considerably for each measure of self-reported hearing ability. Therefore, the non-parametric Mann-Whitney U test was used to compare differences in Qmci scores between the two independent groups (i.e., hearing loss/handicap versus no hearing loss/handicap) for each measure of self-reported hearing ability (Table 4.8).

Scores on the Qmci were not significantly different among people with hearing handicap \((Mdn = 86.00)\) and without hearing handicap \((Mdn = 83.00)\), based on classification using the HHI-S \((U = 201.500, p = .338)\). Similarly, scores were not significantly different among people with hearing loss \((Mdn = 86.50)\) and without hearing loss \((Mdn = 83.00)\), based on classification using the HSAQ \((U = 161.500, p = .181)\). Finally, Qmci scores were not significantly different among people with hearing loss \((Mdn = 79.00)\) and without hearing loss \((Mdn = 84.00)\), based on classification using the single item hearing loss screener \((U = 175.000, p = .240)\).

**Table 4.8**

*Mann-Whitney U tests between hearing status and Qmci scores*

<table>
<thead>
<tr>
<th></th>
<th>Hearing loss/handicap</th>
<th>No hearing loss/handicap</th>
<th>Mann-Whitney U</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHI-S</td>
<td>86.00</td>
<td>83.00</td>
<td>201.500</td>
<td>.338</td>
</tr>
<tr>
<td>HSAQ</td>
<td>86.50</td>
<td>83.00</td>
<td>161.500</td>
<td>.181</td>
</tr>
<tr>
<td>Single item hearing screener</td>
<td>79.00</td>
<td>84.00</td>
<td>175.000</td>
<td>.240</td>
</tr>
</tbody>
</table>

\(^a\)Represents median Qmci scores

Finally, a series of analyses were conducted to explore the association between gender, age, and education and cognitive screener scores. First, point-biserial correlations were conducted to explore the associations between gender and T-MoCA scores as well as gender and Qmci scores. The assumption of homogeneity of variances appeared to be satisfied for the correlation between gender and T-MoCA scores based on Levene’s Test for Equality of Variances \((p = .731)\). Results
from the point-biserial correlation revealed a non-significant relationship between gender and T-MoCA scores ($r_{pb} = .182, p = .164$). The assumption of homogeneity of variances also appeared to be satisfied for the correlation between gender and Qmci scores based on Levene’s Test for Equality of Variances ($p = .690$). Results from the point-biserial correlation revealed a weak positive association between participant gender and Qmci score; however, the association was not significant ($r_{pb} = .285, p = .055$).

Next, the associations between age and cognitive screening scores were explored. Given that the age variable was non-normally distributed, non-parametric Spearman’s correlation coefficients were calculated to explore the direction and strength of these associations. Based on the results of these tests, age was not significantly associated with T-MoCA scores ($r_s = -.044, p = .737$) nor was age significantly associated with Qmci scores ($r_s = -.163, p = .278$). Finally, the associations between education level and cognitive screening scores were explored. To correlate the continuous cognitive screener variables with ordinal education level data, Spearman’s correlation coefficients were computed. Based on the results of these tests, education level and T-MoCA scores have a moderate positive association, such that T-MoCA scores increased as education levels increased; $r_s = .347, p = .007$. Alternatively, age was not significantly associated with Qmci scores ($r_s = .192, p = .202$).

**Exploring the case of poor speech discrimination and age**

In the dataset there was one individual who performed considerably lower in live and recorded voice speech discrimination compared to the remainder of the participants. This participant was the only one to score below the first quartile on either speech discrimination task. This individual was also the oldest participant in the study at the age of 79. Regarding memory performance, this individual scored the lowest on the T-MoCA, Qmci, and CVLT3 index score
among all participants in the investigation. While they self-reported ‘a little trouble hearing’ on the single-item hearing screener (therefore classified as having hearing loss using this measure), they were not classified as having hearing loss based on their HHI-S and HSAQ responses. Given this individual’s poor performance in speech discrimination, they could potentially be an individual who has unrecognized hearing loss.

Because this unique individual was the oldest participant in the study, data from a sub-sample of 10 older adults (those ≥70 years old) were analyzed. Given the small size of this sub-sample, the results from these analyses provided information to guide future research; however, because the study was not designed specifically to recruit individuals 70+ years old, results must be interpreted with caution. This sub-sample of older adults (n = 10) performed lower on cognitive measures compared to averages obtained from the full sample; however, as described above, there was not a significant association between age and T-MoCA, QmcI, nor CVLT3 index scores. Among this sub-sample, the mean T-MoCA score was 19.60 (SD = 1.17), compared to a mean of 20.12 (SD = 1.25) from the full sample and the mean QmcI score was 79.60 (SD = 6.69), compared to a mean of 82.33 (SD = 5.30) from the full sample. Similarly, the sub-sample of older adults also demonstrated poorer performance on the CVLT3 index score with a mean score of 103.40 (SD = 17.49) compared to a mean score of 106.22 (SD = 14.31) from the full sample. Prior to conducting the analysis to explore whether there was a significant difference in means between speech discrimination scores in the live and recorded voice conditions, the assumption of normality for speech discrimination scores was examined. It was considered satisfied for live voice speech discrimination data based on a Shapiro-Wilk test, W(10) = 0.898, p = .210 and for recorded voice speech discrimination, W(10) = .902, p = .231. Visual inspection of a scatterplot suggested a weak, positive, linear association between the two variables. Similar to the paired-samples t-test results
from the full sample, there was not a significant difference in scores for live voice ($M = 42.30$, $SD = 3.30$) and recorded voice speech discrimination ($M = 43.50$, $SD = 4.63$); $t(9) = -1.000$, $p = .343$ among the sub-sample.

The association between self-reported hearing ability and live voice speech discrimination was also explored. However, correlational analyses could not be conducted to explore the relationships between live voice speech discrimination and the HHI-S and HSAQ because none of the participants in the sub-sample were identified as having self-reported hearing loss using these tools; however, three of 10 participants from this sub-sample were identified as having self-reported hearing loss using the single-item hearing screener. A point-biserial correlation between single-item screener responses and live voice speech discrimination scores related a non-significant association; $r_{pb} = -.411; p = .238$.

Similarly, the association between self-reported hearing ability and CVLT3 index scores was also explored. However, correlational analyses could not be conducted to explore the relationships between CVLT3 index scores and the HHI-S and HSAQ because none of the participants in the sub-sample were identified as having self-reported hearing loss using these tools. A point-biserial correlation was conducted to explore the association between single-item screener responses and CVLT3 index scores. This test revealed a non-significant association between these variables; $r_{pb} = -.586; p = .087$. While this correlation approached significance, the limited sample size of the group identified as having hearing loss by the single-item hearing screener limited these findings. The mean CVLT3 index scores for individual with self-reported hearing loss (as defined by the single-item screener) was 89.00 ($SD = 12.77$) compared to a mean score of 109.57 ($SD = 16.02$) for individuals without self-reported hearing difficulty. These results suggested that individuals with self-reported hearing loss performed lower than those without self-
reported hearing loss; however, this difference was not significant based on results from an independent samples t-test; \( t(8) = 1.952, p = .087 \).

Finally, the association between performance in live voice speech discrimination and CVLT3 index scores was explored. The assumption of normality was considered satisfied for CVLT3 index scores based on a Shapiro-Wilk test, \( W(10) = .936, p = .506 \). However, inspection of a scatterplot revealed that the two variables did not share a linear relationship. Therefore, a non-parametric Spearman correlation coefficient was calculated. While live voice speech discrimination scores and CVLT3 index scores were weakly and positive correlated, there was not a significant association between these variables among the sub-sample (\( r_p = .292, p = .413 \)).

