THE ASSOCIATION BETWEEN DEGREE OF HEARING LOSS AND DEPRESSION IN OLDER ADULTS

by

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Abstract

Hearing loss is one of the most prevalent chronic conditions that can affect quality of life among older adults. Evidence from large-scale health studies of self-reported hearing loss and depression documents a strong link between untreated hearing loss and depression in older adults (e.g.; National Council on the Aging, 2000). These studies also show that as self-reported severity of hearing loss increases, the prevalence of self-reported depression increases. However, research has yet to establish that this correlation does not simply represent the underlying response bias associated with self-ratings of hearing loss. If hearing loss contributes towards symptoms of depression, then it is vital that the relationship is understood so that the symptoms of each can be treated appropriately. The primary purpose of the current study was to investigate the relationship between hearing loss and depressive symptoms using objective measures of hearing, thereby removing the effects of self-report bias from estimates of hearing loss. Forty-five participants, who were not receiving treatment for hearing loss, aged 65 and older, were recruited from local geriatric clinics and public venues. Three measures were administered: i) objective measures of hearing: pure tone audiometry and otoacoustic emissions; ii) a subjective measure of hearing: the Hearing Handicap Inventory for the Elderly (HHIE); and iii) a self-assessment of depression: the Center for Epidemiological Studies Depression (CES-D) scale. Multiple regression analysis showed that there was a significant relationship between objectively measured hearing loss and depressive symptoms ($r^2 = 0.102$, $p<0.05$). Depressive symptoms increased with increasing severity of objective hearing loss, revealing a dose-response relationship between objective hearing loss and depressive symptoms. These findings suggest that hearing loss could be a modifiable contributor to depressive symptoms in older adults.

Preface

Chapters 2 and 3 are based on work conducted at UBC's School of Audiology and Speech Sciences by Dr. Lorienne Jenstad and Mary MacDonald. Participant recruitment was conducted in collaboration with the Geriatric Psychiatry Outreach Team and the Short-Term Assessment and Treatment (STAT) centre at Vancouver General Hospital (VGH) and the geriatric outpatient clinic at Saint Paul's Hospital. Mary MacDonald conducted participant recruitment from public venues and scheduled and conducted all test sessions. Mary MacDonald prepared all data for analysis with the assistance of research assistant Elissa Rondeau. Data analysis was carried out by Mary MacDonald under the supervision of Dr. Lorienne Jenstad. All sections of this thesis were written by Mary MacDonald.

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No part of this thesis has been submitted for publication yet. No sections of this thesis were written by the co-authors.

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List of Abbreviations

ARHL	Age-related hearing loss
OHC	Outer hair cell
NCOA	National Council on the Aging
ADL	Activities of daily living
MHI	Mental Health Index
HHIE	Hearing Handicap Inventory for the Elderly
GDS	Geriatric Depression Scale
WHO	World Health Organization
dB HL	Decibels hearing level
ASHA	American Speech-Language-Hearing Association
PTA	Pure-tone average
OAE	Otoacoustic emission
TEOAE	Transient-evoked otoacoustic emission
DPOAE	Distortion-product otoacoustic emission
ROC	Receiver operating characteristic
HHIE-S	Hearing Handicap Inventory for the Elderly – Short Version
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, fourth edition
SCID	Structured Clinical Interview for the DSM
HAM-D	Hamilton Depression Rating Scale
CSDD	Cornell Scale for Depression in Dementia
MADRS	Montgomery-Asberg Depression Rating Scale
RRS	Retardation Rating Scale
BDI	Beck Depression Inventory
SDS	Self-rating Depression Scale
CES-D	Center for Epidemiological Studies Depression Scale
MMSE	Mini-Mental State Exam
WIDHH	Western Institute for the Deaf and Hard of Hearing
TPP	Tympanometric peak pressure
ECV	Ear canal volume
SA	Static admittance
ANSI	American National Standards Institute
HF PTA	High-frequency pure-tone average

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Dedication

To Jay,

For understanding that sometimes we must be willing to get rid of the life we've planned, so as to have the life that is waiting for us.

1 Introduction

Hearing loss occurs in 25-40% of adults over 65, yet up to 80% of these older adults do not use hearing aids, the main treatment for age-related hearing loss (ARHL; Bagai, Thavendiranathan, & Detsky, 2006; Cigolle, Langa, Kabeto, Tian, & Blaum, 2007; Kochkin, 1992; Kochkin, 2000; National Council on the Aging, 2000). Untreated hearing loss in this population has been associated with adverse social and emotional consequences. In particular, evidence from self-report studies of hearing loss and depression indicates that there is a strong link between untreated hearing loss and depression (Cacciatore et al., 1999; Capella-McDonnall, 2005; Chou, 2008; Fellinger, Holzinger, Gerich, & Goldberg, 2007; Kramer, Kapteyn, Kuik, & Deeg, 2002; Naramura et al., 1999; National Council on the Aging, 2000; Saito et al., 2010; Strawbridge, Wallhagen, Shema, & Kaplan, 2000; Wallhagen, Strawbridge, & Kaplan, 1996). However, research has yet to establish that this correlation does not simply represent the demographic and personality factors associated with self-reported hearing status (Cox, Alexander, & Gray, 2007; Gatehouse, 1990). A limited number of studies have investigated whether there is a relationship between depressive symptoms and objective measures of hearing rather than self-report; however, these studies have reported conflicting results (Gopinath et al., 2009; Naramura et al., 1999; Saito et al., 2010; Tambs, 2004). If hearing loss contributes to depressive symptoms in older adults, then it is vital that the relationship is understood so that the symptoms of each can be treated appropriately. Therefore, the current study investigated the relationship between depressive symptoms and hearing loss using objective measures of hearing, to reduce the influence of self-report bias on the apparent correlation. Furthermore, the current study quantified the dose-response relationship between objective hearing loss and depressive symptoms. The following literature review outlines foundations for this research: i) age-related hearing loss and its associated psychosocial outcomes in older adults, ii) tools for measuring hearing loss, and iii) depression, and tools for measuring depression, in older adults.

1.1 Hearing Loss and Aging

Hearing loss is one of the most prevalent chronic disabling conditions among older adults (Cigolle et al., 2007; Mathers, Smith & Concha, 2000; Statistics Canada, 2010a). According to national data from the 2003 Canadian Community Health Survey, approximately 11% of all Canadian adults 65 years or older report having a hearing problem (Millar, 2005). Worldwide epidemiological data show that hearing loss prevalence increases dramatically with age, affecting between 25% and 40% of adults over 65, 40% to 66% of adults over 75, and 80% of adults over 85 years (Cruickshanks et al., 1998; Gates, Cooper, Kannel, & Miller, 1990; Reuben, Walsh, Moore, Damesyn, & Greendale, 1998; Yueh, Shapiro, MacLean, & Shekelle, 2003). When hearing loss is defined using a lower cutoff criterion, prevalence estimates are even higher (Moscicki, Elkins, Baum, & McNamara, 1985). Adults over 65 constitute the fastest growing segment of the Canadian population, with their population expected to more than double by the year 2036 (Statistics Canada, 2010b). Thus, the prevalence of hearing loss is facing an inevitable increase in decades to come.

Presbycusis, or age-related hearing loss (ARHL), is thought to be the result of the combined effects of noise, aging, disease and heredity (Gates & Mills, 2005; Schuknecht et al., 1974). ARHL is most commonly associated with a bilateral, symmetrical sensorineural hearing loss, typically due to loss of or damage to the outer hair cells (OHCs) of the cochlea

(Schuknecht & Gacek, 1993). ARHL is a gradual process, with hearing loss occurring in the high frequencies first. Decreased high-frequency hearing sensitivity alters the reception of speech sounds, which can have significant adverse effects on communication (Bergman, 1980; Hinchcliffe, 1962; Humes, 1996). Older adults with high-frequency hearing loss may find it difficult to understand speech in noisy or reverberant listening environments (Plomp & Duquesnoy, 1980), but often have no problems understanding speech in quiet environments or with familiar conversation partners (Yonan & Sommers, 2000). With increasing age, hearing loss may progress into the mid-frequency (2000 to 4000 Hz) range, the frequency range that contains many voiceless consonants (t, p, k, f, s and sh), making speech understanding even more challenging regardless of the environment or conversation partner (Gordon-Salant, 2005). However, because ARHL often develops slowly and gradually, many older adults develop compensatory strategies, and are therefore unaware of any impairment, or the consequences of the impairment (Burfield & Casey, 1987, as cited in Heine & Browning, 2002).

Provided that hearing loss is recognized, most cases of ARHL are manageable. There are a number of options designed to assist with hearing-related communication difficulties, the most common of which is hearing aids. Regardless, only 20% of elderly individuals with a significant hearing impairment obtain hearing aids (Kochkin, 1992; Kochkin, 2000; National Council on the Aging, 2000). Furthermore, 30% of adults who own hearing aids are dissatisfied with their instruments (Kochkin, 2003), and 16% of hearing aid owners report never using their hearing aids (Kochkin, 2000). If ARHL is left untreated, the negative consequences of ARHL can span far beyond communication difficulties.

1.1.1 Psychosocial Outcomes Associated with Hearing Loss

Untreated hearing loss in older adults has been associated with adverse effects on quality of life (Chia et al., 2007; Dalton et al., 2003; Lee, Smith, & Kington, 1999; Vuorialho, Karinen, & Sorri, 2006). More specifically, psychological, social and emotional functioning seem to be particularly negatively influenced by untreated ARHL (Carabellese et al., 1993). Psychosocial outcomes related to hearing impairment in older adults include social isolation, loneliness and lower self-efficacy (Kramer et al., 2002), poor social functioning (Cacciatore et al., 1999; Dalton et al., 2003; Mulrow et al., 1990a; Ringdahl & Grimby, 2000) anxiety, distress, somatization (Eriksson-Mangold & Carlsson, 1991), and depression (Cacciatore et al., 1999; M. E. Capella-McDonnall, 2005; Fellinger et al., 2007; Kramer et al., 2002; National Council on the Aging, 2000; Strawbridge et al., 2000; Wallhagen et al., 1996).

1.1.1.1 Loneliness and social isolation.

It has been well established that hearing loss in older adults can result in social isolation and loneliness (Christian, Dluhy, & O'Neill, 1989; Hawthorne, 2008; Kramer et al., 2002; Ringdahl & Grimby, 2000; Stevens, 1982; Weinstein & Ventry, 1982). Social isolation is defined as the absence of social support, with social support defined as social contacts, participation in society, living with companionship and feeling valued and supported as a member of a friendship group or community (Heinrich & Gullone, 2006; Marangoni & Ickes, 1989; Victor, Scambler, Bond & Bowling, 2000). Loneliness is the emotional distress that results from deficiencies in an individual’s network of social resources (Peplau & Perlman, 1982). Studies that have quantified hearing loss using pure-tone audiometry have demonstrated that the odds for social isolation (Stevens, 1982) and loneliness (Christian, Dluhy, & O'Neill, 1989) increase as degree of hearing loss increases.

Older adults with hearing loss may be socially isolated or lonely because they have poorer social functioning than adults with normal hearing (Dalton et al., 2003; Mulrow et al., 1990a; Ringdahl & Grimby, 2000; Strawbridge et al., 2000; Wallhagen et al., 1996). Wallhagen et al. (1996) found that, compared to older adults with normal hearing, adults with self-reported hearing impairment were three times more likely to feel left out in social situations even with friends. Similarly, Strawbridge et al. (2000) found that older adults with "a little" self-reported hearing impairment reported feeling left out in a group or feeling lonely or remote in social situations, and that adults with "moderate or more" self-reported hearing impairment reported these feelings to an even greater extent. If older adults experience a reduced quality of social communication, they may be less likely to participate in social situations. Indeed, a large-scale study by the NCOA (2000) demonstrated that older adults with untreated hearing loss were less likely than hearing aid users to be involved in neighbourhood and organized social activities. Furthermore, work by Kramer et al. (2002) demonstrated that older adults with poor self-reported hearing have a smaller social network size than adults with normal hearing. Thus, for older adults with untreated ARHL, both the quality and quantity of social communications may be considerably limited, increasing their risk of social isolation and loneliness.

ARHL may be associated with social isolation and loneliness because it impairs speech understanding (Bergman, 1980; Hinchcliffe, 1962; Humes, 1996), thereby putting older adults with hearing loss at a severe disadvantage in social situations. Older adults with ARHL may lose out on small talk and general information, meaning they may become lost in the conversation or may end up responding inappropriately. Many older adults with ARHL report significant communication difficulties in everyday situations, such as talking with a cashier at the store, being able to follow the conversation when at a physician's office, or understanding the conversation when talking on the telephone (Dalton et al., 2003). Social communication may be particularly difficult if conversation takes place in adverse listening conditions, including background noise and reverberation (as reviewed by Gordon-Salant, 2005), characteristics that are common at parties, churches and theatres. These communication difficulties can have a negative emotional impact, and many researchers have shown that older adults with hearing loss are more likely to report feelings of insecurity, anxiety, and poor self-esteem (Eriksson-Mangold & Carlsson, 1991; Kramer et al., 2002; National Council on the Aging, 2000; Tambs, 2004). As a result, hearing-impaired older adults may withdraw from social situations as an attempt to avoid the difficulty and negative emotions associated with social communication. They may be reluctant to attend or completely stop attending church, theatre, clubs, meetings, parties and other social situations. If an adult with hearing loss withdraws from social situations, his or her interpersonal and social life will likely narrow, which may lead to feelings of sadness, loneliness and isolation.

Because a hearing loss affects communication, the effects of a hearing loss can also impact other people, such as family members and friends of the hearing-impaired individual. These communication partners must make a greater effort to ensure that communication with a hearing-impaired person is successful, often using strategies such as speaking more slowly and clearly, facing the person and repeating the message. In light of these increased communication demands, a small number of studies have examined the impact of hearing loss on the spouse (Armero, 2001; Brooks, Hallam, & Mellor, 2001; Scarinci, Worrall, &

Hickson, 2008; Stark & Hickson, 2004; Wallhagen, Strawbridge, Shema, & Kaplan, 2004). Spouses commonly report frustration and annoyance with misunderstandings and having to repeat themselves, and often act as intermediaries for the hearing-impaired partner in group situations (Armero, 2001; Brooks et al., 2001; Stark & Hickson, 2004; Stephens, France, & Lormore, 1995). In 2008, a qualitative study by Scarinci and colleagues revealed that spouses communicated less with their hearing-impaired partner than prior to the hearing loss, mainly due to increased time and effort involved in communicating. Spouses also reported reduced social activity attributed to their partner's hearing impairment. Similarly, Brooks et al. (2001) found that social activities the couple once enjoyed, such as going to the movies or visiting with friends and family, may be limited or given up altogether because of communication difficulties. The combined results of these aforementioned studies suggests that communication difficulties increase the likelihood that other people will make less contact with the hearing impaired person, leading to increased social isolation.

In older adults, the negative effects of a hearing impairment on social communication may be exacerbated by vision loss (Capella McDonnall, 2009; Capella-McDonnall, 2005; Chia et al., 2006; Chou & Chi, 2004; Crews & Campbell, 2004; Lupsakko, Mantyjarvi, Kautiainen, & Sulkava, 2002). Because ARHL typically impairs speech reception through the auditory modality, many older adults compensate by relying on visual cues, such as lip-reading and facial expressions. Unfortunately, older adults with dual sensory loss, that is, both vision and hearing loss, will have more difficulty compensating and therefore communication performance may be even more affected. As with hearing loss alone, dual sensory loss has been shown to have negative psychological, psychosocial and functional health effects. In their 2006 study, Chia and colleagues used objective tests of both vision and hearing and demonstrated that individuals with dual sensory loss had poorer physical function, general health perceptions and social and mental well-being than individuals without sensory loss. Other recent studies have found similar results using self-report measures of hearing and vision, suggesting that, relative to those with a single sensory impairment, older adults with self-reported dual sensory loss are more likely to exhibit depressive symptoms (Capella-McDonnall, 2009; Capella-McDonnall, 2005; Chou & Chi, 2004; Lupsakko et al., 2002). Work by Crews & Campbell (2004) suggests that self-reported dual sensory loss is also associated with significantly decreased participation in social activities. Compared to adults with no self-reported impairment, older adults with dual sensory loss had more difficulties with activities of daily living (ADL) such as walking, shopping and preparing meals, and had 10% lower rates of participation in activities such as attending church, visiting friends and telephoning colleagues (Crews & Campbell, 2004). Therefore, sensory loss and lack of social communication may threaten older adults' independence and put them at risk for serious social and emotional difficulties.