**Summary of results**

In summary, using a within-subjects design, participants in this investigation did not demonstrate a significant difference in live versus recorded voice speech discrimination performance. Participants’ responses on the three measures of self-reported hearing ability used in this investigation were significantly correlated with one another. However, self-reported hearing ability was not significantly associated with participants’ CVLT3 index scores nor their CVLT3 yes/no recognition scores. Additionally, live voice speech discrimination scores were not significantly correlated with self-reported hearing ability nor CVLT3 index scores. Finally, participants’ scores on the T-MoCA and Qmei cognitive screeners included in the investigation were strongly associated; however, participants did not demonstrate significant differences in performance on either of the cognitive screeners based on their self-reported hearing status, as measured using three measures of self-reported hearing status. Summary data for participant performance on the primary outcome measures included in this investigation, stratified by self-reported hearing ability, are presented in Table 4.9.
Table 4.9

| Performance on primary outcome measures stratified by self-reported hearing ability |
|---------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
|                                 | HHI-S (n = 46)                                                                                   | HSAQ (n = 46)                                                                                   | Single item hearing loss screener (N = 60)                                                      |
|                                 | Hearing handicap (n = 9)                                                                          | No hearing handicap (n = 37)                                                                      | Hearing loss (n = 6)                                                                            | No hearing loss (n = 40)                                                                         | Hearing loss (n = 20)                                                                            | No hearing loss (n = 40)                                                                         |
| Live voice speech discrimination| $M = 43.78$                                                                                       | $M = 43.65$                                                                                     | $M = 44.17$                                                                                     | $M = 43.60$                                                                                     | $M = 42.85$                                                                                     | $M = 44.08$                                                                                     |
|                                 | $SD = 2.77$                                                                                      | $SD = 3.02$                                                                                     | $SD = 2.99$                                                                                     | $SD = 2.97$                                                                                     | $SD = 3.02$                                                                                     | $SD = 2.65$                                                                                     |
| Recorded voice speech discrimination| $M = 42.33$                                                                                       | $M = 44.27$                                                                                     | $M = 42.17$                                                                                     | $M = 44.15$                                                                                     | $M = 42.40$                                                                                     | $M = 43.93$                                                                                     |
|                                 | $SD = 3.35$                                                                                      | $SD = 3.25$                                                                                     | $SD = 3.97$                                                                                     | $SD = 3.20$                                                                                     | $SD = 3.78$                                                                                     | $SD = 2.69$                                                                                     |
| CVLT3 Index Score              | $M = 110.89$                                                                                     | $M = 105.08$                                                                                   | $M = 114.17$                                                                                   | $M = 105.03$                                                                                   | $M^* = 105.36$                                                                                  | $M^* = 106.59$                                                                                  |
|                                 | $SD = 11.19$                                                                                     | $SD = 14.88$                                                                                   | $SD = 11.51$                                                                                   | $SD = 14.43$                                                                                   | $SD = 15.65$                                                                                   | $SD = 13.94$                                                                                  |
| CVLT3                           | $M = 10.11$                                                                                      | $M = 10.19$                                                                                     | $M = 11.17$                                                                                     | $M = 10.03$                                                                                     | $M^* = 10.21$                                                                                  | $M^* = 10.16$                                                                                  |
| Yes/No Recognition Score       | $SD = 2.26$                                                                                      | $SD = 2.40$                                                                                     | $SD = 1.17$                                                                                     | $SD = 2.46$                                                                                     | $SD = 2.29$                                                                                     | $SD = 2.41$                                                                                     |
|                                 | $SD = 1.79$                                                                                      | $SD = 1.18$                                                                                     | $SD = 1.86$                                                                                     | $SD = 1.22$                                                                                     | $SD = 1.40$                                                                                     | $SD = 1.19$                                                                                     |
| Qmci                            | $M = 83.78$                                                                                      | $M = 81.97$                                                                                     | $M = 84.83$                                                                                     | $M = 81.95$                                                                                     | $M^* = 80.43$                                                                                  | $M^* = 83.16$                                                                                  |
|                                 | $SD = 6.06$                                                                                      | $SD = 5.12$                                                                                     | $SD = 5.81$                                                                                     | $SD = 5.19$                                                                                     | $SD = 7.37$                                                                                     | $SD = 3.95$                                                                                     |

*Note. A total of 60 participants completed the single item hearing loss screener task, which was administered via the telephone along with the speech discrimination and T-MoCA tasks. A sub-sample of 46 of these participants completed the CVLT3 and Qmci tasks via a Zoom session.

^$n = 14$

^$n = 32$
CHAPTER 5: DISCUSSION

With the revitalization of aural rehabilitation (AR) and increased use of telepractice services, there is a paucity of research focused on remote assessment. Therefore, the purpose of this investigation was to use a quantitative design to explore how various factors, including the effect of presentation modality on speech discrimination performance and self-reported hearing ability, potentially influence remote memory assessment in older adults. This chapter includes a summary and interpretation of the findings from this investigation along with discussions regarding its significance for speech-language pathologists, limitations, and future directions for research on this topic.

Characteristics of the study sample

For this investigation, a sample of cognitively healthy older adults were recruited. Individuals who used hearing technology were excluded. The average age of participants was comparable to other studies exploring the association between cognition and hearing (De Iorio et al., 2019; Jayakody et al., 2018; Lim & Loo, 2018; Wong et al., 2019). One factor that likely influenced the findings from this study was participant comfort and familiarity with technology. The study sample spent an average of 30.96 hours per week on the computer and the majority of participants reported feeling comfortable and experienced on Zoom. Had individuals with less experience and comfort with technology been recruited, results may have differed.

Additionally, the cognitive screening tools used in this investigation may have influenced the results. Though these tools have been widely used as screening measures and were useful for this investigation, there are associated limitations. First, unlike the T-MoCA, the Qmci has not been standardized for remote administration. Further, with the exception of the clock drawing task in the Qmci, scores derived from both measures are based on auditory-verbal tasks. This
potentially resulted in the exclusion of individuals with auditory-verbal deficits, including hearing loss. Many studies focused on hearing and/or memory assessment have used the MoCA or MMSE to describe participants’ cognitive status (Lim & Loo, 2018; Lin et al., 2013); however, these cognitive screening measures include non-verbal tasks. Therefore, while measures were in place to promote the audibility and intelligibility of all stimuli presented in the investigation, it is possible that the cognitive screening tools used screened out participants with hearing difficulties who would have added valuable information to the study.

Furthermore, potential participants may have been deterred from enrollment due to concerns about remote testing administration, which may have significantly affected the sample characteristics. Such concerns may have included a lack of comfort with technology and the platforms used (which may partially account for the relatively high level of comfort and familiarity with technology among those who agreed to participate), a preference for face-to-face interactions, limited accessibility to the technology required for participation, and concerns regarding data privacy and security. Extensive efforts were made to overcome these limitations in the recruitment process. Despite these concerns, remote administration allowed for participation by a more geographically diverse population than would have been feasible with in-person assessment, with data collected from multiple states and regions across the US.

**Presentation modality: Speech discrimination**

No effect of presentation modality (i.e., live versus recorded voice) on speech discrimination was found in the current investigation. This has important implications for remote assessments of memory and other cognitive domains, such as language. Live voice presentation has greater variability because factors such as stimulus clarity and timing are difficult to control. Research generally supports the use of recorded speech discrimination assessment (Carhart, 1946;
Mueller & Hornsby, 2020; Roeser & Clark, 2008) and it is thus preferable to present recorded stimuli, especially for assessment purposes. However, this remains an area of contention among audiologists, and many continue to use live voice presentation because they believe that it is easier, more flexible, and more efficient (Hornsby & Mueller, 2013; Mendel & Owen, 2011). Given the equivalent speech discrimination observed between presentation modalities and the known increased variability of live voice presentation, the findings of this study support the use of recorded materials for remote assessment purposes. Given the increasing use of telepractice, it is important that clinicians have reliable diagnostic tools that can be administered remotely. As a result of these findings, diagnostic tools that are carefully controlled and can be administered via the telephone or videoconferencing platforms may be developed for the benefit of clinicians and clients alike.

Compared to face-to-face assessment, remote assessment offers both advantages and disadvantages. One such advantage is improved accessibility to care. Receipt of face-to-face services may be limited for certain individuals due to many factors, including lack of access to transportation, geographic limitations (i.e., living in a rural area with no specialist nearby), health and mobility restrictions, and scheduling conflicts, among others. However, participation requires access to technology, such as a telephone or computer or tablet with internet and camera capabilities, along with the knowledge and skills to use these devices. In this investigation, many individuals who were willing to participate in the telephone portion of the investigation did not feel comfortable or confident in their ability to participate in the videoconferencing session.

Another challenge presented by telepractice is the ability to ensure valid and reliable assessment results. Certain assessments have timing constraints and can thus only be given in a recorded format, such as working memory measures and measures of processing speed. One
specific example is the n-back task, a continuous recognition working memory measure in which participants judge whether each item in a sequence matches the stimulus presented $n$ items ago. Results from this investigation support the use of recorded tools, indicating that the remote use of recorded measures such as processing speed and n-back tasks is feasible.

**Self-reported hearing ability**

This investigation used three measures of self-reported hearing ability to classify individuals as having or not having hearing loss. Data from each of these measures were compared with participants’ live voice speech discrimination performance, CVLT3 scores, and cognitive screening scores to test the hypotheses that self-reported hearing ability would be positively correlated with scores on these measures.

**Self-reported hearing and live voice speech discrimination**

In the current investigation, the results failed to reveal a significant association between participants’ self-reported hearing abilities and live voice speech discrimination scores, providing no support for the hypothesis of a positive correlation between the two variables. There are multiple potential explanations for these findings. First, assuming participants accurately self-reported their hearing abilities and that the self-report tools accurately classified individuals as having or not having hearing loss, the measure used to assess live voice speech discrimination may have lacked sensitivity sufficient to detect hearing loss. It is plausible that the sensitivity of the measures used in this investigation would be limited given that speech discrimination is just one of many tools used to assess an individual’s hearing acuity in a comprehensive audiometric assessment.

Alternatively, if it is assumed that the measure of live voice speech discrimination was sufficiently sensitive to accurately detect hearing loss, the measures of self-reported hearing ability
used in this investigation may not have accurately identified those with hearing difficulties. This scenario is especially likely if several participants had mild hearing loss, as self-report tools have poorer sensitivity to mild hearing loss compared to moderate to severe hearing loss (Feltner et al., 2021).

It is also possible that some participants had unrecognized hearing loss, such that while they objectively had difficulty with speech discrimination, they were unaware of their difficulty and therefore did not report having trouble on measures of self-reported hearing ability. In a recent study, approximately 23% of the sample had unrecognized hearing loss (De Iorio et al., 2019). Therefore, it is reasonable to estimate that as many as 13 to 14 participants in this investigation did not self-report hearing loss despite having hearing difficulties. Alternatively, it is estimated that approximately 12% of individuals self-report hearing difficulties despite having normal audiometric thresholds (Tremblay et al., 2016), which suggests that seven to eight participants in this investigation may have fallen into this category. A review of the literature does not yield specific standards for classifying individuals as having or not having self-reported hearing loss or hearing loss based on speech discrimination performance. Therefore, it is not possible to categorize the participants in this study into the four categories of hearing loss discussed in the introduction (Table 2.1). However, it is important to note that unrecognized hearing loss and self-reported hearing loss potentially account for the finding that speech discrimination was not significantly correlated with self-reported hearing ability. Further research exploring the hearing and cognitive skills of individuals with unrecognized and self-reported hearing loss is warranted.

In summary, the finding that live voice speech discrimination was not significantly correlated with self-reported hearing ability suggests that either the live voice speech discrimination or self-reported hearing ability measures used in this investigation were not
sufficiently sensitive to accurately identify individuals with hearing difficulties. Additionally, some participants may have had unrecognized hearing loss and, as a result, may not have self-reported hearing difficulties despite poor performance in live voice speech discrimination.

**Self-reported hearing and memory performance**

The three measures of self-reported hearing ability were also not significantly correlated with participants’ CVLT3 index scores, nor their yes/no recognition scaled scores, despite the prediction that individuals with self-reported hearing difficulties would perform significantly worse on the CVLT3 compared to those without self-reported hearing difficulties. These findings contradict those reported by Amieva et al. (2015), who found a relationship between self-reported hearing ability and cognitive decline. These investigators used secondary data analysis to explore the relationship between self-reported hearing loss and cognition, measured using a single-item questionnaire and the MMSE, respectively. The positive finding of a relationship between self-reported hearing ability and cognition by these authors may be attributable to an older sample population including individuals ages 65 and older, in contrast to the younger sample population in the current investigation. The MMSE also assesses different aspects of cognition compared to the CVLT3, which could further explain this discrepancy.

Limitations associated with live voice speech discrimination may also apply to the CVLT3 in that it is also possible that the CVLT3 was not sensitive or comprehensive enough to capture a significant difference in memory among individuals with and without self-reported hearing loss, assuming the measures of self-reported hearing ability accurately classified individuals. Investigations exploring the relationship between hearing and cognition have used a battery of verbal and non-verbal neuropsychological tests (Jayakody et al., 2018; Lin et al, 2011; Merten et al., 2020; Ray et al., 2018; Wong et al., 2019). Their cognitive batteries have commonly included
measures such as the MMSE, trail making, verbal fluency, visuospatial memory, and processing speed tasks, as well as various adult reading tests. However, given that this assessment was conducted via Zoom, it was necessary to use the CVLT3 because this list learning task allowed the investigator to ensure that participants were not writing down items that were to be remembered.

In addition to the potential impact that characteristics of the CVLT3 had on the results of this investigation, limitations in the tools used to measure self-reported hearing ability may have also contributed to the findings. As previously discussed, some participants may have had unrecognized hearing loss resulting in a failure to accurately self-report their hearing abilities. As such, it is possible that the self-report measures were not sensitive enough to accurately identify individuals with hearing loss.

Finally, it is possible that the relatively young age of the cohort prevented the detection of a relationship between hearing and cognition. There is recent evidence that the relationship between hearing and cognition is weak in midlife, between ages 45 to 64 (Merten et al., 2020). Consistent with this investigation, numerous other published explorations of the relationship between hearing and cognition have included midlife-age participants (De Iorio et al., 2019; Lim & Loo, 2018; Wong et al., 2019). Nevertheless, potential interactions between age and cognitive test selection may have impacted results of this study. The addition of a perceptual processing speed task may have been particularly useful to this end, as longitudinal data have revealed this cognitive skill to be dynamic across the entire adult lifespan (Merten et al., 2020). As such, midlife-age participants with and without hearing loss in this cohort may have had more readily identifiable differences in performance on perceptual processing speed tasks, had they been administered; this speculation requires further investigation.
**Self-reported hearing and cognitive screener scores**

Similar to the findings from the CVLT3, participants’ self-reported hearing abilities were not significantly associated with T-MoCA or Qmcı scores. Qualitatively, it was noted that participants often missed similar items on the cognitive screeners. For example, on the T-MoCA, participants faced the greatest difficulty with was the delayed recall task, while on the Qmcı, participants struggled with the delayed recall task and the immediate story retell task. Performance on certain portions of the cognitive screeners may have not strongly correlated with participants’ self-reported hearing ability, which may explain the lack of a significant correlation between T-MoCA and Qmcı total scores and self-reported hearing ability. While significant correlations between hearing loss and cognitive screeners have been published in other studies (Amieva et al., 2015; Lim & Loo, 2018; Lin et al., 2011), these cognitive measures included both auditory-verbal and non-verbal measures. However, the T-MoCA exclusively uses auditory-verbal tasks and as described above, the Qmcı is almost entirely auditory-verbal as well. The limitations of remote assessment, specifically the exclusive use of auditory-verbal tasks, may partially explain why the findings from this investigation stand in contrast to other investigations.