1.1.1.2 Quality of life and overall functioning.

Hearing loss is consistently associated with reduced quality of life and poor overall functioning in older adults, even when physical health factors such as mobility, pain, sleep problems and chronic diseases are accounted for in the analysis (Bess, Lichtenstein, Logan, & Burger, 1989; Cacciatore et al., 1999; Chia et al., 2007; Dalton et al., 2003; Hogan, O'Loughlin, Miller, & Kendig, 2009; Ishine, Okumiya, & Matsubayashi, 2007; Lee et al., 1999; Ringdahl & Grimby, 2000). In this context, quality of life refers to an individual's subjective assessment of physical and mental health, while overall function refers to an individual's ability to perform activities of daily living such as dressing, personal grooming, shopping and preparing meals. Research has reported a significant decrease in quality of life and overall function with increasing hearing loss severity (Bess et al., 1989; Chia et al., 2007; Dalton et al., 2003; Ringdahl & Grimby, 2000). Furthermore, older adults with hearing loss are less self-sufficient and rely more on others for help performing daily activities than those without hearing loss (Carabellese et al., 1993; Cigolle et al., 2007). The loss of independence in completing daily activities contributes to feelings of worthlessness and low self-esteem (Burfield & Casey, 1987, as cited in Heine & Browning, 2002). As a result, older adults with hearing impairment and limited ability to independently perform daily activities are more likely to be socially withdrawn or depressed (Mitchell, Mathews, & Yesavage, 1993). Hearing loss is therefore an important co-morbidity for reduced quality of life and function in older adults.

1.1.1.3 Depression.

Evidence from self reports of both hearing loss and depression indicates that there is a strong link between untreated hearing loss and depression in older adults (Cacciatore et al., 1999; Capella-McDonnall, 2005; Fellinger et al., 2007; Kramer et al., 2002; National Council on the Aging, 2000; Saito et al., 2010; Strawbridge et al., 2000; Wallhagen et al., 1996). Wallhagen et al. (1996), Cacciatore et al. (1999) and Capella-McDonnall et al. (2005) examined the relationship between hearing loss and depression in older adults using a single question to assess hearing status. All three studies found that, compared with those who reported no hearing loss, participants who reported hearing loss were significantly more likely to report depressive symptoms. Research by Fellinger et al. (2007) examined the association between hearing loss and depression by asking adults of all ages to provide details about their previously diagnosed hearing problems. Fellinger and colleagues (2007) found results similar to those of previous studies, that adults with self-reported hearing loss reported higher depression scores than adults with normal hearing. Similar results were also found by Kramer et al. (2002), who assessed hearing status using a 3-question self-report scale and demonstrated that adults age 55-85 with poor self-reported hearing reported more depressive symptoms than individuals with good hearing. In general, the instruments used to assess hearing loss and depressive symptoms vary across all of the aforementioned studies. Therefore, although these studies have found hearing loss to be adversely associated with depressive symptoms, direct comparisons of their results are difficult.

Literature demonstrates that the relationship between self-reported hearing loss and depressive symptoms is dose-dependent, such that the prevalence of depressive symptoms increases as the severity of self-reported hearing loss increases (National Council on the Aging, 2000; Strawbridge et al., 2000). Strawbridge et al. (2000) categorized self-reported hearing status into three degrees of impairment: no hearing impairment, a little hearing impairment, and moderate or more hearing impairment. Their results demonstrated a non-significant association between self-reported “no hearing impairment” or “a little hearing impairment” and depression, and a significant association between “moderate or more hearing impairment” and depression. Similarly, the NCOA study in 2000 grouped participants into five hearing loss quintiles, ranging from “mild/moderate” to “severe/profound” based on mean overall subjective hearing loss scores. Individuals with “severe/profound” hearing loss exhibited significantly more symptoms of depression than those with “mild” hearing loss, with a general trend of increasing depressive symptoms as degree of self-reported hearing loss increased (National Council on the Aging, 2000). Further studies corroborating a dose-response pattern would strengthen the argument linking hearing loss with negative psychosocial outcomes. Unfortunately, the majority of other studies treat hearing impairment as a dichotomous variable, either present or absent, rather than examining different degrees of impairment.

A limited amount of recent literature has addressed the relationship between depressive symptoms and hearing loss using objective measures of hearing rather than self-report (Gopinath et al., 2009; Naramura et al., 1999; Saito et al., 2010; Tambs, 2004). Objective measures of hearing, such as pure-tone audiometry, can potentially reveal a less biased view of the impact of hearing loss on depressive symptoms because they are less influenced by demographic and personality factors than self reports of hearing (Cox et al., 2007; Gatehouse, 1990). However, these few studies have reported conflicting results about the relationship between pure-tone audiometry and depressive symptoms in older adults, likely due to vast methodological differences. Using a group of 1328 participants aged 60 and up, Gopinath and colleagues (2009) assessed hearing using pure-tone audiometry at 0.5, 1, 2 and 4 kHz, analyzed as a categorical variable, and assessed depressive symptoms using two scales, the Mental Health Index (MHI) and the CES-D-10. They found that depressive symptoms as assessed by the MHI were significantly higher in subjects with mild bilateral hearing loss than in subjects with normal hearing. This association was not observed for depressive symptoms assessed according to the CES-D-10 or for subjects with moderate or severe hearing loss. Although the measures used by Gopinath et al. were appropriate, the authors used cutoff scores to categorize both hearing loss and depression, thereby limiting comparisons with other studies that use alternative definitions of hearing loss and depression. In 2004, Tambs investigated the relationship between hearing loss and depression in 50,398 subjects age 20 to 101 years. Using a self-derived short form of a depression scale with unknown psychometric properties, and three pure-tone averages (low-frequency, 0.25 and 0.5 kHz; mid-frequency, 1 and 2 kHz; and high-frequency, 3, 4, 6 and 8 kHz), Tambs et al. found that only low-frequency hearing loss was significantly associated with worse mental health ratings in adults over 65. Conversely, Saito et al. (2010) concluded that self-reported hearing loss, but not audiometry, is a significant predictor of depressive of symptoms, however a pure-tone threshold was obtained at 1 kHz only. Evidently, authors investigating objectively measured hearing loss in relation to depressive symptoms have yet to reach a consensus on whether such a relationship exists. Standardized audiometric frequencies, such as the four-frequency pure-tone average (0.5, 1, 2 and 4 kHz) recommended by the World Health Organization (WHO, 1999), well-validated depression scales, and similar definitions of both hearing loss and depression must be used across all studies before results can be accurately compared and generalized to the older adult population. Furthermore, studies should define hearing loss on either a categorical or continuous scale, rather than as a dichotomous variable, in order to measure changes in depressive symptoms with increasing severity of hearing loss.

Numerous researchers have proposed explanations for the relationship between ARHL and depressive symptoms in older adults. Horowitz, Reinhardt, Boerner and Travis (2003) suggest that the pathway between hearing loss and depression is mediated by the effects of hearing loss on everyday function. As a result, individuals with poor hearing may be more dependent on caregivers (Carabellese et al., 1993; Christian, Dluhy, & O'Neill, 1989; Cigolle et al., 2007) and this loss of autonomy may threaten self-esteem and independence, both of which are known predictors of depression in older adults (as reviewed by Djernes, 2006). An alternative explanation offered by Horowitz and colleagues (2003) is that the subjective emotional experience of hearing loss affects quality of life beyond the objective functional limitations imposed by the hearing impairment. More specifically, loss of hearing can be a traumatic disability that can evoke fear and anticipation of one's loss of independence. Furthermore, hearing loss impacts activities that are especially valued and enjoyed in life, such as social interaction, so the inability to enjoy such activities may cause psychological distress.

Overall, the majority of previous work has established a relationship between self-reported hearing impairment and depression in older adults using cross-sectional data; therefore, conclusions about the nature of this relationship are limited (Cacciatore et al., 1999; Capella-McDonnall, 2005; Carabellese et al., 1993; Kramer et al., 2002). In an effort to explain the relationship between hearing loss and psychological distress, Corna, Wade, Streiner and Cairney (2009) performed a 6-year longitudinal study examining the mediating effects of psychosocial factors and stressors on this relationship. Corna et al. (2009) concluded that hearing impairment could have a negative impact on psychosocial resources, particularly mastery and self-esteem, which, in turn, are associated with psychological distress. Older adults with poor hearing are also more likely to have social difficulties than their normal hearing peers, including difficulty paying attention, not feeling close to others and feeling left out of a group (Dalton et al., 2003; Heine & Browning, 2002; Strawbridge et al., 2000). Poor social function could lead to more negative interactions with friends and family members (Stafford, McMunn, Zaninotto & Nazroo, 2011) and social withdrawal or isolation, factors that have been associated with the development of depressive symptoms, reduced quality of life, and increased morbidity and mortality (Arlinger, 2003; Barnett & Franks, 1999; Chou, 2008; reviewed by Djernes, 2006; Ebert & Heckerling, 1995; Gates et al., 1996; Hawthorne, 2008; Heine & Browning, 2002; Ringdahl & Grimby, 2000). Thus, it seems reasonable that impaired social function may act as a mediator in the relationship between hearing impairment and depression in older adults.

1.1.2 Preventing Psychosocial Outcomes Associated with Hearing Loss

A growing body of evidence demonstrates that the negative psychosocial outcomes of hearing loss, including depressive symptoms, are reduced in older adults who use hearing aids (Cacciatore et al., 1999; Goorabi, Hosseinabadi, & Share, 2008; Gopinath et al., 2009; Mulrow et al., 1990b; Mulrow, Tuley, & Aguilar, 1992; National Council on the Aging, 2000; Vuorialho et al., 2006). In 2000, the NCOA found that, compared to hearing-impaired older adults who did not use hearing aids, those who used hearing aids were less likely to report feelings of sadness, depression and emotional instability (National Council on the Aging, 2000). On average, there was a 36% reduction in depressive symptoms associated with hearing aid use. Similarly, Cacciatore and colleagues (1999) assessed the role of hearing aids on depressive symptoms in 1332 community-dwelling adults aged 65 and older. In subjects with hearing problems, they found that hearing aid users had a significantly lower score on the Geriatric Depression Scale (GDS). Gopinath et al. (2009) found that subjects who reported using a hearing aid for at least 1 hour per day were significantly less likely to report depressive symptoms than non-hearing aid users. Moreover, females who used their hearing aid for greater than 1 hour per day reported fewer depressive symptoms than females who used their hearing aid less than 1 hour per day. Thus, the correlation between hearing aid use and reduced depressive symptoms suggests that hearing loss may be a potential causal factor for depressive symptoms. However, such conclusions are limited by the cross-sectional nature of the aforementioned studies.

Longitudinal studies on the impact of hearing aid use on psychosocial outcomes suggest a possible causal link between untreated hearing impairment and depressive symptoms (Mulrow et al., 1990b; Mulrow, Tuley, & Aguilar, 1992; Vuorialho et al., 2006). A randomized controlled trial performed by Mulrow et al. (1990b) found that individuals assigned to a hearing aid group for a period of 6 months showed improvements in communication, social and emotional function, and depressive symptoms as compared to individuals randomized to a waiting list group. A follow-up study (Mulrow et al., 1992) showed that these improvements were maintained after 12 months of hearing aid use. Vuorialho and colleagues (2006) used a prospective pre-post design to assess the effects of hearing aid use on quality of life and Hearing Handicap Inventory for the Elderly (HHIE) score in a group of 98 older adults. The HHIE is a scale designed to assess social and emotional handicap secondary to hearing impairment in older adults (Ventry & Weinstein, 1982). Participants were first-time hearing aid users and were interviewed prior to, and 6 months after, hearing aid fitting. When individuals are fitted with amplification, 40-60% of hearing aid users report fewer social and emotional problems on the HHIE at 6-month follow-up than at baseline (Vuorialho et al., 2006). Hearing aid users also reported a significant positive improvement in self-reported health status. Since social and emotional dysfunction and depressive symptoms are reduced when hearing loss is treated, then early identification and treatment of hearing loss has the potential to allay its negative psychosocial outcomes before they occur.

1.2 Measuring Hearing Loss

From the literature review presented in the previous sections, it is evident that researchers studying the relationship between hearing loss and other variables have measured and defined hearing loss in a number of different ways. In order to accurately interpret the findings of these studies, and generalize these results to the older adult population, it is important to understand the relative advantages and disadvantages of the various measurement techniques and definitions of hearing loss. There are two primary methods of measuring hearing impairment. First, hearing impairment can be quantified using objective assessments such as pure-tone audiometry and otoacoustic emissions. Second, hearing impairment can be quantified using subjective assessments obtained from self-report questionnaires. Subjective assessments measure activity limitations and participation restrictions secondary to hearing impairment rather than hearing impairment itself. In this context, the term impairment refers to the measureable loss of hearing function, while the terms *activity limitation* and *participation restriction* refer to difficulties executing activities and difficulties in involvement in life situations as a result of hearing loss (WHO, 2001). The following sections will discuss both objective and subjective measures of hearing impairment and examine the relationship between them.

1.2.1 Objective Measures of Hearing Impairment

1.2.1.1 Pure-tone audiometry.

Pure-tone audiometry is unequivocally considered the gold standard procedure of the audiological evaluation (Schlauch & Nelson, 2009). The results of pure-tone audiometry represent the most fundamental objective estimate of peripheral hearing sensitivity, and are used to quantify the degree, configuration and type of hearing loss, and to gain information about the possible site of lesion. Audiometric results are also used in assessing hearing aid candidacy or the need for audiological (re)habilitation.

During pure-tone audiometry testing, thresholds are obtained for a series of pure-tone stimuli. The term threshold, in the context of audiometry, refers to the lowest sound intensity at which a listener can identify the presence of a signal at least 50% of the time (American National Standards Institute, 2004a). Low audiometric thresholds indicate that an individual has good peripheral hearing sensitivity, while high audiometric thresholds indicate poor peripheral hearing sensitivity.

To obtain a series of audiometric thresholds, pure-tone stimuli are presented to a listener via headphones or insert phones (air conduction testing), bone oscillators (bone conduction testing) or loudspeakers (soundfield testing). Pure tone signals, each with a specific frequency at octave and inter-octave intervals between 250 and 8000 Hz, are presented at a series of intensities. The listener is instructed to provide a behavioural response, such as raising a hand or pressing a button, in response to the stimulus. Hearing threshold (expressed in terms of decibels hearing level, dB HL) at each frequency is recorded on an audiogram, which is a graphical representation of peripheral hearing sensitivity. This process continues until an audiometric threshold is found at each pure-tone frequency of interest in both ears. The specific clinical method for determining hearing thresholds can vary, however the American Speech-Language-Hearing Association (ASHA, 2005) recommends the use of standard protocol, known as the modified Hughson-Westlake procedure (Carhart & Jerger, 1959), outlined in Appendix A. The Hughson-Westlake procedure is based on a psychophysical procedure called the method of limits (Fechner, 1860, as cited in Harrell, 2002), which involves the presentation of tones that are clearly audible at first and then decrease in intensity with each correct identification. The use of a standard clinical protocol optimizes the reliability of audiometric thresholds, making pure-tone audiometry ideal as an objective measure of hearing for individuals who can provide reliable behavioural responses.

For clinical and research purposes, it is often favourable to represent hearing in a single metric rather than report multiple individual thresholds. This value can then be used to classify an individual's hearing status. The results of pure-tone audiometry can be summarized as a single metric in a variety of ways. There is no standardized method of reporting hearing loss in the literature, so the choice of method often depends on research goals and the population of interest. Some of the variables considered in reporting hearing loss are: the choice of metric used to summarize the audiogram, whether the audiogram frequencies are weighted by speech importance, the choice of frequencies and ear to include in the summary, and what cut-off value indicates hearing loss.

One metric used to summarize hearing is percentage hearing loss (American Academy of Otolaryngology & American Council of Otolaryngology, 1979; Tempest, 1977). Percentage hearing loss is most frequently used when compensating workers for hearing loss due to occupational noise exposure, and is determined using a series of mathematical calculations. First, an average of a selected range of audiometric frequencies is calculated for each ear. Next, a percentage value is assigned for every decibel by which that average exceeds a certain cutoff value, or "low fence", in each ear (e.g. 1% per 2dB above 25 dB HL). Finally, a mathematical formula is used to combine the percentage values for each ear, weighted to emphasize the importance of the better ear, into an overall binaural percentage loss. The most commonly used formula for calculating percentage hearing loss is that of the AAO (AAO & ACO, 1979), which uses an average of 0.5, 1, 2 and 3 kHz, defines monaural loss as 1%/dB above a low fence of 25 dB HL, and calculates binaural loss using a weighting of 5x for the better ear. However, although percentage hearing loss uses thresholds as the basis of calculation, it provides limited information about an individual's audiometric thresholds. Because researchers and clinicians often require a summary of pure-tone audiometry thresholds, the audiogram is most frequently summarized in a pure-tone average (PTA) measure, which requires no assumption about the cut-off separating normal hearing from hearing impairment.

The PTA is a mathematical average of thresholds at selected speech frequencies (250, 500, 1000, 2000, 4000 and 8000 Hz). Different frequencies can be used to calculate the PTA in order to best estimate the potential impact of the hearing loss on communication. The three-frequency PTA of 500, 1000 and 2000 Hz (Carhart, 1971) is commonly used and is known as the PTA for speech because the majority of the speech spectrum falls within the 500 to 2000 Hz range (Schlauch & Nelson, 2009). However, the three-frequency PTA underestimates hearing impairment in individuals with hearing impairment at frequencies above 2000 Hz, a configuration common among many older adults. Furthermore, a number of investigators have demonstrated that hearing sensitivity at 4000 Hz is important for speech recognition in older adults, particularly in noisy listening conditions (Horwitz, Ahlstrom, & Dubno, 2008; Humes, 1996; Wiley et al., 1998). Additionally, the strongest correlations between PTA and self-reported hearing occur when the PTA includes thresholds within the frequency range of 0.5 to 4 kHz (Chang, Ho, & Chou, 2009; Clark, Sowers, Wallace, & Anderson, 1991; Lutman, Brown, & Coles, 1987; Nondahl et al., 1998; Sindhusake et al., 2001). Thus, both the World Health Organization (WHO, 1999) and ASHA (1981) recommend the use of a 4-frequency PTA that includes 500, 1000, 2000 and 4000 Hz, because it provides a more accurate reflection of the possible impact of hearing loss on speech understanding and communication.