**Speech discrimination and memory**

Interestingly, there was also no significant correlation between live voice speech discrimination performance and CVLT3 index scores, a finding for which there are several potential explanations. First, the mean CVLT3 index score was slightly above average at 106.22. It is possible that relatively high memory skills among the sample and/or a lack of heterogeneity of scores reduced the strength of the association between memory and speech discrimination skills. It is also possible that the cognitive constructs assessed by the CVLT3, which include free and
cued immediate and delayed recall, as well as yes/no recognition, are not the constructs associated with hearing difficulties.

Similarly, participants’ speech discrimination skills may not have been variable enough to capture an association between speech discrimination and memory performance, assuming such a relationship exists. Because a non-standardized measure was used to remotely assess speech discrimination out of necessity, there is no validated point of reference for comparison, making it difficult to ascertain whether this sample’s speech discrimination scores were representative of the general population. Of note, participants’ speech discrimination scores are comparable to results obtained from a face-to-face investigation conducted by Mendel and Owen (2011) that included individuals with and without hearing loss. Overall, memory and/or speech discrimination skills among participants may have been too homogenous to identify an association between these two factors. While limited conclusions can be drawn from speech discrimination data because the measure was given in a non-standardized manner, including this tool in this investigation was important to answer the empirical question of whether individuals perform significantly differently in live versus recorded voice presentation conditions.

Anecdotally, the current investigation was initially planned to include more in-depth measures of speech discrimination; however, due to COVID-19, the investigation was modified to allow for remote data collection. The study was originally intended to emphasize speech discrimination to a larger extent and included tasks of varying levels of difficulty that may have been more sensitive to hearing loss. However, a prerequisite for conducting this type of study is establishing equivalent speech discrimination performance between a recorded voice condition and a live voice condition. While this investigation was successful in this regard, doing so allowed less time for more complex and detailed measures of speech discrimination.
Implications for remote assessment and aural rehabilitation

Results from this investigation provide valuable information for clinicians conducting remote assessment via telepractice, which has been recognized by the Centers for Disease Control and Prevention as an important trend in healthcare ([CDC], Demeke et al., 2021). The finding that speech discrimination performance did not differ significantly in live versus recorded voice presentation conditions supports the use of audio-recorded materials for remote assessment and indicates that speech intelligibility is not significantly reduced when recordings are used. Advantages for clinicians include improved control of stimulus timing and clarity with the use of recorded tools, as well as the ability to remotely administer tasks that must be given in a recorded format, such as the n-back task described above. Additionally, the ability to assess individuals’ progress using recorded tools increases the reliability of results obtained through ongoing assessment, which is essential to ensure interventions are effective.

While this investigation did not demonstrate significant associations between measures of self-reported hearing ability, speech discrimination, and memory, it did reveal benefits and limitations in telepractice, and specific obstacles clinicians should expect when providing care remotely. The benefits of remote assessment included the ease in which schedules could be accommodated and the ability to virtually meet with individuals without geographic limitations. Prior to initiating assessment tasks, the use of a speech audibility and intelligibility task ensured that participants had auditory access to spoken language. While this approach is commonly used by auditory-verbal therapists to confirm proper functioning of a client’s hearing technology, clinicians should strongly consider speech audibility and intelligibility checks prior to conducting remote assessment, regardless of a client’s hearing acuity. Audio quality is widely recognized in the literature to potentially impact the results obtained through telehealth interactions (Loh et al.,
A barrier to telepractice observed throughout this investigation was the inability to directly control participants’ acoustic environments. Also, the stability of telephone and internet connections is another factor that must be considered when providing telepractice services. However, there was no need to stop administering any tasks because of background noise or interruption, all subjects continuously participated without loss of telephone or internet connection, and participants remained attentive to tasks, all of which provide evidence that the results of this investigation are valid.

It should be noted that the oldest participant in the study received the lowest score on live and recorded voice speech discrimination, the CVLT3, T-MoCA, and Qmci among the entire sample. Despite poor speech discrimination performance, this person reported having ‘a little trouble’ hearing, which is suggestive of unrecognized hearing loss, as discussed above. Notably, this individual also performed poorly on the cognitive measures included in the investigation. While this participant represents a very small portion of the sample, this cognitive and hearing profile could represent a considerable number of people when considering a larger population. Individuals with poor speech discrimination skills and difficulty with cognitive tasks who also have unrecognized hearing loss comprise an important group to target for interventions.

**Limitations**

Despite the general influence of background noise that could affect any remote assessment, procedures were used to control the timing and clarity of stimulus presentation and the acoustic environment as closely as possible, providing confidence in the validity of the results. First, a visual cue for voice onset was used to control presentation rate for consistency across participants and a sound-level meter was used during the presentation of live and recorded voice materials to maintain intensity within the range of typical conversational speech. Secondly, because this study
incorporated remote data collection, measures had to be feasibly administered through virtual platforms to be included in this investigation. Had a typical comprehensive hearing assessment been administered in this investigation, the correlations between pure-tone averages and remote speech discrimination performance, CVLT3 scores, and self-reported hearing ability could have been explored. Finally, although a sample size calculation was completed to ensure adequate power for this analysis, it is still possible that results were limited by the relatively small sample size for this investigation. Further, the remote nature of this study may have deterred individuals from participating who would have agreed to if the data had been collected in a face-to-face setting, possibly introducing a sampling bias.

**Future directions**

Upon interpretation of these results, multiple areas require further investigation. First, the lack of a significant difference in speech discrimination performance in live versus recorded voice presentation modalities presents numerous research opportunities. Specifically, the strength of association between hearing ability and cognitive performance on various tasks such as working memory, processing speed, and inhibition, could be further explored exclusively with audio-recorded stimuli. This is especially relevant given the qualitative observation that delayed recall tasks on the cognitive screeners were the most commonly missed items among participants. Additionally, since lexical and semantic factors likely contributed to speech discrimination performance, further analyses could explore the effects of these factors on speech discrimination during remote assessment. Regarding the finding that self-reported hearing ability was not significantly correlated with memory performance in remote assessment, future studies should be conducted to identify assessments that are both sensitive enough to detect any association between these factors and that could feasibly be administered via telepractice.
Regarding telepractice, it would be interesting to explore the relationship between pure-tone air conduction hearing thresholds and performance on a variety of remotely administered, verbal and non-verbal cognitive assessments to examine whether the relationship between hearing and cognition persists when cognitive assessment is conducted remotely. It is also important for future investigations to explore strategies speech-language pathologists can use to help people feel more comfortable and confident with telepractice. Specifically, it is important to explore factors that facilitate successful telepractice experiences, barriers to this service delivery approach, and strategies to address these barriers. Finally, given that hearing loss has been identified as a potentially modifiable risk factor associated with accelerated cognitive decline (Lin et al., 2011; Loughrey et al., 2018), further investigations exploring the efficacy of auditory-brain based interventions with hearing loss are imperative, in both face-to-face and virtual settings.

Conclusions

In conclusion, given the recent increased utilization of telepractice for aural rehabilitation, this dissertation explored hearing and other factors potentially influencing performance in remote assessment. Specifically, this investigation examined the relationships between self-reported hearing ability, speech discrimination, and memory performance in remote assessment. Salient results from this investigation include the finding that participants did not demonstrate a significant difference in live versus recorded voice speech discrimination performance in telephone assessment, which supports the use of audio-recorded tools in remote assessment and consequently increases the variety of tasks appropriate for telepractice. Additionally, in contrast to evidence obtained from face-to-face studies, this investigation failed to reveal a significant association between self-reported hearing ability and memory performance in remote assessment. It is clear that in addition to providing valuable information for clinicians to implement into their own
clinical practices, the results from this investigation also generated multiple directions for future research.
### APPENDIX A

**NON-COMPUTERIZED, CLINICIAN DIRECTED AURAL REHABILITATION AND AUDITORY TRAINING PROGRAMS**

<table>
<thead>
<tr>
<th>Program</th>
<th>Evidence-based citation; Developer</th>
<th>Target Population</th>
<th>Type of Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHATS: The Miami Cochlear Implant, Auditory and Tactile Skills Curriculum</td>
<td>Vergara, Mikel, &amp; Miami (1994); Intelligent Hearing Systems</td>
<td>For children who use cochlear implants (CIh)</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>TeenTrain, Auditrain</td>
<td>Geoff Plant; Med-El</td>
<td>CI users</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>The Developmental Approach to Successful Listening II (DASL II)</td>
<td>Stout &amp; Van Dert Windle (1992); Cochlear Ltd.</td>
<td>For children</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>SKI-HI Curriculum</td>
<td>Watkins, Taylor, &amp; Pittman (2004); Hope Inc.</td>
<td>For children with hearing loss (HL)</td>
<td>✓</td>
</tr>
<tr>
<td>Learn to Talk Around the Clock</td>
<td>Rossi (2006); Distributed by AG Bell</td>
<td>For use with parents of children with HL</td>
<td>✓</td>
</tr>
<tr>
<td>SPICE (Speech Perception Instructional Curriculum Evaluation)</td>
<td>Anderson; Central Institute for the Deaf</td>
<td>For children with HL; Hearing aid (HA) users; CI users</td>
<td>✓ ✓</td>
</tr>
</tbody>
</table>
## APPENDIX B

### COMPUTERIZED, HOME-BASED AURAL REHABILITATION AND AUDITORY TRAINING PROGRAMS

<table>
<thead>
<tr>
<th>Computerized, Home-Based Aural Rehabilitation and Auditory Training Programs</th>
<th>Type of Program</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Program</strong></td>
<td><strong>Evidence-based citation; Developer</strong></td>
</tr>
<tr>
<td>Angel Sound (originally from Computer Assisted Speech Training; CAST)</td>
<td>Fu, Galvin, Wang, &amp; Nogaki (2004); TigerSpeech Technology Inc., Emily Fu Foundation</td>
</tr>
<tr>
<td>Customized Learning Exercises for Aural Rehab (cLEARN™)*</td>
<td>Barcroft et al. (2011); cLEARN Ears Train the Brain</td>
</tr>
<tr>
<td>Listening and Communication Enhancement (LACE™)</td>
<td>Sweetow and Sabes (2006); Neuretix</td>
</tr>
<tr>
<td>Brain Fitness™</td>
<td>Smith et al. (2009); Posit Science</td>
</tr>
<tr>
<td>cAReza</td>
<td>Internal studies only; Siemens</td>
</tr>
<tr>
<td>Hear at Home</td>
<td>Geoff Plant; Med-El</td>
</tr>
<tr>
<td>Listening Up! Training for beginners and advanced listeners</td>
<td>Vanessa Hoffman; Med-El</td>
</tr>
<tr>
<td>Otto’s World of Sounds</td>
<td>Oticon</td>
</tr>
<tr>
<td>Read My Quips™</td>
<td>Levitt, Oden, Simon, Noack, &amp; Lotze (2011); Sense Synergy</td>
</tr>
<tr>
<td>Seeing and Hearing Speech</td>
<td>Richie, Kewley-Port, &amp; Coughlin (2005); Sensimetrix</td>
</tr>
<tr>
<td>SoundScape</td>
<td>Med-El</td>
</tr>
<tr>
<td>Sound and Way Beyond</td>
<td>Cochlear Ltd.</td>
</tr>
<tr>
<td>The Communication Corner</td>
<td>Cochlear Ltd.</td>
</tr>
</tbody>
</table>

*Note: cLEARN™ was formerly called I Hear What You Mean*
## APPENDIX C

### COMPUTERIZED, CLINICIAN DIRECTED AURAL REHABILITATION AND AUDITORY TRAINING PROGRAMS

<table>
<thead>
<tr>
<th>Program</th>
<th>Evidence-based citation; Developer</th>
<th>Target Population</th>
<th>Type of Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Clix</td>
<td>Internal studies only; Advanced Bionics</td>
<td>CI users</td>
<td>Analytic; Synthetic; Auditory-Cognitive</td>
</tr>
<tr>
<td>Computer Assisted Speech Perception Sentences (CasperSent)</td>
<td>Mackersie, Boothroyd, &amp; Minniear (2001); Boothroyd and Gallaudet University Rehabilitation Engineering and Research Center</td>
<td>For people with HL</td>
<td>✓</td>
</tr>
<tr>
<td>Eurobics</td>
<td>Diehl (1999); Ingvallson, Young, &amp; Wong (2014); Cognitive Concepts, Inc., 1996</td>
<td>CI users *Children with reading difficulty</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>Fast ForWord</td>
<td>Scientific Learning Corporation, 1999</td>
<td>*Children with reading difficulty</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>KidTrax, TeenTrax, and SpeechTrax</td>
<td>Plant, Bernstein, &amp; Levitt (2015); Med-El</td>
<td>For people with HL</td>
<td></td>
</tr>
<tr>
<td>Kungliga Tekniska Högskolan (KTH) Speech Tracking</td>
<td>Bernstein et al. (2012); Levitt and Oden/Advanced Hearing Concepts and Geoff Plant/Med-EL</td>
<td>For people with HL</td>
<td>✓</td>
</tr>
<tr>
<td>Speech Perception Assessment and Training System for the Hearing Impaired (SPATS-HI)</td>
<td>Miller et al. (2007); Communication Disorders Technology, Inc.</td>
<td>HA users; CI users</td>
<td>✓ ✓</td>
</tr>
</tbody>
</table>

*Note: Eurobics and Fast ForWord are auditory-based phonological awareness interventions for children. These programs were designed target auditory processing skills with the goal of improving literacy skills. These programs are included on the “clinician directed” chart because a clinician, teacher, or other adult would be needed to supervise a child’s participation in training.*
APPENDIX D: AUDIBILITY AND SPEECH INTELLIGIBILITY CHECK

The examiner will say, “Hi, thank you for joining me today. Before we get started, I want to make sure that you are able to hear me. I would like for you to put your telephone on speaker or use headphones, if you have them. Which would you prefer? (if participant indicates a preference for headphone use, wait for them to retrieve headphones and plug them in; otherwise wait for participant to set phone to speaker). Next, the examiner will say, “please make sure that you are in a quiet room without background noise, such as the TV (pause to allow participant time to reduce or eliminate environmental distractors). Is your computer/tablet/phone at a comfortable volume for you right now? (wait for the participant to provide confirmation). I want to make sure you can hear me. Please repeat after me. Birthday, sidewalk, hardware, airplane.”

If the participant indicates that they cannot hear the examiner’s voice, the examiner should say, “okay, please turn your volume up to at least 75%. (wait for participant to adjust volume). I want to make sure you can hear me. Please repeat after me again. Baseball, armchair, mousetrap, pancake.”

If the participant indicates that they still cannot hear the examiner’s voice, the examiner should say, “okay, please turn your volume all the way up. (wait for participant to adjust volume). I want to make sure you can hear me. Please repeat after me again. Eardrum, oatmeal, toothbrush, sunset.”