In research settings, PTA may be reported for only one ear, and the choice of ear depends on the purpose of reporting hearing loss. Studies that aim to investigate population prevalence of hearing loss occasionally define hearing loss based on the worse ear in order to account for all individuals with any hearing loss (Cruickshanks et al., 1998; Nondahl et al., 1998). However, the majority of studies have used the better ear in the assessment of hearing loss, assuming that hearing in the better ear best corresponds with an individuals' subjective perception of hearing function (Chang et al., 2009; Clark et al., 1991; Gates et al., 1990; Hashimoto, Nomura, & Yano, 2004; Reuben et al., 1998; Sindhusake et al., 2001; Uchida, Nakashima, Ando, Niino, & Shimokata, 2003). Indeed, evidence supports this assumption, demonstrating that pure-tone sensitivity in the better ear is more strongly correlated with self-reports of hearing than pure-tone sensitivity in the worse ear (Brainerd & Frankel, 1985; Clark et al., 1991; Gates et al., 1990; Lutman et al., 1987; Sindhusake et al., 2001; Weinstein & Ventry, 1983). Therefore, if the purpose of reporting hearing loss is to study its potential impact on the individual, then better ear PTA is the most appropriate measure.

There are a variety of ways that PTA can be used to classify an individual as hearing impaired. First, PTA can be used to dichotomize hearing loss by selecting a cutoff intensity, such as 25 dB HL, above which hearing is said to be impaired (e.g., as used by Cruickshanks et al., 1998; Moscicki et al., 1985; Reuben et al., 1998). PTA can also be used to categorize hearing loss according to severity, such as mild or moderate, using a series of cutoff values (e.g., as used by Sindhusake et al., 2001; Gopinath et al., 2009). Cutoff values are frequently used in epidemiological studies because they provide a means to summarize large amounts of data in order to generate hearing loss prevalence estimates (as reviewed by Pascolini & Smith, 2009). However, cutoff values vary between studies, and different investigators have proposed different cutoffs above which hearing impairment is considered to be "disabling" (Pascolini & Smith, 2009). Alternatively, PTA can be presented as a continuous variable on an ordinal scale, without the use of cutoff values. This type of scale is ideal if the purpose of research is not to provide hearing loss prevalence estimates but rather to examine the relationship between hearing loss and other variables. By treating hearing loss as a continuous variable, researchers can examine changes in other variables as severity of hearing loss increases, and evaluate whether a dose-dependent relationship exists.

In summary, pure-tone audiometry is a valuable objective measure of peripheral hearing sensitivity that is performed using a standard clinical protocol. The results of pure-tone audiometry can be summarized in a number of ways, the most common of which is the pure-tone average (PTA). The choice of ear and the frequencies included in the PTA can vary, but a PTA including 500, 1000, 2000 and 4000 for the better ear is thought to provide the best estimate of the potential impact of hearing loss on communication. For research purposes, PTA can be used to classify an individual's hearing status in a number of ways; research examining the association between hearing loss and other variables should present PTA as a continuous rather than a dichotomous or categorical variable.

1.2.1.2 Otoacoustic emissions.

Although pure-tone audiometry is commonly defined as an objective measure of hearing, it nonetheless requires patient cooperation in the form of behavioural responses. Other, more objective, audiological measures exist that do not require behavioural responses and can be used in conjunction with pure-tone audiometry to determine hearing sensitivity.

One such objective measure is otoacoustic emission (OAE) testing, which assesses cochlear function, as opposed to the psychological sensation of hearing.

OAEs were first described by Kemp (1978) as sounds that originate from the physiological activity of the cochlea and can be measured in the external auditory canal. More specifically, OAEs reflect the activity of the cochlear outer hair cell (OHC; Brownell, Manis, Zidanic, & Spirou, 1983; Brownell, 1990), which is the primary site where age-related changes in hearing occur (Schuknecht & Gacek, 1993). A decrease in OAE responses in an ear with normal outer and middle ear function, therefore, usually represents impaired OHC function and a corresponding decrease in hearing sensitivity.

According to conventional nomenclature, there are two general categories of OAEs: spontaneous and evoked. Spontaneous OAEs are rare in clinical use because they are not produced by all normal ears (Whitehead, Lonsbury-Martin, & Martin, 1992). Evoked OAEs, on the other hand, can be measured in nearly all ears that have normal cochlear function, while ears with impaired cochlear function typically do not produce a response or produce responses of a reduced level (Gorga et al., 1993a; Gorga et al., 1997; Gorga, Nelson, Davis, Dorn, & Neely, 2000; Lonsbury-Martin, Harris, Stagner, Hawkins, & Martin, 1990). Therefore, evoked OAE testing, either transient evoked OAE (TEOAE) or distortion product OAE (DPOAE) testing, is in common clinical use as an objective measure of cochlear function.

1.2.1.2.1 TEOAEs.

Transient-evoked otoacoustic emissions (TEOAEs) are typically evoked with a transient, or click, stimulus (Kemp, 2007). The transient activates the basilar membrane across a wide range of frequencies simultaneously, giving rise to a complex sound waveform that reflects activity of the OHCs (Hall, 2000). The complex waveform can be subsequently analyzed as a function of frequency. TEOAE amplitude or amplitude-noise ratio can be calculated across different frequency bands to provide an estimate of OHC function at that frequency band within the cochlea.

1.2.1.2.2 DPOAEs.

Distortion product otoacoustic emissions (DPOAEs) are evoked by the simultaneous presentation of two closely-spaced pure tones, referred to as primaries, or frequency 1 (f1) and frequency 2 (f2) (Kemp, 1978; Lonsbury-Martin et al., 1990). These primaries stimulate the cochlea, giving rise to distortion products that reflect the nonlinear response properties of the OHCs. The DPOAE response originates from the cochlea as a tonal signal that is not present in the eliciting stimulus complex. The most commonly measured and most robust DPOAEs occur at a frequency corresponding to 2f1-f2 (Gaskill & Brown, 1990; Probst, Lonsbury-Martin, & Martin, 1991). The level of the 2f1-f2 DPOAE is therefore used clinically as a means for assessing cochlear function. The stimulus protocol used most commonly to elicit the 2f1-f2 DPOAE uses a primary frequency ratio (f2/f1) of 1.22, with primary levels set at 65 dB SPL (L1) and 55 dB SPL (L2). Previous work has demonstrated that these parameters yield the greatest separation between normal and impaired ears (Stover, Gorga, Neely, & Montoya, 1996; Whitehead, Stagner, McCoy, Lonsbury-Martin, & Martin, 1995). When these parameters are used, the region of the cochlea activated is near the f2 place, and therefore the presence of a 2f1-f2 DPOAE reflects normal OHC function at the f2 place (Brown & Kemp, 1984; Gaskill & Brown, 1996; Martin, Ohlms, Franklin, Harris, & Lonsbury-Martin, 1990).

Many research studies have examined DPOAE test performance by comparing DPOAE measurements to the pure-tone audiogram (Gorga et al., 1993a; Gorga et al., 2005; Lonsbury-Martin & Martin, 1990; Martin et al., 1990). DPOAE testing is accurate at identifying hearing loss for mid and high frequencies (1500 to 6000 Hz), but performs poorly for lower frequencies (<1000 Hz) and for 8000 Hz (Gorga, Neely, Bergman et al., 1993a; Gorga et al., 1997). Furthermore, DPOAE testing is best at separating normal from impaired ears when hearing thresholds are better than 25 dB HL, at which level DPOAEs are always present in normal ears (Bonfils & Avan, 1992; Gorga et al., 1993a; Gorga et al., 1997; Martin et al., 1990). Once hearing thresholds exceed 50-60 dB HL, DPOAEs are always absent. This creates a "zone of uncertainty" when audiometric thresholds are between 25 and 50-60 dB HL, where DPOAE amplitudes may be either present or absent. This uncertainty can make DPOAE outcomes difficult to interpret for individuals with a slight to moderate hearing loss.

1.2.1.2.3 TEOAEs versus DPOAEs.

Both TEOAEs and DPOAEs share characteristics that make them ideal for objective measurement of cochlear function. However, DPOAEs may be more suitable than TEOAEs for determining cochlear function at specific frequencies. While TEOAEs seem to have good frequency specificity for the range of 1000 Hz to 4000 Hz (Robinette, 2003), their detection and frequency content are influenced by the status of the entire cochlea (Avan, Bonfils, Loth, Narcy, & Trotoux, 1991; Probst, Coats, Martin, & Lonsbury-Martin, 1986). Therefore, TEOAEs generate a composite value that can be used for a general interpretation of cochlear function. Conversely, DPOAEs appear to arise from more localized sources (Avan & Bonfils, 1993), giving a better frequency-specific estimate of cochlear integrity than TEOAEs. For DPOAEs, the frequency at which the response occurs is predicted exactly by the frequencies of the primary stimulus tones. Furthermore, while neither TEOAEs nor DPOAEs can be used to predict behavioural threshold levels by frequency (Gorga et al., 1997; Stover, Neely, & Gorga, 1996), in ears with sensory loss, DPOAEs are generally reduced or eliminated only for the f2 stimulus frequency regions that coincide with the impaired region audiometrically (Gaskill & Brown, 1990; Smurzynski, Leonard, Kim, Lafreniere, & Jung, 1990; Stover, Neely, & Gorga, 1996).

In terms of separating individuals with normal hearing from individuals with mild or greater cochlear loss, TEOAE and DPOAE measures differ. TEOAEs are more sensitive than DPOAEs at 1000 Hz, TEOAEs and DPOAEs are essentially equivalent at 2000 and 3000 Hz, and DPOAEs are more sensitive than TEOAEs from 4000 to 6000 Hz (Gorga et al., 1993b; Gorga et al., 1997; Prieve et al., 1993). Therefore, DPOAEs are preferable for assessment of cochlear status in adults over 65, given the relative prevalence of high-frequency hearing loss in this age group.

1.2.1.2.4 Characterizing DPOAE responses.

In order to use DPOAEs to identify people with decreased hearing sensitivity, it is important to select a response criterion that accurately differentiates normal hearing from hearing loss. Researchers have employed various criteria to evaluate hearing status, the most common of which are DPOAE absolute amplitude and DPOAE-noise ratio at a single frequency (Gorga et al., 1993a; Gorga et al., 1997; Gorga et al., 2000; Torre, Cruickshanks, Nondahl, & Wiley, 2003). If both DPOAE absolute amplitude and DPOAE-Noise ratio are high, then this means that the response (at 2f2-f1) is large and is well differentiated from the level of the background noise, so cochlear function near f2 is likely normal. However, because of the aforementioned “zone of uncertainty” in DPOAE test performance, some ears with mild hearing loss may produce large DPOAEs, while some ears with normal hearing may show absent DPOAEs. Absent DPOAEs in an individual with normal hearing can be due to subtle outer ear, middle ear or cochlear problems that may attenuate DPOAE levels but have no effect on behavioural pure-tone thresholds (Naeve, Margolis, Levine, & Fournier, 1992). Consequently, there is no single criterion value for which all normal ears produce a large response and all impaired ears produce a lesser response, and therefore a DPOAE response criterion should be selected based on the characteristics of the population of interest. Age group may be a particularly important consideration, since the high prevalence of hearing loss in older adults (Cruickshanks et al., 1998) may result in different sensitivity, specificity, and positive and negative predictive values of DPOAE responses for older adults. A recent study of a large sample of older adults (age 48-92 years) analyzed receiver-operating characteristics (ROC) for both DPOAE absolute amplitude and DPOAE-noise criteria. The authors recommended the use of DPOAE-noise rather than DPOAE absolute amplitude, with a +9 dB DPOAE-noise ratio being the most ideal criterion to differentiate normal hearing from hearing loss in this population (see Figure 1.1) (Torre et al., 2003).

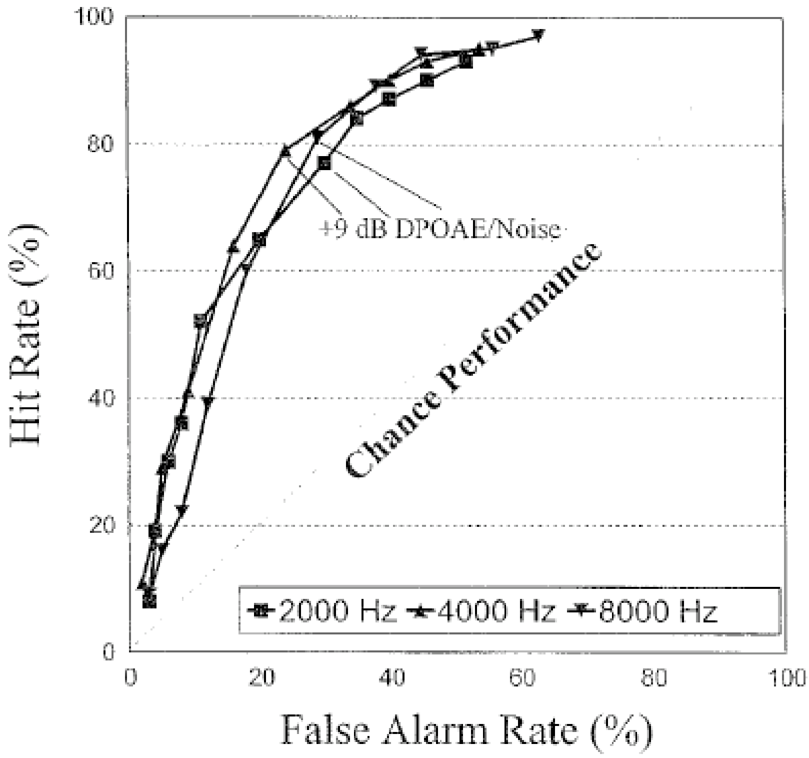

Figure 1.1. Hit rate as a function of false alarm rate for various DPOAE/noise ratios at 2000, 4000 and 8000 Hz.

Note. For the calculation of the receiver operating characteristic (ROC) curves, hearing loss was defined as a threshold greater than or equal to 25 dB HL. The dashed line from the lower left corner to the upper right corner represents a test that performs at the chance level. Selected DPOAE/noise ratios are indicated on the curves. DPOAE = distortion product otoacoustic emission. Reprinted from "Distortion Product Otoacoustic Emission Response Characteristics in Older Adults," by P. Torre 3rd., K.J. Cruickshanks, D.M. Nondahl and T.L. Wiley, 2003, *Ear & Hearing, 24*(1), p. 26. Copyright 2003 by Lippincott Williams & Wilkins, Inc. Reprinted with permission.

1.2.2 Self-Report Measures of Hearing

Although pure-tone audiometry is considered the gold standard measure of hearing, performing it on a large scale is not always possible due to insufficient equipment and trained personnel. Moreover, if the purpose of a research project is to assess activity limitations or participation restrictions secondary to hearing impairment, then self-perceived hearing loss may be a more suitable measure than audiometry. Thus, many researchers and clinicians rely on self-report questionnaires to determine hearing status. Perhaps the most widely used clinical tool for measuring self-reported hearing loss in older adults is the Hearing Handicap Inventory for the Elderly (HHIE), shown in Appendix B.1 (Ventry & Weinstein, 1982).

The HHIE is a 25-item questionnaire that was originally designed to identify social and emotional handicap secondary to hearing impairment (Ventry & Weinstein, 1982). It has since been validated for use as a screening tool for hearing loss in adults over 65 years of age (Lichtenstein, Bess, & Logan, 1988a; McBride, Mulrow, Aguilar, & Tuley, 1994; Weinstein & Ventry, 1983; Weinstein, Spitzer, & Ventry, 1986). Items on the questionnaire have been designed to include activities and situations in which elderly individuals are likely to be involved. Furthermore, in order to acknowledge the multidimensional nature of activity limitations and participation restrictions due to hearing loss, approximately half of the items assess the self-reported emotional (E) consequences of hearing loss, and half assess the social/situational (S) consequences. Each item on the questionnaire is scored as yes (4 points), sometimes (2 points) or no (0). Scores on the HHIE range from 0 (no handicap) to 100 (significant handicap). Different scores have been proposed as a cutoff above which individuals are identified as hearing impaired, but the choice of a cutoff ultimately depends on the purpose of screening for hearing loss in that population. For example, if the purpose of hearing screening is to identify only individuals likely to benefit substantially from amplification, the cutoff score will be higher than the cutoff score used to identify individuals with *any* level of hearing impairment. Alternatively, rather than using a cutoff score, HHIE score can also be treated as a continuous variable, with increasing values indicating an increase in self-reported hearing impairment.