When the participant confirms audibility and intelligibility of speech presented by the examiner (up to maximum device volume), the examiner will say, “now that we have confirmed that you are able to hear, please do not adjust the volume on your device during our time together today.”
The examiner will provide a single repetition of the information at each volume level (i.e., comfortable listening level, ~75% volume, and up to 100% volume) if the examinee requests a repetition. If the examinee cannot accurately repeat 4/4 words at the self-selected comfortable volume, provide a repetition of the four trial words. If the participant is unable to accurately repeat 4/4 words after the second presentation at the self-selected comfortable volume, follow the procedure to conduct an audibility and speech intelligibility check at approximately 75% volume and repeat the procedure at 100% volume, if needed. After a repetition of the four words at 100% volume, if the participant is unable to accurately repeat 4/4 words the examiner should discontinue the administration of the videoconferencing session explain that the session requires the participant to have the ability to hear the examiner.

*Note: The audibility and speech intelligibility check procedure described above will be repeated to ensure audibility and speech intelligibility in the Zoom session.
APPENDIX E: INTAKE FORM

The examiner will say, “I am going to ask you some questions about yourself— for example, this information will help me describe directions for future studies.” (Repetitions allowed)

Age: __________

Gender:
   ____ Male
   ____ Female

Race:
   ____ African American
   ____ American Indian or Alaska Native
   ____ Asian
   ____ Pacific Islander
   ____ White
   ____ Other

Ethnicity:
   ____ Hispanic or Latino
   ____ Not Hispanic or Latino

Education:
   ____ High School
   ____ Some college
   ____ Associate’s degree
   ____ Bachelor’s degree
   ____ Graduate degree

The examiner will say, “I am going to ask you about your medical and learning history as well as your vision. This information will also help me describe directions for future studies.”

(Repetitions allowed)

Do you have a history of neurological injury affecting your brain, such as a brain injury or stroke? Yes  No
   If yes, please explain: ______________________________

Do you have a learning disability? Yes  No
   If yes, please explain: ______________________________

Do you have any difficulty with your vision? Yes  No
   If yes, please explain: ______________________________
APPENDIX F: TELEPHONE MONTREAL COGNITIVE ASSESSMENT (T-MOCA)

The examiner will say, “I am going to ask you some questions that require concentration. Some of them are easy and some of them are more difficult. I just want you to do your best. If you can’t hear me or you need anything clarified, please ask me.” One repetition of instructions is permitted for each task unless noted otherwise in administration instructions below.

Memory: The examiner will say, “This is a memory test. I am going to read a list of words that you will have to remember now and later on. Listen carefully. When I am through, tell me as many words as you can remember. It doesn’t matter in what order you say them.” The examiner will then read a list of five words (leg, cotton, school, tomato, white) at a rate of one word per second. When the examinee indicates that he/she is finished (has recalled all words), or can recall no more words, the examiner will say, “I am going to read the same list for a second time. Try to remember and tell me as many words as you can, including words you said the first time.” Then the examiner will read the list a second time regardless of examinee’s accuracy on trial one and the examinee will be asked to recall the word list immediately. At the end of the second trial, the examiner will say, “I will ask you to recall those words again at the end of the test.” Repetitions of the five-word list are not permitted.

Attention:

- Forward digit span: The examiner will say, “I am going to say some numbers and when I am through, repeat them to me exactly as I said them.” The examiner will read the five-number sequence at a rate of one digit per second. Repetitions of five-digit sequence is not permitted.
- Backward digit span: The examiner will say, “Now I am going to say some more numbers, but when I am through you must repeat them to me in the backwards order.” The examiner
will read the three-number sequence at a rate of one digit per second. Repetition of the three-number sequence is not permitted.

- **Vigilance**: The examiner will say, “I am going to read a sequence of letters. Every time I say the letter A, tap with pencil or pen on the side of your computer. If I say a different letter, do not tap.” Repetition of the letter sequence is not permitted.

- **Serial 7s**: The examiner will say, “Now I will ask you to count by subtracting seven from 60, and then, keep subtracting seven from your answer until I tell you to stop.” The examiner should repeat the instructions one time if necessary. The examiner may not repeat the examinee’s answers. If the participant asks what her/his last given answer was or what number (s)he must subtract from his/her answer, the examiner should respond by repeating the instructions if not already done so. The examiner should stop the examinee once he/she has subtracted five numbers from 60 (regardless of accuracy).

**Language**

- **Sentence repetition**: The examiner will say, “I am going to read you a sentence. Repeat it after me, exactly as I say it (pause). The child walked his dog in the park after midnight.” Following the examinee’s response, the examiner will say, “Now I am going to read you another sentence. Repeat it after me, exactly as I say it (pause). The artist finished his painting at the right moment for the exhibition.” Repetitions of stimuli are not permitted.

- **Verbal fluency**: The examiner will say, “Now I want you to tell me as many as words as you can think of that begin with the letter B. I will tell you to stop after one minute. Proper nouns, numbers, and different forms of a verb are not permitted. Are you ready?” (pause) (time for 60 seconds) “stop.” If the examinee names two consecutive words that begin with
another letter of the alphabet, the examiner repeats the target letter if the instructions have not been repeated one time already.

**Abstraction:** The examiner will say, “I will give you two words and I would like you to tell me to what category they belong to (pause). An orange and a banana.”

- If the examinee responds correctly, the examiner will reply, “yes, both items are part of the category fruits.”
- If the examiner responds in a concrete manner, the examiner will give one additional prompt, “tell me another category to which these items belong.”
- If the examinee does not give the appropriate response (i.e., fruits), the examiner says, “yes, and they also belong to the category fruits.”

After the practice trial, the examiner will say, “now a hammer and a screwdriver.” Following the examinee’s response, the examiner will administer a second trial by saying, “Now, matches and a lamp.” One prompt (for the entire abstraction section) may be given if none was used during the practice trial.

**Delayed recall:** The examiner will say, “I read some words to you earlier, which I asked you to remember. Tell me as many of those words as you can remember.”

**Orientation**

- **Date:** The examiner will say, “Tell me today’s date, day of the week, month, and year.”
- **Place:** The examiner will say, “What institution am I calling you from?”
- **City:** The examiner will say, “What is the city in which our institution is located?”
APPENDIX G: NU-6 ORDERED BY DIFFICULTY (VERSION II) SHORT INTERVAL

The examiner will say, “you will be hearing my voice or a recording of a man’s voice saying some single-syllable words. I want you to repeat back the words that you hear. Some of the words may be difficult for you to hear. If you’re not sure what the word is, take a guess.”

(Repetitions not allowed)

List 2 and List 4 are provided below

<table>
<thead>
<tr>
<th>NU 6 List 2</th>
<th>NU 6 List 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gin</td>
<td>Yearn</td>
</tr>
<tr>
<td>Pike</td>
<td>Perch</td>
</tr>
<tr>
<td>Keg</td>
<td>Fit</td>
</tr>
<tr>
<td>Pick</td>
<td>Pass</td>
</tr>
<tr>
<td>Keep</td>
<td>Shirt</td>
</tr>
<tr>
<td>Turn</td>
<td>Ripe</td>
</tr>
<tr>
<td>Dab</td>
<td>Came</td>
</tr>
<tr>
<td>Gaze</td>
<td>Peg</td>
</tr>
<tr>
<td>Learn</td>
<td>Tape</td>
</tr>
<tr>
<td>Ton</td>
<td>Kick</td>
</tr>
<tr>
<td>Shack</td>
<td>Neat</td>
</tr>
<tr>
<td>Pad</td>
<td>Lease</td>
</tr>
<tr>
<td>Mill</td>
<td>Bath</td>
</tr>
<tr>
<td>Thought</td>
<td>Back</td>
</tr>
<tr>
<td>Nice</td>
<td>Gas</td>
</tr>
<tr>
<td>Wag</td>
<td>Check</td>
</tr>
<tr>
<td>Rot</td>
<td>Thumb</td>
</tr>
<tr>
<td>Match</td>
<td>Wash</td>
</tr>
<tr>
<td>Said</td>
<td>Join</td>
</tr>
<tr>
<td>Chief</td>
<td>Judge</td>
</tr>
<tr>
<td>Lore</td>
<td>Should</td>
</tr>
<tr>
<td>Bought</td>
<td>Make</td>
</tr>
<tr>
<td>Dead</td>
<td>Long</td>
</tr>
<tr>
<td>Shawl</td>
<td>Such</td>
</tr>
<tr>
<td>Calm</td>
<td>Wife</td>
</tr>
</tbody>
</table>
APPENDIX H: TALSA SPEECH DISCRIMINATION TASK

Stimuli for this task consist of 20 word and 20 nonword pairs. Each set of words has 10 pairs with the same two items and 10 pairs with different items. All words are concrete and low in frequency.
APPENDIX I: GENERAL QUESTIONNAIRE

Vision Screening

Examiner will say: “I am going to show you some numbers on the screen. I am showing you these numbers because I am going to show you some pictures and patterns during the Zoom session today and I want to make sure you can see images on my screen. Please read these numbers aloud to me.” The examiner will present the following list of numbers on the screen. To do so, numbers will be printed in size 16 Times New Roman Font on a blank piece of white paper. The participant will be given as much time as needed to provide a response. Any error on the vision screening will result in a failed screening.