1.2.3 Self-Report Measures versus Pure-Tone Audiometry

Given that self-report measures of hearing are widely used as screening tools for hearing loss, a number of studies have examined the relationship between pure-tone audiometry and self-report measures of hearing in older adults (Brainerd & Frankel, 1985; Chang et al., 2009; Clark et al., 1991; Kramer, Kapteyn, Festen & Tobi, 1996; Lutman et al., 1987; Nondahl et al., 1998; Sindhusake et al., 2001; Uchida et al., 2003). Some of these studies have suggested that self-report is a satisfactory method to assess hearing impairment and subsequent activity limitations and participation restrictions (Clark et al., 1991; Kramer et al., 1996; Lutman et al., 1987). Both Lutman and colleagues (1987) and Kramer and colleagues (1996) proposed that self-report measures provide a more comprehensive picture of functional hearing status and therefore have a higher external validity than pure-tone audiometry. Moreover, a number of large-scale epidemiological studies conclude that self-report measures such as the HHIE are sufficiently sensitive and specific to provide reasonable estimates of hearing loss prevalence, even though they tend to underestimate hearing loss (Nondahl et al., 1998; Sindhusake et al., 2001; Uchida et al., 2003).

However, other investigations have demonstrated that the correlation between hearing impairment and self-reported hearing handicap in elderly adults is only moderate, with correlation coefficients ranging from 0.38 to 0.61 (Brainerd & Frankel, 1985; Chang et al., 2009; Weinstein & Ventry, 1983). Chang and colleagues (2009) found that only 21.4% of subjects with moderate to profound hearing impairment perceived themselves as hearing impaired on the HHIE-short version (HHIE-S), suggesting that factors other than degree of hearing impairment contribute to self-reported hearing. Indeed, several investigations have examined the effects of non-auditory variables on self-reported hearing impairment. In 1991, Gatehouse examined self-rated auditory disability in relation to non-verbal IQ and personality. He found that IQ and personality had a large impact on self-reported disability, explaining 20% more variance than the variance explained by hearing threshold and age (Gatehouse, 1990). Similar findings were reported by Cox, Alexander and Gray (2007), who assessed the relative contributions of personality and audiometric data to self-reports of hearing. Their findings demonstrated that personality characteristics, particularly neuroticism, were more predictive of self-reported hearing than was severity of audiometric hearing loss. Additionally, individuals who scored higher in agreeableness and conscientiousness were more likely to display response bias on the self-report of hearing, reporting fewer hearing problems in order to portray themselves more positively.

Another non-auditory factor that may contribute to self-reports of hearing is age. Research has consistently demonstrated that people in different age groups are likely to assess their hearing problems differently, with older adults being less likely to self-report participation restrictions compared with younger respondents, even after correcting for degree of hearing loss (Gatehouse, 1990; Gordon-Salant, Lantz, & Fitzgibbons, 1994; Lutman et al., 1987; Sindhusake et al., 2001; Smits, Kramer, & Houtgast, 2006; Uchida et al., 2003; Wiley, Cruickshanks, Nondahl, & Tweed, 2000). Numerous explanations for this age difference have been postulated. In their 2005 systematic review, Valete-Rosalino and Rozenfeld (2005) suggested that older adults may underestimate their hearing difficulty because of the popular belief that hearing loss is a normal part of aging, rather than a health problem that deserves special attention. Furthermore, since the progression of hearing loss in older adults is typically a gradual one, changes in communication function may be subtle and go largely unrecognized. Contrary to these findings from Valete-Rosalino and

Rozenfeld, which demonstrate that older adults tend to minimize the problems caused by their hearing loss, Gordon-Salant and colleagues (1994) hypothesized that older adults with hearing loss may in fact experience fewer activity limitations and participation restrictions than younger adults with hearing loss. Older adults in retirement may have fewer communication demands than younger adults, so they may view hearing loss as a less significant health concern and score lower on self-report measures such as the HHIE (Gordon-Salant et al., 1994; Nondahl et al., 1998). Regardless, these studies imply that older adults may unreliably report their own hearing loss, and that hearing loss prevalence in older populations may be underestimated if it is measured solely by self-report (Nondahl et al., 1998).

The contribution of non-auditory factors to self-reports of hearing is particularly problematic in statistical models examining the association between self-reported hearing and other variables, particularly when those other variables are also based on self-report and may be subject to the same biases as self-reported hearing. Age and personality factors create an unknown degree of error in self-report hearing measurements, and the impact of this error on multivariate models is largely unknown (Sindhusake et al., 2001; Valete-Rosalino & Rozenfeld, 2005). Consequently, research that uses self-reported hearing is essentially comparing self-perceived hearing function and all of its associated non-auditory factors, rather than actual hearing loss, with other variables. Therefore, if the purpose of a study is to assess associations between hearing loss and other factors, an objective measure of hearing such as pure-tone audiometry is most appropriate. Audiometry is less influenced by non-auditory confounding variables than self-reported hearing because it uses a standardized, clinician-administered protocol. Using audiometric measures of hearing loss will therefore minimize the influence of unknown confounding variables on the relationship between hearing loss and other variables such as psychosocial outcomes.

1.3 Depression and Aging

Depression is one of the most common mental health disorders in North America, and is thought to be the most frequent cause of emotional suffering in older adults (Blazer, Burchett, Service, & George, 1991; Blazer, Hughes, & George, 1987; Patten et al., 2006). According to data from the 2003 Canadian Community Health Survey, approximately 6.4% of Canadian adults over 65 years of age will suffer from a major depressive disorder (Béland, 2002). Many clinicians and researchers agree that, by comparison to depression in younger adults, depression in adults over 65 requires special consideration because it is often complicated by other age-related health issues (Chou & Chi, 2005; Dozeman et al., 2010; Drayer et al., 2005; Lebowitz et al., 1997; Newmann, Engel, & Jensen, 1991). Furthermore, if left untreated, depression in older adults may in turn contribute to morbidity and mortality in other age-related health conditions (Ramasubbu & Patten, 2003).

The diagnostic criteria of major depression are defined in the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) of the American Psychiatric Association (1994; see Appendix C). These diagnostic criteria consist of a number of depressive symptoms. However, some researchers suggest that the presentation of depression may be quite different in older adults than in younger persons, and that older adults may not exhibit the typical symptoms of major depression (Gallo & Gonzales, 2001; Gallo & Rabins, 1999). They may experience more helplessness (Depue & Monroe, 1978), hopelessness (Abramson, Metalsky, & Alloy, 1989) and anxiety (Gallo & Rabins, 1999) than younger adults. Furthermore, older adults with depression often exhibit somatic symptoms such as fatigue or loss of appetite, which may be mistaken for a physical illness (Drayer et al., 2005). Because of the somewhat atypical presentation of depression and increased somatic complaints in this population, researchers and clinicians working with older adults should use depression screening tools that assess certain depressive symptoms, such as social withdrawal or feelings of hopelessness, in addition to symptoms in the DSM-IV (Radloff, 1977; Sheikh & Yesavage, 1986). Depressive symptoms included in such screening tools represent symptoms that may contribute to major depression, but are not diagnostic of a major depressive episode.

Depression is the result of a complex set of predictive factors. A systematic review conducted by Djernes in 2006 determined that the main predictors of depressive disorders and depressive symptoms in older adults are female gender, somatic illness, cognitive impairment, functional impairment, lack or loss of close social contacts, and a history of depression. Another study of a large sample of community-dwelling adults emphasized that depression was most strongly predicted by social isolation (Hawthorne, 2008). Growing attention is being paid to these predictors as a means of identifying high-risk groups and preventing late-life depression. Accordingly, Smit, Ederveen, Cuijpers, Deeg, and Beekman (2006) suggested that the most cost-effective preventative interventions for depression are those focused on older adults with depressive symptoms, functional deficits, and a small social network size. Thus, efforts to lower the prevalence of depression in the elderly should target prevention and treatment of chronic illness and health related functional impairment, and compensation for social isolation (Djernes, 2006). Hearing loss meets these criteria and thus should be one of the areas targeted for depression prevention and treatment. For this reason, the current study examines the relationship between hearing loss and depressive symptoms in older adults, and aims to determine whether hearing loss is a modifiable contributor to symptoms of depression.

1.3.1 Depression Evaluation Tools

A wide range of instruments to evaluate depression exists. In order to select an appropriate instrument, the clinician or researcher must take into account the characteristics of the sample population and the purpose of evaluating depressive symptoms in that population (Colasanti, Marianetti, Micacchi, Amabile, & Mina, 2010). When designing the current study, we identified a number of characteristics that would constitute an ideal depression measure given our sample population and research goals. First, the depression measure should explore a broad range of emotional and social symptoms of depression, and quantify both number and severity of depressive symptoms. This will allow us to explore the potential multi-factorial impact of hearing loss on social and emotional function and determine whether certain depressive symptoms are more prevalent than others. Second, the chosen depression measure should be validated for use on an older adult population, and should be feasible for use on adults with up to mild cognitive impairment. Third, the depression measure should limit items pertaining to somatic symptoms that might be due to depression as well as to physical disorders. This will minimize the contribution of confounding co-morbid conditions to the depression score. Finally, the depression measure should be easy and relatively quick to administer, suitable for administration by untrained interviewers.

The majority of depression evaluation instruments are screening tools, designed to facilitate case-finding and the diagnosis of depression, and are not intended as a substitute for diagnostic clinical interviews or objective diagnostic techniques. Most depression screening instruments have been validated by comparison with a comprehensive diagnosis performed by a mental health professional. In the majority of research studies, the gold-standard for comparison is criteria from a version of the DSM, such as the DSM-IV (American Psychiatric Association, 1994). In some cases, the comparison is a diagnosis of depression based on a semi-structured or structured interview, such as the Structured Clinical Interview for the DSM (SCID; First & Gibbon, 2004). Depression screening tests may be administered by an evaluator (hetero-evaluation scales) or by the patients themselves (self-rating scales).

1.3.1.1 Hetero-evaluation tools.

Perhaps the most widely known hetero-evaluation scale for depression is the Hamilton Depression Rating Scale (HAM-D; Hamilton, 1960). The HAM-D is considered the gold standard of hetero-evaluation scales when studying depression, and is the scale against which many depression scales are compared (Bagby, Ryder, Schuller, & Marshall, 2004). Other commonly used hetero-evaluation scales for depression include the Cornell Scale for Depression in Dementia (CSDD; Alexopoulos, Abrams, Young, & Shamoian, 1988), the Montgomery-Asberg Depression Rating Scale (MADRS; Montgomery & Asberg, 1979) and the Retardation Rating Scale (RRS; Bonin-Guillaume, Sautel, Demattei, Jouve, & Blin, 2007). These hetero-evaluation scales are limited by the fact that proper administration requires a trained interviewer with specific psychiatric skills. As such, hetero-evaluation scales are not ideal for research conducted by untrained interviewers.

1.3.1.2 Self-rating scales.

Self-rating scales of depression are simple instruments that are completed by the respondent and then scored by the interviewer. Owing to their self-response structure, such instruments are only suited to respondents with good cognitive function, as reviewed by

Colasanti et al. (2010). Two commonly used self-rating scales are the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) and the Self-rating Depression Scale (SDS; Zung, 1965; Zung, 1967). The BDI has been widely used for monitoring variations in the severity of depression over time (Beck, 1988). However, the BDI has not been used extensively for depression screening in older adults, and may in fact tend to overestimate depression in geriatric patients since it contains items on somatic symptoms. Similarly, the SDS carries a high risk for false positives in adults over 70 years because it gives emphasis to somatic complaints (Yesavage et al., 1982). Due to the limitations of the BDI and the SDS, the two most widely used screening instruments for depressive symptomatology among older populations are the Geriatric Depression Scale (GDS; Sheikh & Yesavage, 1986) and the Center for Epidemiological Studies-Depression Scale (CES-D; Radloff, 1977).

The GDS is a 30-item self-report scale designed to screen for clinical depression in adults over 55 years of age. The scale is based on yes/no questions, with each item scored 0 or 1 points. Questions have been formulated to target the most frequent symptoms in depressed geriatric patients and to exclude certain somatic symptoms. This scale has high criterion validity, with a sensitivity of approximately 75 % and specificity of 77%, depending on the cut-point used (Wancata, Alexandrowicz, Marquart, Weiss, & Friedrich, 2006). The GDS also has high test-retest reliability, even in patients with mild cognitive impairment.

The CES-D is a 20-item self-report scale (see Appendix B.2) that was developed to measure current level of depressive symptomatology in community-dwelling adults (Radloff, 1977). It has since been validated for use in older adults, including those with mild cognitive impairment (Radloff & Teri, 1986). The scale was designed for use in studies of the relationships between depression and other variables. The items of the scale are symptoms associated with depression, including: depressed mood, feelings of guilt and worthlessness, feelings of helplessness and hopelessness, psychomotor retardation, loss of appetite and sleep disturbance. The items on the scale that assess somatic symptoms have minimal overlap with symptoms of physical illness (Berkman et al., 1986). Each symptom is rated by frequency of occurrence within the past week on a scale ranging from 0 (rarely or none of the time) to 3 (most or all of the time). Responses are scored on a scale from 0 to 60, with high scores suggesting a greater severity of depressive symptoms. Different scores have been proposed as a cutoff above which individuals have a significant level of psychological distress, but the choice of a cutoff ultimately depends on characteristics of the sample population, as well as the purpose of screening for depressive symptoms in that population. The CES-D scale has high criterion validity, with a sensitivity of approximately 71% and specificity of 79%, depending on the cutoff score used (Wancata et al., 2006). Rather than using a cutoff score, CES-D score can also be treated as a continuous variable, with increasing scores indicating an increased severity of depressive symptoms.

Comparison studies of self-rating scales for depression demonstrate that both CES-D and the GDS have excellent properties, including similar criterion validity, for use as depression screening instrument in elderly patients (Blank, Gruman, & Robison, 2004; Lyness et al., 1997; Wancata et al., 2006). However, setting is a central consideration in the selection of a screening instrument, and the CES-D has been shown to work best in medical and outpatient settings, while the GDS seems to work best in nursing homes (Blank et al., 2004). Furthermore, as opposed to the GDS, which contains only yes-no items, the CES-D Scale allows for classification of both severity and number of depressive symptoms.

1.4 Purpose of Study

If hearing loss contributes towards symptoms of depression, then it is vital that the relationship is understood so that the symptoms of each can be treated appropriately. Previous research has established a strong relationship between self-reported hearing loss and depressive symptoms, wherein depressive symptoms increase as severity of self-reported hearing loss increases. However, research has yet to establish conclusively that this relationship does not simply represent the influence of non-auditory factors on self-report measures of hearing. As such, there is a need to investigate this relationship using objective measures of hearing, to reduce the contribution of non-auditory factors to the apparent correlation. Therefore, the primary purpose of the proposed study is to quantify the relationship between hearing loss and depressive symptoms in older adults using objective measures of hearing.

Four main research questions were addressed. First, we compared two objective measures of hearing, DPOAEs and pure-tone audiometry, to confirm the objectivity of audiometric thresholds in the study sample. The finding of a significant correlation between pure-tone audiometry and DPOAE results would support the use of audiometric thresholds as an objective measure of hearing in this study. Second, we determined whether the strength of the relationship between the subjective measure of hearing (HHIE score) and the objective measure of hearing (PTA) in the sample population was consistent with values reported in the literature. Third, we determined whether the previously described relationship between subjective hearing loss (HHIE score) and symptoms of depression (CES-D score) exists in the sample population. Finally, we determined whether a relationship exists between objective measures of hearing (PTA) and symptoms of depression (CES-D score), and quantified the strength of this relationship. Based on the results of previous studies, we hypothesized that **both** self-reported hearing loss and depressive symptoms would increase as degree of objectively-measured hearing loss increased. This relationship should not depend on age, gender and educational level.

2 Methods

The following chapter includes 5 sections. The first gives information about the method of participant recruitment. The second provides information about the study participants. The third section describes the instruments and study protocol used for each testing session. The fourth section describes how results from each instrument were scored or compiled in preparation for analysis. The final section describes how the results were analyzed in order to address our research questions.

2.1 Recruitment

Participants were recruited using two main methods: via physicians at hospital-based geriatric clinics (specifically, the geriatric psychiatry outreach team at Vancouver General Hospital and the geriatric outpatient clinic at St. Paul's Hospital), and via community-based self-identification. At the geriatric clinics, flyers indicating the inclusion criteria were posted in both the waiting rooms and clinicians' offices. The inclusion criteria required that all participants were age 65 years and older, had never used hearing aids nor attended aural rehabilitation classes, were fluent speakers of Canadian English and had no more than a mild cognitive impairment. The flyers advised potential participants to speak to their clinician if they were interested in learning more about the study. If the clinician then determined that a participant met the proposed inclusion criteria, the clinician gave the potential participant an invitation letter with instructions on how to contact the researchers if he or she was interested in participating in the study. Clinicians at the geriatric clinics also actively recruited participants who met the proposed inclusion criteria but may not have noticed the flyers.

In the community, flyers indicating the inclusion criteria were posted in public venues including adult community centres, libraries and private physician's offices. Flyers were also sent to a mailing list of UBC Faculty of Medicine volunteer patients. The flyers advised potential participants to contact the researchers if they were interested in participating.

2.2 Participants

Forty-six participants took part in this study. All participants were adults age 65 years and older who had never used hearing aids nor attended aural rehabilitation classes and were fluent speakers of Canadian English. One female participant was excluded from the analysis due to a long-standing profound unilateral hearing loss for which exact audiometric thresholds could not be obtained and seemed unlikely to be ARHL. Of the remaining 45 participants, 27 females and 18 males (mean age 73.4 years) completed the study. Seven participants were recruited via clinician referral and the remaining 38 were recruited via community-based self-referral. Demographic and background information for the 45 participants is presented in Table 3.1.

Participants recruited through geriatric clinics were judged by the referring clinician to have no more than a mild cognitive impairment. Participants who were recruited through community-based self-referral were screened for cognitive function using the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975), shown in Appendix D. The minimum required score was 24/30, which is the recommended cut off score to rule out more than a mild cognitive impairment (Mitchell, 2009). All self-referred participants passed the MMSE screening, with scores ranging from 24 to 30. Otoscopy and tympanometry were also performed to ensure that both ear canals were free of major obstructions or gross abnormalities that would interfere with audiometry and DPOAE measurement. For all participants, no contraindications were observed upon otoscopic or tympanometric exam.

2.3 Instrumentation and Procedure

Each participant took part in a single session of approximately one and a half hours. All participants were given a $15 honorarium for their participation in the research session. During this session, participants were first asked to review and sign an information and consent form. Next, the MMSE screening (if needed) and background information form (see Appendix E) were completed, followed by otoscopy and tympanometry. Once these screening measures were complete, testing consisted of 1) objective hearing tests: pure-tone audiometry and DPOAEs, and 2) questionnaires: the HHIE and CES-D. The order of test administration was counterbalanced such that half of the participants completed the questionnaires first, and half of the participants completed the objective hearing tests first. Pure-tone audiometry and DPOAE testing were conducted in a double-walled audiometric sound booth at either the University of British Columbia School of Audiology and Speech Sciences or the Western Institute for the Deaf and Hard of Hearing (WIDHH) audiology clinic. WIDHH was used as a second test site due to its proximity to the recruitment sites and to public transportation. Participants were offered their choice of testing location when the appointment was scheduled.

2.3.1 Tympanometry

Single-frequency tympanograms were measured with standard clinical tympanometers using a 226-Hz probe tone to obtain tympanometric peak pressure (TPP), ear canal volume (ECV), and peak-compensated static admittance (SA). Tympanometry was considered normal if ECV was between 0.9 c^3 and 2.0 c^3 (Wiley et al., 1996), SA was between 0.2 and 1.5 mmhos (Roup, Wiley, Safady, & Stoppenbach, 1998; Wiley et al., 1996) and if TPP was between +50 and -100 daPa (Jerger, 1970). Tympanograms were then categorized using Jerger tympanometric types, in which SA and TPP are used to classify tympanograms by shape (Jerger, 1970). Jerger tympanometric types, in conjunction with ECV and otosccopic findings, were used to verify an intact tympanic membrane and an unoccluded ear canal. More information on the Jerger classification system is provided in Appendix F.

2.3.2 Pure-Tone Audiometry

Pure-tone audiometric testing was completed using standard diagnostic audiometers (*Grason Stadler GSI-61*). All audiometers at both testing sites had been calibrated according to American National Standards Institute (ANSI S3.6-2004*)* standards (2004). Ambient noise levels in each sound booth were measured, as part of annual calibration, to maintain compliance with ANSI S3.1-1991 standards (1991). Pure-tone air conduction thresholds were established using insert earphones (Ear Tone ER-3A) in each ear at the standard octave and interoctave audiometric frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. Thresholds were obtained using the modified Hughson-Westlake procedure, as outlined in Appendix A (Carhart & Jerger, 1959).

2.3.3 DPOAEs

DPOAE testing was performed using one of three OAE systems: i) Intelligent Hearing Systems USB box and SmartOAE Software, ii) Otodynamics Otoport DP & TE and Otolink ILO version 6 software, or iii) Otodynamics Echoport ILO0292 USB-1 and Otolink ILO version 6 software. All three systems are standard clinical systems that provide equivalent measurements; the test system used for each participant depended solely on test location and equipment availability. DPOAE responses were obtained using an OAE probe tip in each ear at DPOAE 2f1 – f2 frequencies of 1500, 2000, 3000, 4000, 6000 and 8000 Hz.

These frequencies were chosen because they represent the frequencies for which DPOAE test performance is best when pure-tone threshold at a single frequency is used as the gold standard (Dorn, Piskorski, Gorga, Neely, & Keefe, 1999; Gorga et al., 1993a; Gorga et al., 1997; Stover, Gorga, Nelly, & Montoya, 1996). The primary frequency ratio (f2/f1) was 1.22, and primary levels were set at 65 dB SPL (L1) and 55 dB SPL (L2). Using these parameters, the region of the cochlea activated is near the f2 place, and therefore the presence of a 2f1-f2 DPOAE reflects normal cochlear function at the f2 place (Brown & Kemp, 1984; Gaskill & Brown, 1996; Martin et al., 1990). Presence or absence of a 2f2-f1 DPOAE can therefore be used to verify a normal or impaired audiometric threshold at the pure-tone frequency closest to f2.

2.3.4 HHIE

HHIE questionnaires were given to participants in paper form printed in 18-point Verdana font (see Appendix B). The questionnaire was self-administered by the participant and took approximately 10 minutes to complete.

2.3.5 CES-D

CES-D questionnaires were given to participants in paper form printed in 18-point Verdana font (see Appendix C). The questionnaire was self-administered by the participant and took approximately 10 to 15 minutes to complete.

2.4 Treatment of the Data

Hearing levels were quantified by calculation of two different pure-tone averages (PTA) for each ear, i) PTA using threshold values at 500, 1000, 2000 and 4000 Hz (e.g., as used by Nondahl et al., 1998; Sindhusake et al., 2001), hereafter referred to as “PTA” and ii) high-frequency PTA using threshold values at 1000, 2000, 4000 and 8000 Hz, hereafter referred to as "HF PTA". For the purpose of analysis, better ear PTA was used since better ear hearing status may be a more important predictor of functional impact (Brainerd & Frankel, 1985; Gates et al., 1990; Sindhusake et al., 2001). DPOAE results were analyzed with a "pass" at a single frequency defined as an SNR of ≥ 9 dB SPL. An overall DPOAE score was calculated by counting the number of DPOAE frequencies failed in each ear.

HHIE score was calculated by the researcher after each session. Each of the 25 items on the questionnaire was assigned a value of 4 points (yes), 2 points (sometimes) or 0 points (no). The points for each item were then summed to give a total score, with scores ranging from 0 (least possible hearing handicap) to 100 (worst possible hearing handicap) (Ventry & Weinstein, 1982). CES-D score was also calculated by the researcher after each session. Each of the 20 items was assigned a value of 3, 2, 1 or 0 points. The points for each item were then summed to give a total score, with scores ranging from 0 (low psychological distress) to 60 (high psychological distress). Data from the background information form was used to categorize potential covariates, including age, gender, living arrangement and education (see Table 3.1). Living arrangement was treated as a dichotomous variable (alone or with others), while education was treated categorically.

2.5 Statistical Analysis

Statistical analysis was performed with SPSS version 11.5.0 for Windows (SPSS Inc., 2002). Four main research questions were addressed. First, to support the use of audiometric thresholds as an objective measure of hearing, better ear high-frequency PTA was analyzed in comparison to DPOAE results. Pearson product-moment correlation coefficients were calculated using high frequency PTA as the dependent variable and number of DPOAE frequencies failed as the independent variable (*N*= 90 ears). HF PTA was used for this analysis because DPOAE responses are more representative of cochlear function in high-frequency regions of the basilar membrane (Arnold, Lonsbury-Martin, & Martin, 1999; Schmuziger, Probst, & Smurzynski, 2005). Next, three separate multiple regression analyses, all following the same structure, were conducted: i) to examine the relationship between the subjective and objective measures of hearing, a regression analysis was conducted with HHIE score as the dependent variable and better ear PTA as the independent variable; ii) to determine the relationship between the subjective measure of hearing and depression score, a regression analysis was conducted with CES-D score as the dependent variable and HHIE score as the independent variable; iii) to determine the relationship between the objective measure of hearing and depression score, a regression analysis was conducted with CES-D score as the dependent variable and better ear PTA as the independent variable.

All three regression analyses followed a two-step procedure. First, a forward regression was performed using potential covariates to determine the subset of predictor variables that significantly affected the dependent variable. The variables examined as possible covariates for depression score were age, living arrangement and education. An additional covariate, worse ear PTA, was included in the analysis of CES-D and better ear PTA. In the second step of the regression analysis, the predictor variables of interest were forced into the regression model. All regression models were built by examining the contribution of the potential predictor variables using alpha-level criterion of $p < 0.05$. Statistical significance for the regression model was determined using a one-way ANOVA. Results of correlation analysis and the regression analyses were considered significant if $p < 0.05$.

3 Results

The following chapter outlines the results of the statistical analyses performed on the study data. In the first section, the characteristics of the study sample are reported, including descriptive statistics, audiometric and tympanometric data, and depression score data. Next, correlations among all possible predictor variables are presented. Then, the results from the correlation analysis between audiometry and DPOAE results are presented. The audiometry-DPOAE correlation analysis addresses the first research question about the use of audiometry as an objective measure of hearing. Following that, results are presented from the regression analyses for i) the subjective and objective hearing measures, and ii) the subjective hearing measure and the depression score. These combined analyses address the second and third research questions, about the relationship between subjective and objective measures of hearing, and the relationship between subjective hearing loss and depressive symptoms, in our study population. Finally, results regarding the regression analysis for the objective measure and the depression score are reported. These results help to answer our fourth and primary research question, whether there is a relationship between objective hearing loss and depressive symptoms.

3.1 Characteristics of the Study Sample

The descriptive statistics of the study sample are presented in Table 3.1, classified by participant age and gender.

Table 3.1. Gender and Age-Stratified Descriptive Statistics for the Study Sample

	Age (yrs)								
	All Ages	65-69		70-74		75-79		≥80	
	Total	M	F	M	F	M	F	M	F
N	45	7	10	3	8	5	5	3	4
Education									
Less than high school	6	1	0	0	0	0	1	1	3
High school diploma	7	0	0	1	3	1	0	1	1
Trade-vocational	4	1	1	0	1	0	1	0	0
Non-university post secondary	6	0	2	0	2	1	1	0	0
University	22	5	7	2	2	3	2	1	0
Living Arrangement									
Living alone	25	1	8	1	4	3	5	1	2
Living together with partner or others	20	6	2	2	4	2	0	2	2
Recruitment Source									
Clinic	7	0	1	1	1	0	3	0	1
Community	38	7	10	2	7	5	2	3	3
Mean Self-Reported Duration of Hearing Loss (yrs) (*SD*)	6.6 (*11.2*)	6.7 (*8.8*)	5.9 (*6.4*)	17.8 (*31.0*)	6.7 (*7.8*)	1.0 (*1.7*)	6.4 (*10.3*)	4.0 (*5.2*)	2.7 (*3.1*)

Mean tympanometric data for the study sample are presented in Table 3.2, classified by participant age and gender.

Table 3.2. Gender and Age-Stratified Tympanometric Data for the Study Sample

	Age (yrs)								
	All Ages	65-69		70-74		75-79		≥80	
	Total	M	F	M	F	M	F	M	F
N (ears)	89	14	20	6	16	10	10	6	7
Jerger tympanogram classification									
A	81	14	19	6	16	8	8	4	6
As	0	0	0	0	0	0	0	0	0
Ad	1	0	0	0	0	0	1	0	0
B	1	0	0	0	0	0	1	0	0
C	6	0	1	0	0	2	0	2	1

Mean audiometric data for the study sample are presented in Table 3.3, classified by participant age and gender.

Table 3.3. Gender and Age-Stratified Audiometric Data for the Study Sample

	Age (yrs)							
	65-69		70-74		75-79		≥80	
	M	F	M	F	M	F	M	F
PTA dB HL (*SD*)								
Better ear	22.68 *(6.06)*	19.88 *(15.36)*	21.67 (*13.01*)	21.88 (*9.23*)	31.50 (*15.94*)	27.50 (*7.65*)	24.58 (*8.13*)	33.44 (*5.81*)
Worse ear	26.25 (*5.50*)	28.5 (*16.37*)	25.83 (*14.05*)	24.69 (*8.55*)	41.50 (*19.41*)	38.00 (*4.56*)	26.25 (*8.20*)	38.13 (*4.84*)
HF PTA dB HL (*SD*)								
Better ear	29.29 (*8.31*)	25.50 (*16.45*)	31.25 (*15.96*)	29.22 (*11.89*)	41.58 (*11.62*)	37.50 (*6.43*)	39.58 (*12.01*)	45 (*3.68*)
Worse ear	33.04 (*9.68*)	34.50 (*14.65*)	35.83 (*16.12*)	34.06 (*12.57*)	51.25 (*14.82*)	49.25 (*5.05*)	40.83 (*11.61*)	50.63 (*3.61*)

Note. *N* = 45. PTA frequencies were 0.5, 1, 2 & 4 kHz. High-frequency PTA frequencies were 1, 2, 4 & 8 kHz. PTA = pure tone average; dB HL = decibels hearing level; HF PTA = high-frequency PTA.

Responses to individual CES-D questionnaire items (depressive symptoms) for the study sample are presented in Table 3.4, classified by participant age and gender, and categorized according to the pattern of factor loadings described by Radloff (1977).

Table 3.4. Gender and Age-Stratified Responses to Individual CES-D Items for the Study Sample, Categorized According to Factor Loadings

	Age (yrs)								
	65-69		70-74		75-79		≥80		All Ages
CES-D Item	M	F	M	F	M	F	M	F	Total
Depressed Affect									
14. I felt lonely.	1	4	1	3	2	4	0	1	16
18. I felt sad.	1	3	1	4	2	3	1	1	16
6. I felt depressed.	1	4	1	2	2	4	1	0	15
9. I thought my life had been a failure.	1	2	1	4	1	3	0	0	12
3. I felt that I could not shake off the blues even with help from my family or friends.	1	2	1	2	1	2	0	0	9
10. I felt fearful.	1	1	0	2	0	1	1	1	7
17. I had crying spells.	0	3	0	0	0	0	0	0	3
Positive Affect									
8. I felt hopeful about the future.	1	4	1	4	2	1	1	1	15
12. I was happy.	2	4	1	4	0	1	0	0	12
4. I felt that I was just as good as other people.	1	1	1	3	2	0	0	2	10
16. I enjoyed life.	1	3	1	3	0	2	0	0	10
Somatic and Retarded Activity									
11. My sleep was restless.	4	5	3	5	3	3	1	2	26
1. I was bothered by things that usually don't bother me.	7	2	1	3	2	4	0	1	20
5. I had trouble keeping my mind on what I was doing.	3	0	1	4	3	3	2	1	17
7. I felt that everything I did was an effort.	2	3	1	3	3	3	1	1	17
20. I could not get "going".	1	4	1	3	4	3	0	1	17
13. I talked less than usual.	1	1	1	1	0	1	0	0	5
2. I did not feel like eating; my appetite was poor.	1	0	0	1	1	1	0	0	4
Interpersonal									
15. People were unfriendly.	0	1	1	1	1	0	0	0	4
19. I felt that people dislike me.	0	0	0	1	0	3	0	0	4

Note. N = 45. Totals indicate the number of participants who reported experiencing a particular item at least "some or a little of the time (1-2 days)" during the past week. CES-D = Center for Epidemiological Studies Depression scale. The pattern of factor loadings is adapted from "The CES-D Scale: A Self-Report Depression Scale for Research in the General Population," by L.S. Radloff, 1977, *Applied Psychological Measurement, 1*, 385-401.

3.2 Correlations among Predictor Variables

The correlations among all possible pairs of predictor variables are presented in Table

3.5, with significant correlations (p<0.05) starred*.

Table 3.5. Pearson Correlations (*r*) Among All Possible Pairs of Predictor Variables

	Age	Living Arrangement	Education	HHIE Score	Better Ear PTA	Worse Ear PTA
Age	1.000	.045	-.544*	.113	.320*	.271*
Living Arrangement	—	1.000	-.052	-.230	-.150	-.283*
Education	—	—	1.000	-.067	-.241	-.243
HHIE Score	—	—	—	1.000	.647*	[a]
Better Ear PTA	—	—	—	—	1.000	.865*
Worse Ear PTA	—	—	—	—	—	1.000

Note. *Correlation is significant at the 0.05 level (1-tailed). HHIE = Hearing Handicap Inventory for the Elderly; PTA = pure-tone average.
[a] This correlation analysis was not performed.

3.3 Correlation between High-Frequency PTA and DPOAE Results

Analysis of correlation between HF PTA and number of DPOAE frequencies failed was performed to confirm whether, in this sample, audiometric thresholds could be considered an objective measure of hearing. A scatter plot illustrating the correlation between number of DPOAE frequencies failed and HF PTA is shown in Figure 3.1. Pearson correlation coefficients indicated that there was a significant positive correlation between number of DPOAE frequencies failed and HF PTA (R^2=0.2704, N=90 ears, p< 0.01). These results show that HF PTA increased (i.e., hearing got worse) as number of DPOAE frequencies failed increased.