7  3  2  9  6

Level of comfort using videoconferencing platform

The examiner will say, “next I am going to ask you some questions about your familiarity and comfort with technology.” (Repetitions allowed)

• How comfortable are you feeling right now using Zoom with me on a scale from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable? __________

• Approximately how many hours per week do you spend on the computer? _________

• Does or did your job require you to use a computer regularly? Yes No

• Have you ever had an appointment with a healthcare professional over the telephone or videoconferencing? Yes No

  o If yes, how would you rate the experience on a scale from 1-10 (1 being lowest/most negative rating and 10 being the highest/most positive rating)? __________

  o If no, would you consider receiving this type of healthcare in the future? Yes No
Questionnaire regarding comfort and familiarity with Zoom

The examiner will say, “please respond to the following statements by providing a number on a scale from 1 to 5. Number one indicates strongly disagree and number five indicates strongly agree.” (Repetitions allowed)

Response options:

<table>
<thead>
<tr>
<th>Strongly disagree (1)</th>
<th>Disagree (2)</th>
<th>Neutral (3)</th>
<th>Agree (4)</th>
<th>Strongly agree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>o I feel comfortable using Zoom on my own. ________</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o I have a positive attitude toward using Zoom. ________</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o I have experience using Zoom ______</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o I am comfortable using Zoom ______</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The examiner will say, “now I am going to ask you about your hearing.” (If participant requests a repetition, the question can be repeated two times. If the patient is unable to respond to the question after three presentations, the participant will be excluded from the investigation).

Self-reported hearing status
Which statement best describes your hearing (without a hearing aid or other listening device)?

_____ Excellent
_____ Good
_____ A little trouble
_____ Moderate trouble
_____ A lot of trouble
_____ Deaf

Do you use hearing technology?  Yes  No
If participant indicates ‘yes,’ explain that hearing aid use is exclusionary criteria.

Mask Use:
Do feel that mask use has affected your ability to understand others?  Yes  No

Which statement best describes your ability to understand people who are wearing masks?

_____ No change from normal
_____ Mildly harder to understand
_____ Moderately harder to understand
_____ Significantly harder to understand
APPENDIX J: HEARING HANDICAP INVENTORY—SCREENING QUESTIONNAIRES

The examiner will say, “I am going to read some questions aloud. You will also see the question on your screen. Please answer ‘yes,’ ‘no,’ or ‘sometimes’ for each question.”

Hearing Handicap Inventory in the Elderly—Screening Questionnaire

*This tool will be administered to participants ≥ 60 years old.

1. Does a hearing problem cause you to feel embarrassed when you meet new people?
2. Does a hearing problem cause you to feel frustrated when talking to members of your family?
3. Do you have difficulty hearing when someone speaks in a whisper?
4. Do you feel handicapped by a hearing problem?
5. Does a hearing problem cause you difficulty when visiting friends, relatives, or neighbors?
6. Does a hearing problem cause you to attend religious services less often than you would like?
7. Does a hearing problem cause you to have arguments with family members?
8. Does a hearing problem cause you difficulty when listening to TV or radio?
9. Do you feel that any difficulty with your hearing limits or hampers your personal or social life?
10. Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?

Hearing Handicap Inventory for Adults—Screening Questionnaire

*This tool will be administered to participants < 60 years old.

1. Does a hearing problem cause you to feel embarrassed when you meet new people?
2. Does a hearing problem cause you to feel frustrated when talking to members of your family?
3. Do you have difficulty hearing / understanding co-workers, clients, or customers?
4. Do you feel handicapped by a hearing problem?
5. Does a hearing problem cause you difficulty when visiting friends, relatives, or neighbors?
6. Does a hearing problem cause you difficulty in the movies or in the theater?
7. Does a hearing problem cause you to have arguments with family members?
8. Does a hearing problem cause you difficulty when listening to TV or radio?
9. Do you feel that any difficulty with your hearing limits or hampers your personal or social life?
10. Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?

**Scoring Procedure**

The same scoring procedure will be used for both questionnaires:

- ‘No’ responses will be assigned 0 points
- ‘Sometimes’ responses will be assigned 2 points
- ‘Yes’ responses will be assigned 4 points
- Points on the ten items will be totaled
  - Total scores between 0-8 indicate no hearing handicap
  - Total scores between 10-24 indicate mild-moderate hearing handicap
  - Total scores between 26-40 indicate severe handicap
APPENDIX K: HEARING SELF-ASSESSMENT QUESTIONNAIRE

The examiner will say, “I am going to read you some more questions aloud. You will also see these questions on your screen. This time, please answer ‘never,’ ‘rarely,’ ‘sometimes,’ ‘often,’ or ‘always’ for each question.”

1. Do you have difficulty understanding the speech of family members, friends, or acquaintances?
2. Do you have difficulty understanding the speech of people you do not know or are not close to?
3. Do you have difficulty following conversations in noisy environments, for example on the street, in a coffee shop, or while being in larger company?
4. Do you sometimes miss a part of TV or radio program, even if the volume is set to loud?
5. Do you have difficulty following telephone conversations?
6. Do you have difficulty understanding the speech of a person distant from you?
7. How often does your hearing bother or upset you?
8. How often do you avoid conversations or withdraw from them because of your hearing?
9. Does the way you hear both or upset the people talking to you?
10. Do people tell you that you might have a hearing problem?

Scoring Procedure

- ‘Never’ responses will be assigned 0 points
- ‘Rarely’ responses will be assigned 1 point
- ‘Sometimes’ responses will be assigned 2 points
- ‘Often’ responses will be assigned 3 points
- ‘Always’ responses will be assigned 4 points
• Points on the ten items will be totaled
  
  o A cut-off score of $\geq 15$ will be used to define hearing loss
APPENDIX L: CALIFORNIA VERBAL LEARNING TEST, THIRD EDITION (CVLT3)

<table>
<thead>
<tr>
<th>CVLT3 Brief Form Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning trial 1 followed by immediate recall</td>
</tr>
<tr>
<td>Learning trial 2 followed by immediate recall</td>
</tr>
<tr>
<td>Learning trial 3 followed by immediate recall</td>
</tr>
<tr>
<td>Learning trial 4 followed by immediate recall</td>
</tr>
<tr>
<td>30-second distractor task</td>
</tr>
<tr>
<td>Short delay free recall</td>
</tr>
<tr>
<td>10-minute delay</td>
</tr>
<tr>
<td>Long delay free recall</td>
</tr>
<tr>
<td>Long delay cued recall</td>
</tr>
<tr>
<td>Yes/No recognition</td>
</tr>
</tbody>
</table>

*Note. This is the structure that does not include the optional forced choice recognition task, which will not be included in this investigation.