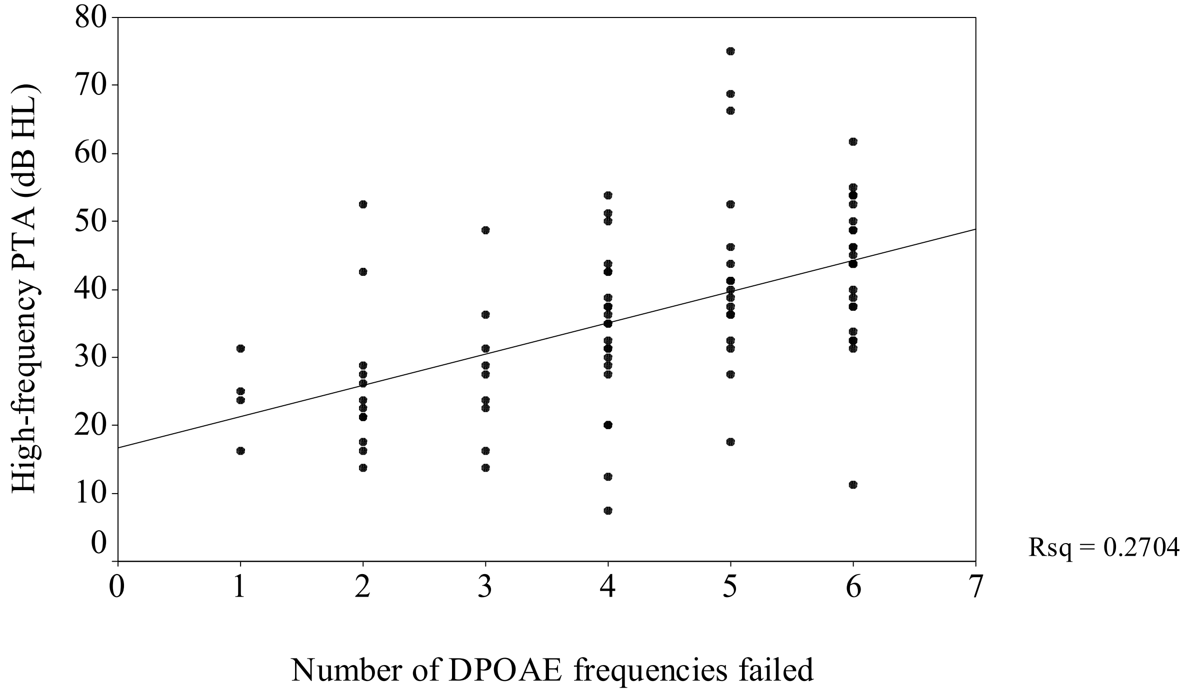

Figure 3.1. Scatter plot illustrating the relationship between number of DPOAE frequencies failed and high-frequency PTA.

Note. Trend line is the linear relationship between the variables. Each data point corresponds to one ear (*N* = 90 ears). PTA = pure-tone average; DPOAE = distortion product otoacoustic emission; dB HL = decibels hearing level.

3.4 Relationship between Subjective and Objective Measures of Hearing

A regression analysis was performed to determine the amount of variance in the subjective hearing measure (HHIE score) accounted for by the objective measure of hearing (better ear PTA). The purpose of this analysis was to determine whether the relationship between subjective and objective measures of hearing in the sample population was similar to that found by previous research. Table 3.6 shows the R^2 value for the regression model along with the significance of the model (F), and Figure 3.2 shows a scatter plot illustrating the relationship between subjective and objective measures of hearing. None of the covariates analyzed (age, living arrangement and education) were found to be statistically significant predictors and therefore were not pulled into the final regression model. It was found that the PTA accounted for 41.8% of HHIE score variance. The results show that HHIE score increased (i.e., got worse) as PTA increased (i.e., hearing got worse).

Table 3.6. Regression Model for HHIE Score Predicted by Better Ear PTA

Dependent Variable	Predictors Included in the Regression Model	*R*	R^2	*F*	*df1*	*df2*	Sig. *F*
HHIE Score	Better Ear PTA	.647	.418	30.895	1	43	.000

Note. Predictors excluded from regression model are not shown. HHIE = Hearing Handicap Inventory for the Elderly; PTA = pure-tone average.

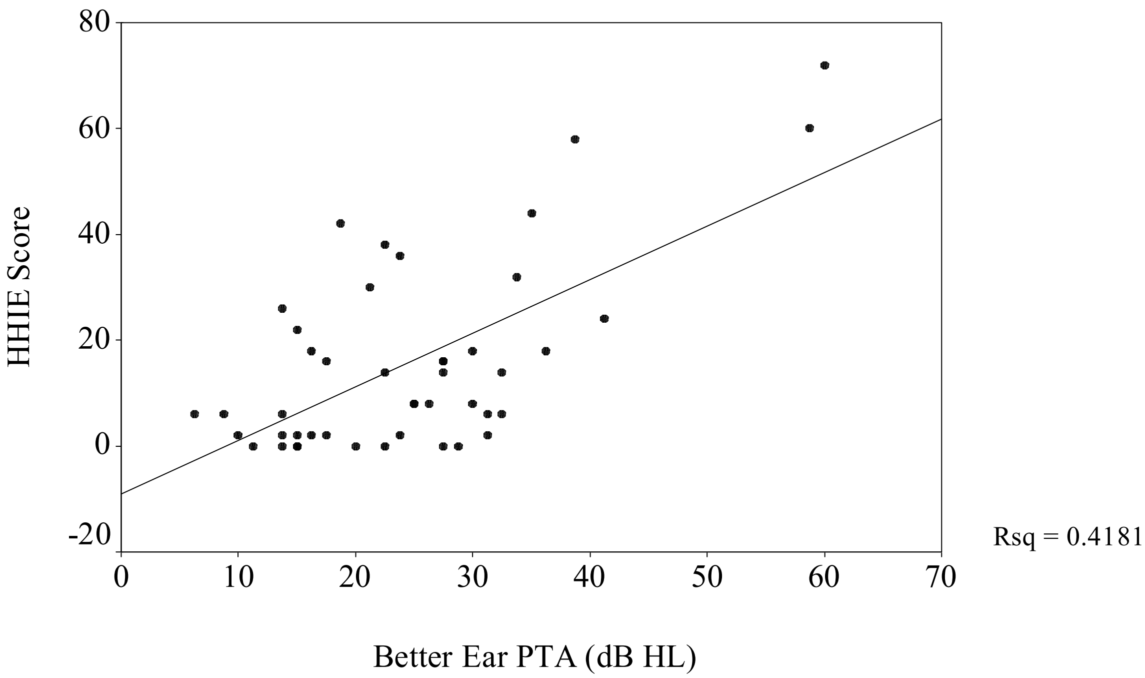

Figure 3.2. Scatter plot illustrating the relationship between HHIE score and better ear PTA.

Note. Trend line is the linear relationship between the variables. Each data point corresponds to one participant (*N* = 45). HHIE = Hearing Handicap Inventory for the Elderly; PTA = pure-tone average; dB HL = decibels hearing level.

3.5 Relationship between Subjectively Measured Hearing and Depression Score

A regression analysis was performed to determine the amount of variance in depression score (CES-D score) accounted for by the subjective measure of hearing (HHIE score). The purpose of this analysis was to determine whether the relationship between self-reported hearing loss and depression found by previous studies exists in the sample population. Table 3.7 shows the R^2 value for the regression model along with the significance of the model (F) and Figure 3.3 shows a scatter plot illustrating the relationship between HHIE score and CES-D score. None of the covariates analyzed (age, living arrangement and education) were found to be statistically significant predictors and therefore were not pulled into the final regression model. It was found that the HHIE score accounted for 26.4% of the CES-D score variance. The results show that CES-D score increased (i.e., got worse) as HHIE score increased (i.e., got worse).

Table 3.7. Regression Model for CES-D Score Predicted by HHIE Score

Dependent Variable	**Predictors Included in the Regression Model**	***R***	R^2	***F***	***df1***	***df2***	**Sig. *F***
CES-D Score	HHIE Score	.514	.264	15.415	1	43	.000

Note. Predictors excluded from regression model are not shown. CES-D = Center for Epidemiological Studies Depression scale; HHIE = Hearing Handicap Inventory for the Elderly.

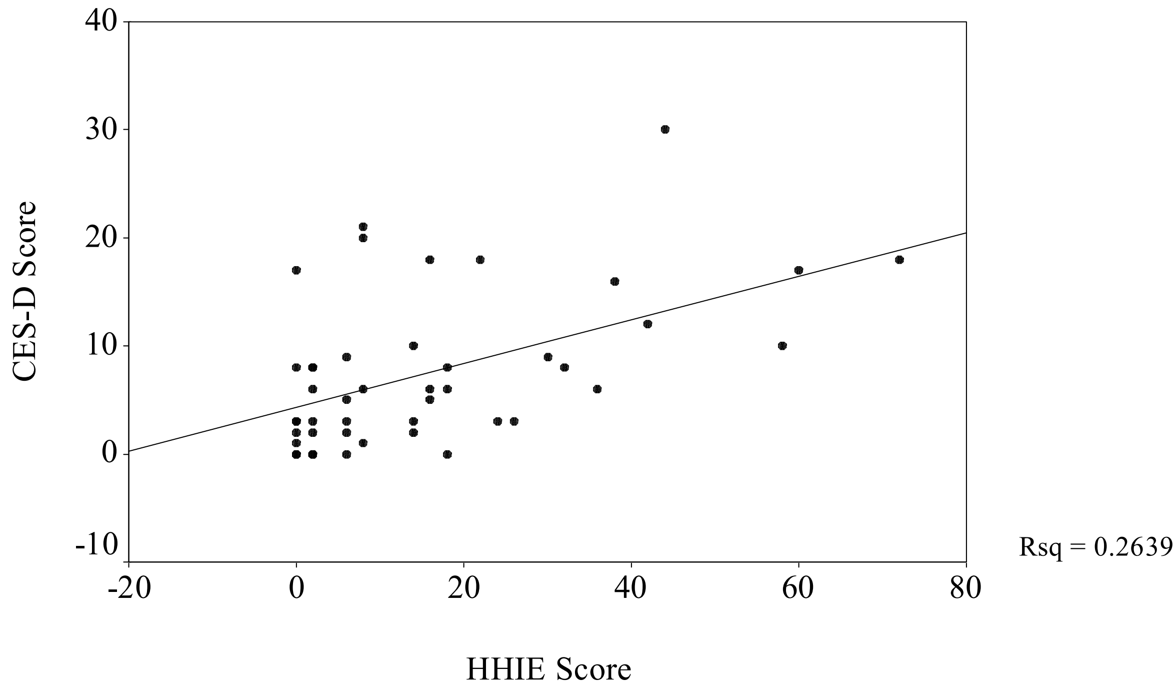

Figure 3.3. Scatter plot illustrating the relationship between HHIE score and CES-D score.

Note. Trend line is the linear relationship between the variables. Each data point corresponds to one participant (*N* = 45). CES-D = Center for Epidemiological Studies Depression scale; HHIE = Hearing Handicap Inventory for the Elderly.

3.6 Relationship between Objectively Measured Hearing and Depression Score

A regression analysis was performed to determine the amount of variance in depression score (CES-D score) accounted for by the objective measure of hearing (better ear PTA). The purpose of this analysis was to address our primary research question, whether there is a relationship between objectively measured hearing and depressive symptoms. Table 3.8 shows the R^2 value for the regression model and the significance of the model (F) and Figure 3.4 shows a scatter plot illustrating the relationship between better-ear PTA and CES-D score. None of the covariates analyzed (age, living arrangement, education and worse ear PTA) were found to be statistically significant predictors and therefore were not pulled into the final regression model. It was found that the PTA accounted for 10.2% of the CES-D score variance. The results show that CES-D scores increased (i.e., got worse) when better-ear PTA increased (i.e., hearing got worse).

Table 3.8. Regression Model for CES-D Score Predicted by Better Ear PTA

Dependent Variable	Predictors Included in the Regression Model	*R*	R^2	*F*	*df1*	*df2*	Sig. *F*
CES-D Score	**Better Ear PTA**	**.320**	**.102**	**4.891**	**1**	**43**	**.032**

Note. Predictors excluded from regression model are not shown. CES-D = Center for Epidemiological Studies Depression scale; PTA = pure-tone average.

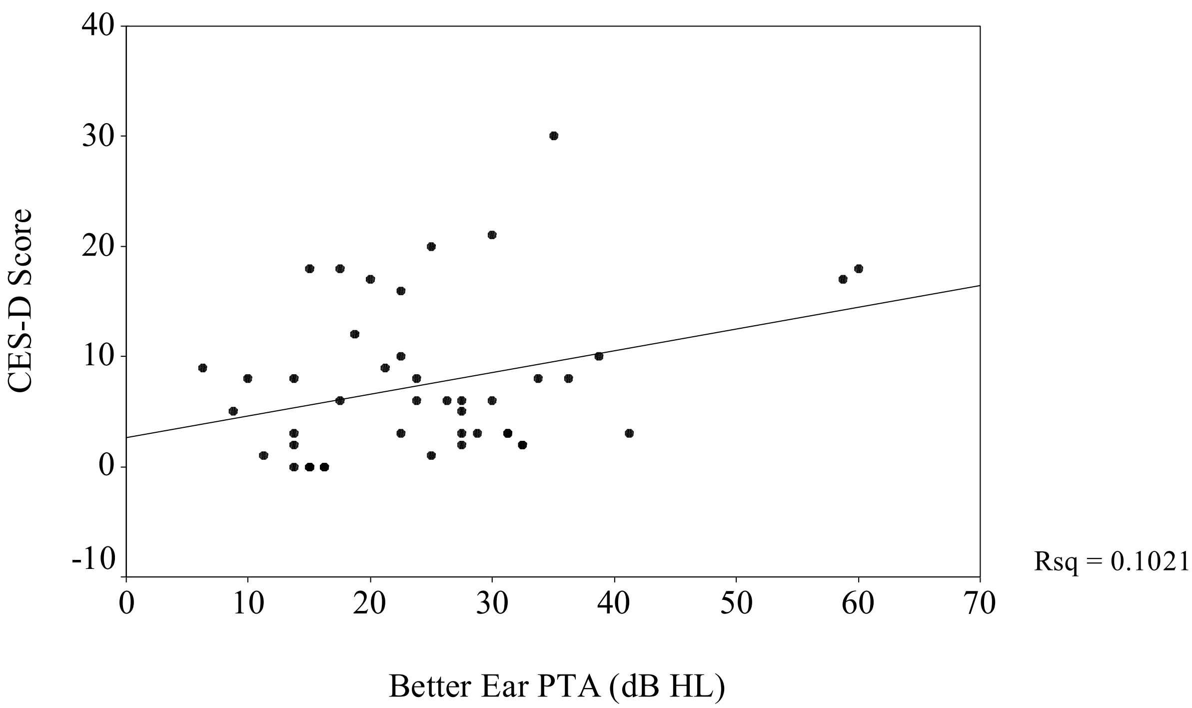

Figure 3.4. Scatter plot illustrating the relationship between better ear PTA and CES-D score.

Note. Trend line is the linear relationship between the variables. Each data point corresponds to one participant (*N* = 45). CES-D = Center for Epidemiological Studies Depression scale; PTA = pure-tone average; dB HL = decibels hearing level.

4 Discussion

The primary objective of this study was to investigate the apparent relationship between hearing loss and depressive symptoms using objective measures of hearing. In order to do so, four research questions were addressed. First, we compared two objective measures of hearing, DPOAEs and HF PTA, to confirm that audiometric thresholds could be considered an objective measure of hearing in the study sample. Second, we determined whether the strength of the relationship between the subjective measure of hearing (HHIE score) and the objective measure of hearing (PTA) in the study sample was consistent with values reported in the literature. Third, we determined whether the previously described relationship between subjective hearing loss (HHIE score) and symptoms of depression (CES-D score) exists in the sample population. Finally, we determined whether a relationship exists between objective hearing loss (PTA) and symptoms of depression (CES-D score), and quantified the strength of this relationship.

4.1 Characteristics of the Study Sample

The gender distribution of our participants was demographically representative: 40% of participants were male and 60% were female, consistent with the Canadian population estimates of 44% and 56%, respectively, for adults over 65 (Central Intelligence Agency, 2011). Fifty-six percent (25/45) of study participants reported living alone while 44% (20/45) reported living with others, values that are also demographically representative (Cranswick & Thomas, 2005). Our sample population also had a similar level of education to the general population of older adults in Vancouver, British Columbia: 71% of participants (32/45) reported having education beyond high school, 49% (22/45) of whom reported having a university education. Canadian Census data from 2006 showed that 50% of Vancouver-dwelling adults age 65 to 74 years and 70% of those age 75 years and over have a university education (Statistics Canada, 2006). Finally, when hearing impairment is defined as a better-ear PTA worse than 25 dB HL, 47% (21/45) of the participants in our study were classified as hearing impaired, a value consistent with results reported by large-scale epidemiological studies (Moscicki et al., 1985; Reuben et al., 1998; Sindhusake et al., 2001). Thus, with respect to gender, living arrangement, education level and hearing impairment, our sample population is similar to and representative of the general population of older adults.

During the testing session, participants were asked to indicate the age at which they first began to notice difficulty with their hearing. These data were collected with the intention of examining self-reported duration of hearing loss as a covariate for depression score. However, these data were not included in any analyses because we noted that most participants stated a highly approximate age, with many participants indicating an age range (e.g., "age 60-65"). Furthermore, in many cases (n = 15) subjects reported having no hearing difficulty, despite audiometric findings indicating a hearing loss. Given these limitations, duration of hearing loss was not included as a variable in the regression analyses because we suspected that it would introduce an unknown amount of error into the regression model.

4.2 Correlation between High-Frequency PTA and DPOAE Results

Our comparison of the two objective measures of hearing; that is, HF PTA and number of DPOAE frequencies failed, showed a significant positive correlation between the two variables (Pearson correlation coefficient (r)= 0.520), whereby HF PTA increased (i.e. hearing got worse) as number of DPOAE frequencies failed increased. Correlation analysis between DPOAEs and audiometry was performed using a high-frequency PTA (1, 2, 4 and 8 kHz) because there is evidence that hearing sensitivity at high frequencies is strongly correlated with DPOAE amplitude (Avan, Elbez, & Bonfils, 1997; Schmuziger et al., 2005). More specifically, DPOAE amplitude at a given 2f1-f2 frequency may in fact reflect cochlear damage in regions that are tuned to frequencies higher than the 2f1-f2 frequency (Schmuziger et al., 2005). For example, if a listener exhibits reduced or absent DPOAEs but normal hearing thresholds between 1 and 4 kHz, cochlear damage in the 8 kHz region may be influencing the DPOAE amplitude. Thus, by including 8 kHz in our HF PTA, we were able to optimize the correlation between DPOAEs and PTA and accurately assess the suitability of pure-tone audiometry as an objective measure of hearing.

The correlation between HF PTA and number of DPOAE frequencies failed supports the use of pure-tone audiometry as an objective measure of hearing in this study, however it represents only a weak correlation. The majority of the literature comparing DPOAE incidence and pure-tone thresholds reports similar findings (Hoth, Gudmundsdottir, & Plinkert, 2010; Scudder, Culbertson, Waldron, & Stewart, 2003), with absolute correlation coefficients ranging from 0.131 to 0.48, depending on the DPOAE frequency measured. The lack of perfect agreement between DPOAEs and pure-tone thresholds is not surprising, because the two measures are in fact measuring different mechanisms within the auditory system. Firstly, DPOAEs do not measure actual hearing sensitivity, but rather the health of the cochlear outer hair cells. There is evidence that damage to outer hair cells may be present before any changes in pure-tone thresholds are detected (Bohne & Clark, 1982; Hall, 2000; Gorga et al., 1997). Thus, some participants in the current study may have had normal pure-tone thresholds at failed DPOAE frequencies, thereby decreasing the correlation between the two measures. Secondly, DPOAE amplitudes are often difficult to interpret for individuals with a slight to moderate hearing loss, that is, between 25 and 50-60 dB HL (Bonfils & Avan, 1992; Gorga et al., 1993a; Gorga et al., 1997; Lonsbury-Martin et al., 1990). Within this 25 to 50-60 dB HL "zone of uncertainty" OAEs may be either present or absent. Given that the better ear HF PTA in our study sample ranges from 7.5 to 66.25 dB HL, we would expect the DPOAE measures to be inconclusive and not necessarily related to PTA. Thus, our results are similar to results previously reported and confirm the expected relationship between the two measures. This was important because, even though pure-tone audiometry is the gold-standard measure, it is subject to error if a participant is unable to respond appropriately, a participant provides unreliable responses, or a participant deliberately attempts to feign or exaggerate a hearing loss.

4.3 Relationship between Subjective and Objective Measures of Hearing

The relationship between subjective and objective measures of hearing (HHIE score and PTA, respectively) in our sample population is consistent with values reported in the literature. In our study sample, PTA explained 41.8% of the HHIE score variance (R=0.647), representing a moderate correlation. In a study of 100 older adults, Weinstein and Ventry (1983) reported a moderate correlation between better-ear pure-tone sensitivity and HHIE (γ_s= 0.61), also with less than 50% of the variability in HHIE scores being explained by pure-tone thresholds**.** Chang and colleagues (2009) studied 1220 adults aged 65 years and older and found a Spearman's correlation coefficient of 0.52 (p<0.01). Interestingly, Chang et al. also reported that 78.6% of adults with moderate to profound hearing impairment did not report a hearing handicap on the HHIE. Across the literature, the general trend is a weak-to-moderate correlation between audiometric and self-report measures of hearing (Brainerd & Frankel, 1985; Chang et al., 2009; Weinstein & Ventry, 1983). The imperfect nature of this relationship is well-known, because although the HHIE has been validated for use as a screening tool for hearing loss (Lichtenstein, Bess, & Logan, 1988b; McBride et al., 1994; Smith, Nathan, Wayner, & Mitnick, 1992; Weinstein & Ventry, 1983; Weinstein et al., 1986), it was originally designed to measure activity limitations and participation restrictions secondary to hearing impairment (Ventry & Weinstein, 1982). Adults with nearly identical audiometric data may encounter dramatically different activity limitations and participation restrictions, and thus different HHIE scores. HHIE scores in our study sample range from 0 to 72 (of a maximum of 100), therefore our sample represents a wide range of self-reported hearing impairment, ranging from no impairment to significant impairment. The purpose of our analysis was to confirm that the relationship between objective and subjective measures of hearing in our study sample was similar to that found in the literature, and the results found support that conclusion; thus, in this respect, our sample is similar to and representative of the general population of older adults.

The strength of the correlation between objective and subjective measures of hearing loss in the aforementioned studies varied depending on the choice of ear and the audiometric frequencies included in the PTA. As discussed, the majority of studies have used a PTA that includes thresholds in the frequency range of 0.5 to 4 kHz in the better ear, and this PTA yields the strongest correlations between PTA and self-reported hearing (Chang et al., 2009; Clark et al., 1991; Gates et al., 1990; Hashimoto et al., 2004; Lutman et al., 1987; Nondahl et al., 1998; Reuben et al., 1998; Sindhusake et al., 2001; Uchida et al., 2003). In our study, PTA was calculated from audiometric thresholds at 0.5, 1, 2 and 4 kHz in the better ear, in keeping with the convention of most previous studies. Worse ear PTA was analyzed as a covariate for CES-D score, but was not a statistically significant predictor and therefore was not pulled into the final regression model. Thus, the PTA and choice of ear used in our analyses allowed us to confidently examine the relationship between PTA and other variables, and then compare our results to those of other studies.

4.4 Relationship between Subjectively Measured Hearing and Depression Score

Our analysis showed that self-reported depressive symptoms (CES-D score) increased as self-reported hearing loss (HHIE score) increased, with HHIE score accounting for 26.4% of the CES-D score variance (R=0.514). The relationship between self-reported hearing loss and depression in our sample population is consistent with previous reports of such a relationship in the literature (Cacciatore et al., 1999; Capella-McDonnall, 2005; Kramer et al., 2002; National Council on the Aging, 2000; Saito et al., 2010; Strawbridge et al., 2000; Wallhagen et al., 1996). In a study of 580 Japanese adults over 65, Saito et al. (2010) found that self-reported hearing handicap, evaluated using the HHIE-S, was an independent predictor of Geriatric Depression Scale (GDS) score. Similar findings were reported by and Wallhagen et al. (1996) and Capella-McDonnall (2005), in which self-reported hearing status was assessed using a single question, and depression was assessed using surveys of mental health variables. In both studies, older adults with self-reported hearing impairment were significantly more likely to report depression than those without self-reported hearing impairment.

Although literature has demonstrated that older adults with self-reported hearing impairment are significantly more likely to report depressive symptoms than their normal hearing peers, there is a lack of consensus on the magnitude of this relationship. The magnitude of the relationship reported by Cacciatore et al. (1999) was much larger than that reported by the current study, with self-reported hearing loss accounting for 72% of the variance in Geriatric Depression Scale (GDS) score. Other researchers report a relationship smaller in magnitude than that found by the present study; in their study of 3107 adults age 55-85, Kramer et al. (2002) found that self-reported poor hearing explained less than 1% (0.47%) of the variance in CES-D score ($p<0.001$). However, cross-comparisons between findings are challenging because of vast methodological differences between studies. The most likely explanation for discrepancies between results, including those of the current study, is the use of different measures for both self-reported hearing loss and depression. Further comparison between our results and those reported in the literature is limited without a comparison of the relative psychometric properties of the measurement scales used. Nevertheless, the general trend of an adverse association between self-reported hearing impairment and depressive symptoms remained the same between studies and was again confirmed in the present study, and provided a sufficient basis for investigating this relationship using objective measures of hearing.

4.5 Relationship between Objectively Measured Hearing and Depression Score

Our results confirm our primary hypothesis, that *objectively* measured hearing loss (PTA) is significantly associated with depressive symptoms (CES-D score) in our sample population of older adults. The relationship between objectively measured hearing loss and self-reported depressive symptoms is consistent with the relationship found by previous studies that used self-report measures of hearing. In the current study we found that objectively measured hearing loss (PTA) accounted for 10.2% (R=0.320) of the variance in depressive symptoms (CES-D score). As discussed, previous authors have shown that self-reported hearing loss is a significant predictor of depressive symptoms in older adults (Capella-McDonnall, 2005; Saito et al., 2010; Wallhagen et al., 1996).

Furthermore, we have demonstrated that depressive symptoms increase with higher levels of objective hearing loss. Thus, by analyzing hearing loss and depressive symptoms as continuous variables, we were able to suggest that the relationship between objective hearing loss and depressive symptoms is dose-dependent. Most previous studies have analyzed hearing loss and depressive symptoms as dichotomous variables and were therefore unable to make such conclusions about the nature of this relationship. However, the relatively few studies that have analyzed self-reported hearing loss as a categorical variable have reported a similar dose-response relationship (NCOA, 2000; Strawbridge et al., 2000). Strawbridge et al. (2000) demonstrated that self-reported “no hearing impairment” or “a little hearing impairment” were non-significant predictors of depressive symptoms, while self-reported “moderate or more hearing impairment” was a significant predictor of depressive symptoms. Similarly, the NCOA study (2000) found a general trend of increasing depressive symptoms with increasing degrees of self-reported hearing loss, wherein individuals with “severe/profound” hearing loss reported significantly more symptoms of depression than those with “mild” hearing loss (National Council on the Aging, 2000). A dose-response relationship suggests that hearing loss is a potential causal factor for depressive symptoms, warranting further investigation in longitudinal studies. Further research surrounding the relationship should analyze hearing loss as either a categorical or continuous variable. In order to strengthen the argument that hearing impairment is linked with depression, future research should analyze hearing loss as either a continuous or categorical variable, to verify the dose-response pattern found by the current study.

Of the relatively few studies that have investigated the relationship between depression and hearing loss using pure-tone audiometry, our methodology and results are most comparable to work by Gopinath et al. (2009) and Naramura et al. (1999), although certain differences remain apparent. Gopinath et al. (2009) found that mild bilateral hearing loss (PTA) was a significant predictor of depressive symptoms on the Mental Health Index (MHI), however they also reported that moderate or severe hearing loss did not explain a significant proportion of the variance in depressive symptoms. Naramura et al. (1999) reported a significant single correlation between moderate to severe objective hearing impairment and Self-rating Depression Scale (SDS) score ($R= 0.277$; $R^2=0.0767$), but found that this relationship was no longer significant after multivariable adjustment for age, physical health, subjective hearing status and cognitive function.

The most likely explanation for discrepancies between our results and those of Naramura et al. (1999) and Gopinath et al. (2010) is the use of different definitions of hearing loss or different measures of depressive symptoms. It is also possible that selection bias artificially inflated our observed relationship between hearing loss and depressive symptoms. Participants who self-referred may have been more aware of a hearing impairment and more affected by subsequent activity limitations and participation restrictions. However, attempts were made to minimize such a selection bias by avoiding subject recruitment from audiology clinics, where a higher than average proportion of adults would be likely to self-report hearing loss. Conversely, it is also possible that the magnitude of our reported hearing loss-depressive symptom relationship was underestimated, since CES-D scores within our sample population ranged from 0 to only 30 of a maximum possible 60. However, our study sample was found to be representative of the general older adult population across a number of key variables, so we can reasonably assume that the incidence of depressive symptoms is representative of this population as well. Regardless of potential sources of bias, to the best of our knowledge, ours is the first study to measure pure-tone thresholds from 0.5-4 kHz and document a significant increase in depressive symptoms with increasing pure-tone thresholds.

In the current study we found that self-reported hearing loss (HHIE score) accounted for a greater proportion (26.4%) of the variance in depressive symptoms (CES-D score) than did objectively measured hearing loss (PTA; 10.2%). The increased variability in depressive symptoms explained by self-reported hearing loss may suggest that individuals who notice and report the social and emotional consequences of hearing loss are more likely to experience its resulting psychosocial effects, manifested as depressive symptoms. Alternatively, it may indicate that both objective and self-report measures of hearing explain 10.2% of the variance in depressive symptoms, the proportion attributed to the person's actual hearing loss, and that self-reported hearing loss explains an additional 16.2% of the variance in self-reported depressive symptoms because of demographic or personality factors associated with self-report measures. The findings of Naramura et al. (1999) suggest that this is likely; researchers found that the relationship between PTA and depressive symptoms was no longer significant after adjusting for subjective hearing status, among other variables. Given that our study aimed to remove the underlying response bias associated with self-reports of hearing from the hearing loss-depressive symptoms relationship, then we should expect that objective hearing loss will explain a smaller proportion of the variance in depressive symptoms than self-reported hearing loss, as was found in our pattern of results.

Several possible mechanisms might explain the observed relationship between hearing loss and depressive symptoms in older adults. Many authors agree that the relationship is mediated by a variety of complex psychosocial factors, of which the most commonly cited is impaired social function. In older adults, impaired social function has been identified as both a consequence of untreated hearing loss (Dalton et al., 2003; Heine & Browning, 2002; Strawbridge et al., 2000) and as a predictor of depressive symptoms (Chou, 2008; reviewed in Djernes, 2006; Hawthorne, 2008). Poor social function is also associated with other known predictors of depression, including loneliness, social isolation and diminished quality of life (as reviewed in Arlinger, 2003; Heine & Browning, 2002). Based on these findings, it seems logical that the relationship between objectively measured hearing loss and depressive symptoms in our study population is mediated by impaired social function. However, conclusions regarding the explanatory pathways between hearing loss and depression in older adults are limited due to the cross-sectional nature of this and most previous studies. Social function may be an important explanatory variable in the hearing loss-depression association and should be considered in future longitudinal research.

Alternatively, it is plausible that the depressive symptoms observed in our study are not caused by hearing impairment but rather by associated co-morbid conditions. Older adults with hearing impairments are more likely to have additional chronic conditions, such as mobility impairment, cardiovascular disease and diabetes, which have also been associated with depression (Bainbridge, Hoffman, & Cowie, 2008; Crews & Campbell, 2004; Huang, Dong, Lu, Yue, & Liu, 2010). Our small sample size did not allow us to control for additional confounding variables, therefore co-morbid conditions could be mediating the depression scores in the current study. Individual responses to specific items on the CES-D suggest that this is possible: participants tended to respond more positively to somatic items, such as “I was bothered by things that usually don’t bother me” or “my sleep was restless” (Radloff, 1977). However, the items on the CES-D were designed to minimize overlap with symptoms of physical illness (Berkamn et al., 1986). Furthermore, a number of large-scale studies have adequately controlled for chronic conditions and found that the relationship between hearing loss and depression persists (Capella-McDonnall, 2005; Corna et al., 2009; Gopinath et al., 2009; Kramer et al., 2002; Saito et al., 2010; Strawbridge et al., 2000). Finally, hearing loss itself has been associated with increased reporting of somatic symptoms, which may explain the CES-D response patterns (Eriksson-Mangold & Carlsson, 1991; Fellinger et al., 2007; Nachtegaal et al., 2009). Given these findings by previous authors, it seems unlikely that reported depressive symptoms in our study were confounded by co-morbid conditions. However, the pathway of causality cannot be determined without controlling for such conditions.

4.6 Clinical Implications

The results of the current study have important health implications. Given that our results demonstrate increased depressive symptoms with higher levels of hearing impairment, even once the potential confound of self-report of both measures is removed, then hearing loss could be a modifiable contributor to depression in the older population. A number of studies have demonstrated that the negative psychosocial effects of hearing loss are largely reversible with adequate rehabilitation (Goorabi et al., 2008; Gopinath et al., 2009; Mulrow et al., 1990b; Mulrow, Tuley, & Aguilar, 1992; National Council on the Aging, 2000; Vuorialho et al., 2006). Rehabilitation can include such interventions as education about communication strategies, use of hearing aids or hearing assistance technology, and cochlear implants. Hearing aids are the most widely used treatment for ARHL, yet only a small percentage of those who could benefit from hearing aids actually use them (Kochkin, 1993). Researchers have cited a number of potential barriers to obtaining or using hearing aids, including a lack of commitment by the healthcare system to the utilization of hearing aids

(Cohen-Mansfield & Taylor, 2004). Older adults with hearing loss may not pursue rehabilitation if healthcare providers fail to recognize hearing loss or believe that hearing loss is simply a normal part of aging (Pitts & Ward, 2010). However, if healthcare providers working with this population are aware that age-related hearing loss is not “normal” and has a number of potential negative psychosocial consequences, including depression, they may be more likely to screen for hearing loss and can better educate patients and encourage them to seek rehabilitation for ARHL. Once hearing loss is recognized, rehabilitation for ARHL should focus not just on hearing aid fitting, but also on self-efficacy and social communication skills in order to acknowledge the complex relationship between hearing loss and psychosocial outcomes. Rehabilitation of this nature may require collaboration with multidisciplinary teams of health professionals such as physicians, psychologists or social workers.