Sample Scoring

The CVLT3 Brief Form utilizes a nine-word list. See sample data and scoring provided by the test publisher below each section (Delis et al., 2017).

Immediate Recall

The maximum possible raw score for each learning trial is nine (i.e., this would indicate that the participant recalled 9/9 words accurately). Participants receive a raw score for each of the four learning trials. Each raw score is converted to scaled score and percentile rank using normative data provided in the test manual. These four scores contribute to the participant’s immediate recall score.

<table>
<thead>
<tr>
<th>Immediate Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Score</strong></td>
</tr>
<tr>
<td>Trial 1 Correct</td>
</tr>
<tr>
<td>Trial 2 Correct</td>
</tr>
<tr>
<td>Trial 3 Correct</td>
</tr>
<tr>
<td>Trial 4 Correct</td>
</tr>
</tbody>
</table>
Delayed Recall

The maximum possible raw score for the short delay free recall, long delay free recall, and long delay cued recall tasks is also nine (i.e., this would indicate that the participant recalled 9/9 words correctly). Each raw score is converted to a scaled score and percentile rank using normative data provided in the test manual. These three scores contribute to the participant’s delayed recall score.

<table>
<thead>
<tr>
<th>Score</th>
<th>Raw score</th>
<th>Scaled score</th>
<th>Percentile rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Delay Free Recall Correct</td>
<td>8</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Long Delay Free Recall Correct</td>
<td>8</td>
<td>11</td>
<td>63</td>
</tr>
<tr>
<td>Long Delay Cued Recall Correct</td>
<td>9</td>
<td>13</td>
<td>84</td>
</tr>
</tbody>
</table>

Yes/No Recognition

The maximum possible raw score for the yes/no recognition task is also nine (i.e., this would indicate that the participant accurately recognized 9/9 words from the assessment). This raw score is converted to a scaled score and percentile rank using normative data provided in the test manual.

<table>
<thead>
<tr>
<th>Score</th>
<th>Raw score</th>
<th>Scaled score</th>
<th>Percentile rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hits</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Standard Score Summary

To calculate the standard score summary, the four scaled scores that compose the immediate recall section are added together and the three scaled scores that compose the delayed recall section are added together. Then, the sum of the seven total scaled scores from the immediate and delayed recall tasks are added. Each sum of scaled scores can be converted to an index score and percentile rank using normative data provided in the test manual.
### Standard Score Summary

<table>
<thead>
<tr>
<th>Index</th>
<th>Sum of scaled scores</th>
<th>Index score</th>
<th>Percentile rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trials 1–4 Correct</td>
<td>41</td>
<td>102</td>
<td>55</td>
</tr>
<tr>
<td>Delayed Recall Correct</td>
<td>34</td>
<td>108</td>
<td>70</td>
</tr>
<tr>
<td>Total Recall Correct</td>
<td>75</td>
<td>105</td>
<td>63</td>
</tr>
</tbody>
</table>
APPENDIX M: **QUICK MILD COGNITIVE IMPAIRMENT SCREEN (QMCI)**

The examiner will say, "I am going to ask you some questions that require concentration, some of them are easy and some of them are more difficult. I just want you to do your best. If you can't hear me or you need anything clarified, please ask me. Before we begin please get a white sheet of paper, a pencil, and an eraser." Once the examinee has retrieved these items, the examiner will begin the assessment. One repetition of instructions is permitted for each task unless noted otherwise in administration instructions below.

**Orientation**

- **Country:** The examiner will say, "what country is this?"
- **Year:** The examiner will say, "what year is it?"
- **Month:** The examiner will say, "what month is it?"
- **Date:** The examiner will say, "what is today’s date?"
- **Day of week:** The examiner will say, "day of the week is this?"

**Word Registration**

The examiner will say, "I am going to say 5 words. After I have said these 5 words, repeat them back to me. Are you ready?" (begin once participant indicates readiness): dog, rain, butter, love, door

**Clock Drawing**

The examiner will say, "Draw a clock. Put in all the numbers and set the time to 10 past 11."

**Delayed Recall**

The examiner will say, "A few minutes ago I named five words. Name as many of those words as you can remember."
Verbal Fluency

The examiner will say, “Name as many animals as you can in one minute. Ready? Go.”

Logical Memory

The examiner will say, “I am going to read you a short story. After I have finished reading, I want you to tell me as much of the story as you can. OK?” (once participant signifies agreement, then begin reading the paragraph at about 1 second for each word unit). “The red fox ran across the ploughed field. It was chased by a brown dog. It was a hot May morning. Fragrant blossoms were forming on the bushes.”
REFERENCES


Stahl, S. M. (2017). Does treating hearing loss prevent or slow the progress of dementia? Hearing is not all in the ears, but who’s listening? *CNS Spectrums, 22*(3), 247-250.


Yuan, J., Sun, Y., Sang, S., Pham, J. H., & Kong, W. J. (2018). The risk of cognitive impairment associated with hearing function in older adults: A pooled analysis of data from eleven studies. *Scientific Reports, 8*(1), 1-10.


ABSTRACT

HEARING AND OTHER FACTORS INFLUENCING MEMORY PERFORMANCE IN REMOTE ASSESSMENT

by

ERIKA SQUIRES

May 2022

Advisor: Dr. Margaret Greenwald

Major: Communication Sciences and Disorders

Degree: Doctor of Philosophy

With the revitalization of aural rehabilitation (AR) and increased use of telepractice services, there is a paucity of research examining factors that have the potential to affect remote assessment. An assessment of memory is commonly included in a comprehensive AR assessment because recently developed auditory-cognitive training programs include auditory-based cognitive activities, such as auditory memory tasks. This investigation explored the effect of presentation modality on speech discrimination performance and whether self-reported hearing ability correlated with remote memory assessment in older adults.

Older adults self-reported their hearing abilities and completed speech discrimination and memory tasks. Data were collected remotely via a telephone session and an optional videoconferencing session. Measures were taken to control the acoustic environment as well as the timing and clarity of stimulus presentation as closely as possible using telepractice. These measures included the use of a sound-level meter app, a speech audibility and intelligibility check, and voice onset cues to ensure consistent presentation timing.

A quantitative design was used to explore the associations between the primary outcome measures and a paired samples $t$-test was used to examine the effect of presentation modality on
speech discrimination. Self-reported hearing ability and remote speech discrimination were not significantly associated with memory performance. Additionally, measures of self-reported hearing ability and speech discrimination were not significantly correlated. Participant age, gender, and education level were not significantly correlated with any of the primary outcome measures. Speech discrimination did not differ significantly for live voice versus recorded voice.

The findings from this study support the use of audio-recorded stimuli for remote assessment, which increases the reliability of administration as well as the variety of tasks appropriate for telepractice. The lack of a significant association between self-reported hearing ability and memory performance conflicts with findings from research conducted face-to-face. Therefore, future investigations should explore potential reasons for this finding, as it could impact remote assessment strategies. Additional work is also needed to better understand factors that facilitate and serve as barriers to successful implementation of telepractice.
AUTOBIOGRAPHICAL STATEMENT

ERIKA SQUIRES

Erika Squires is a speech-language pathologist who earned her Bachelor of Applied Arts in Communication Disorders from Central Michigan University and her Master of Arts in Speech Language Pathology from the University of Toledo. Since obtaining her clinical certification, Erika has obtained clinical experience in private practice as well as inpatient rehabilitation and acute care settings. Additionally, she has supervised graduate students in the Wayne State University Speech Language Hearing Clinic. Erika has experience teaching at the undergraduate and graduate levels and has taught at Wayne State University as well as Eastern Michigan University.

Erika’s clinical, teaching, and research interests include aural rehabilitation, acquired cognitive-linguistic disorders, health communication, and interdisciplinary teaming. Erika has published articles in American Speech Language Hearing Association journals as well as journals focused on interdisciplinary training. Additionally, she has presented at numerous state and national conferences.