4.7 Future Directions

The results of the current study demonstrate a significant and dose-dependent association between objectively measured hearing impairment and depressive symptoms in a cross-sectional sample of older adults. These findings emphasize the need for prevention, early identification and management of hearing loss in older adults in order to allay its potential negative health outcomes. In order to better generalize these results beyond the current sample, further research is needed. Our study used a small sample size of older adults and therefore our results may not accurately reflect the relationship between hearing loss and depression. Furthermore, our findings may be limited by selection bias, since adults who agreed to participate may be more socially active than the majority of adults in the community. Future studies using larger, more representative samples may provide a better understanding of whether such a relationship exists. The population used in this study consisted of predominantly White, community-dwelling, well-educated adults; this sample was found to be representative of the general population of older adults with respect to gender, living arrangement, education level and hearing impairment. However, our results may not generalize to other ethnicities, older adults in nursing homes or those with lower educational levels. The prevalence of other co-morbid conditions in the study sample was not documented and thus may have contributed to the relationship between hearing loss and depression. Finally, the cross-sectional nature of our study limits conclusions about the cause-and-effect relationship between hearing loss and depressive symptoms. A better understanding of the causal pathway between hearing loss and depression requires a larger body of longitudinal analyses with controls for suspected confounding variables.

Future research should also focus on the influence of prevention, early identification and management of hearing loss on health outcomes in older adults. Of particular research emphasis should be the feasibility of adult hearing screening, and the role of multi-disciplinary healthcare professionals in its implementation. Future studies must also closely examine whether early detection and treatment of hearing loss is effective at reducing depressive symptoms and other associated psychosocial outcomes. Researchers should investigate ways to improve compliance with treatment, such as hearing aids, once such treatment has been implemented. Finally, researchers and clinicians should collaborate to develop strategies for knowledge translation, ensuring that hearing-impaired older adults, their families and their healthcare professionals recognize the importance and potential health implications of hearing loss.

4.8 Conclusion

In summary, the current study established the following findings:

i. There is a significant positive correlation between HF PTA and number of DPOAE frequencies failed, thereby supporting the use of pure-tone audiometry as an objective measure of hearing in this study sample.

ii. There is a significant moderate association between self-report and objective measures of hearing (HHIE and PTA, respectively) in the sample population, which is consistent with values reported in the literature.

iii. There is a significant relationship between self-reported hearing loss (HHIE score) and depression (CES-D score) in the sample population, which is consistent with findings reported in the literature.

iv. There is a significant relationship between objectively measured hearing loss (PTA) and depressive symptoms (CES-D score) in the sample population, such that depressive symptoms increase with higher levels of objective hearing loss. These findings confirm our primary hypothesis, and suggest that hearing loss could be a modifiable contributor to depressive symptoms in older adults.

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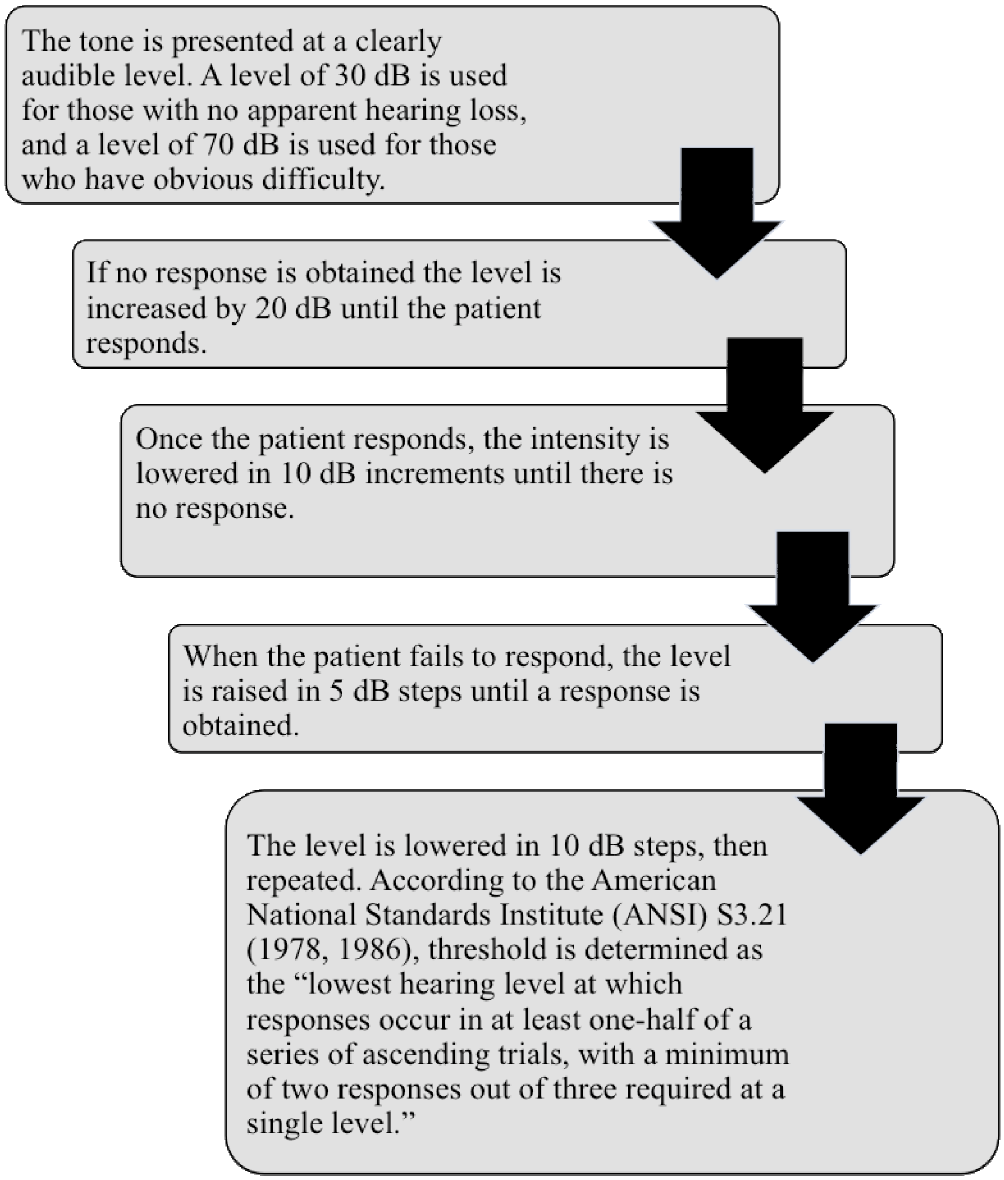
Appendices

Appendix A : The Modified Hughson-Westlake Procedure for Pure-Tone Audiometry (Carhart & Jerger, 1959)



Appendix B : Questionnaires

B.1 Hearing Handicap Inventory for the Elderly (HHIE; Ventry & Weinstein, 1982)

Instructions: The purpose of this scale is to identify the problems your hearing loss may be causing you. Answer YES, SOMETIMES, or NO for each question.

		Yes (4)	Some-times (2)	No (0)
S-1	Does a hearing problem cause you to use the phone less than you would like?			
E-2	Does a hearing problem cause you to feel embarrassed when meeting new people?			
S-3	Does a hearing problem cause you to avoid groups of people?			
E-4	Does a hearing problem make you irritable?			

HHIE (continued)

		Yes (4)	Some-times (2)	No (0)
E-5	Does a hearing problem cause you to feel frustrated when talking to members of your family?			
S-6	Does a hearing problem cause you difficulty when attending a party?			
E-7	Does a hearing problem cause you to feel “stupid” or “dumb”?			
S-8	Do you have difficulty when someone speaks in a whisper?			
E-9	Do you feel handicapped by a hearing problem?			

HHIE (continued)

		Yes (4)	Some-times (2)	No (0)
E-10	Does a hearing problem cause you to have difficulty when visiting friends, relatives, or neighbours?			
S-11	Does a hearing problem cause you to attend religious services less often than you would like?			
E-12	Does a hearing problem cause you to be nervous?			
S-13	Does a hearing problem cause you to visit friends, relatives, or neighbours less often than you would like?			

HHIE (continued)

		Yes (4)	Some-times (2)	No (0)
S-14	Does a hearing problem cause you to have arguments with family members?			
S-15	Does a hearing problem cause you difficulty when listening to the TV or radio?			
S-16	Does a hearing problem cause you to go shopping less often than you would like?			
E-17	Does any problem or difficulty with your hearing upset you at all?			
E-18	Does a hearing problem cause you to want to be by yourself?			

HHIE (continued)

		Yes (4)	Some-times (2)	No (0)
S-19	Does a hearing problem cause you to talk to family members less often than you would like?			
E-20	Do you feel that any difficulty with your hearing limits or hampers your personal or social life?			
S-21	Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?			
E-22	Does a hearing problem cause you to feel depressed?			
S-23	Does a hearing problem cause you to listen to TV or radio less often than you would like?			

HHIE (continued)

		Yes (4)	Some-times (2)	No (0)
E-24	Does a hearing problem cause you to feel uncomfortable when talking to friends?			
E-25	Does a hearing problem cause you to feel left out when you are with a group of people?			
For Researcher's Use Only:				
		Total Score:	________	
		Score E:	________	
		Score S:	________	

B.2 20-Item Center for Epidemiological Studies Depression (CES-D) Scale (Radloff, 1977)

INSTRUCTIONS: Below is a list of the ways you might have felt or behaved. Please check the response that best represents how often you have felt this way during the past week.

During the past week:
1. I was bothered by things that usually don't bother me. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 2. I did not feel like eating; my appetite was poor. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days)

During the past week:
3. I felt that I could not shake off the blues even with help from my family or friends. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 4. I felt that I was just as good as other people. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 5. I had trouble keeping my mind on what I was doing. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days)

20-Item CES-D (continued)

During the past week:
6. I felt depressed. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 7. I felt that everything I did was an effort. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 8. I felt hopeful about the future. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days)

During the past week:

9. I thought my life had been a failure.
   - ☐ Rarely or None of the Time (Less than 1 Day)
   - ☐ Some or a Little of the Time (1-2 Days)
   - ☐ Occasionally or a Moderate Amount of Time (3-4 Days)
   - ☐ Most or All of the Time (5-7 Days)

10. I felt fearful.
    - ☐ Rarely or None of the Time (Less than 1 Day)
    - ☐ Some or a Little of the Time (1-2 Days)
    - ☐ Occasionally or a Moderate Amount of Time (3-4 Days)
    - ☐ Most or All of the Time (5-7 Days)

11. My sleep was restless.
    - ☐ Rarely or None of the Time (Less than 1 Day)
    - ☐ Some or a Little of the Time (1-2 Days)
    - ☐ Occasionally or a Moderate Amount of Time (3-4 Days)
    - ☐ Most or All of the Time (5-7 Days)

During the past week:
12. I was happy. ☐ Rarely or None of the Time (Less than 1 Day) ☐ Some or a Little of the Time (1-2 Days) ☐ Occasionally or a Moderate Amount of Time (3-4 Days) ☐ Most or All of the Time (5-7 Days) 13. I talked less than usual ☐ Rarely or None of the Time (Less than 1 Day) ☐ Some or a Little of the Time (1-2 Days) ☐ Occasionally or a Moderate Amount of Time (3-4 Days) ☐ Most or All of the Time (5-7 Days) 14. I felt lonely. ☐ Rarely or None of the Time (Less than 1 Day) ☐ Some or a Little of the Time (1-2 Days) ☐ Occasionally or a Moderate Amount of Time (3-4 Days) ☐ Most or All of the Time (5-7 Days)

During the past week:
15. People were unfriendly. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 16. I enjoyed life. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days) 17. I had crying spells. ☐Rarely or None of the Time (Less than 1 Day) ☐Some or a Little of the Time (1-2 Days) ☐Occasionally or a Moderate Amount of Time (3-4 Days) ☐Most or All of the Time (5-7 Days)

20-Item CES-D (continued)

During the past week:
18. I felt sad. ☐ Rarely or None of the Time (Less than 1 Day) ☐ Some or a Little of the Time (1-2 Days) ☐ Occasionally or a Moderate Amount of Time (3-4 Days) ☐ Most or All of the Time (5-7 Days) 19. I felt that people dislike me. ☐ Rarely or None of the Time (Less than 1 Day) ☐ Some or a Little of the Time (1-2 Days) ☐ Occasionally or a Moderate Amount of Time (3-4 Days) ☐ Most or All of the Time (5-7 Days) 20. I could not get "going". ☐ Rarely or None of the Time (Less than 1 Day) ☐ Some or a Little of the Time (1-2 Days) ☐ Occasionally or a Moderate Amount of Time (3-4 Days) ☐ Most or All of the Time (5-7 Days)
For Researcher's Use Only: **Total Score:** ________

Appendix C : DSM-IV Criteria for a Major Depressive Episode (American Psychiatric Association, 1994)

A. Five (or more) of the following symptoms have been present during the same 2-week period and represent a change from previous functioning; at least one of the symptoms is either (1) depressed mood or (2) loss of interest or pleasure.

   NOTE: DO not include symptoms that are clearly due to a general medical condition, or mood-incongruent delusions or hallucinations.

   1. Depressed mood most of the day, nearly every day, as indicated by either subjective report (e.g., feels sad or empty) or observation made by others (e.g., appears tearful). Note: In children and adolescents, can be irritable mood.
   2. Markedly diminished interest or pleasure in all, or almost all, activities most of the day, nearly every day (as indicated by either subjective account or observation made by others).
   3. Significant weight loss when not dieting or weight gain (e.g., a change of more than 5% of body weight in a month), or decrease or increase in appetite nearly every day Note: In children, consider failure to make expected weight gains.
   4. Insomnia or hypersomnia nearly every day
   5. Psychomotor agitation or retardation nearly every day (observable by others, not merely subjective feelings of restlessness or being slowed down).
   6. Fatigue or loss of energy nearly every day.
   7. Feelings of worthlessness or excessive or inappropriate guilt (which may be delusional) nearly every day (not merely self-reproach or guilt about being sick).
   8. Diminished ability to think or concentrate, or indecisiveness, nearly every day (either by subjective account or as observed by others).
   9. Recurrent thoughts of death (not just fear of dying), recurrent suicidal ideation without a specific plan, or a suicide attempt or a specific plan for committing suicide.

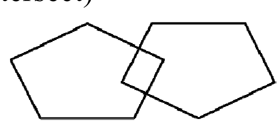
B. The symptoms do not meet criteria for a Mixed Episode.

C. The symptoms cause clinically significant distress or impairment in social, occupational or other important areas of functioning.

D. The symptoms are not due to the direct physiological effects of a substance (e.g., a drug of abuse, a medication) or a general medical condition (e.g., hypothyroidism).

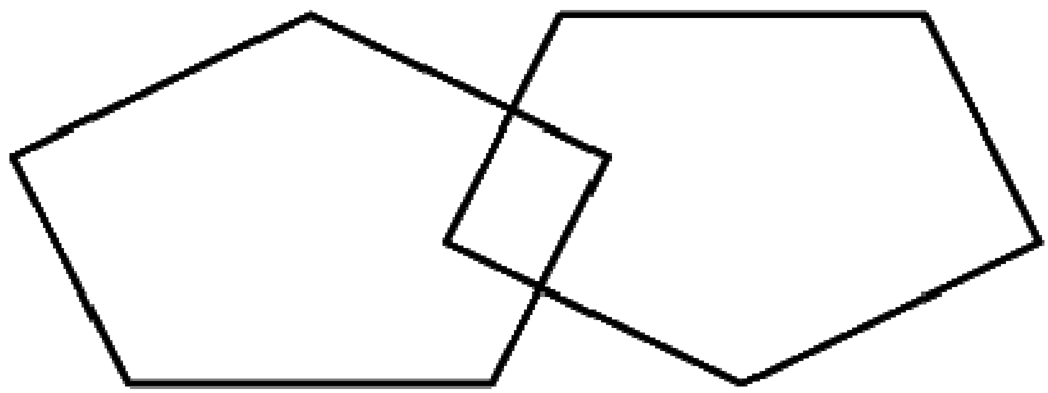
Appendix D : Mini-Mental State Exam (MMSE; Folstein, Folstein & McHugh, 1975)

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: Province? Regional district? City? Department? Floor?"
3		The examiner names 3 unrelated objects, 1 second to say each, then asks the patient to name all three of them. Give 1 point for each correct answer at the first repetition. Continue to repeat them until the patient learns all three (up to 6 trials). If they do not learn all 3, recall cannot be meaningfully tested.
5		"I would like you to count backwards from 100 by sevens." (93, 86, 79, 72, 65,…) Stop after 5 answers. Alternative: Spell "world" backwards (DLROW)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		The examiner shows the patient two simple objects, such as a wristwatch and a pencil, and asks the patient to name them.
1		"Repeat the phrase: No ifs, ands, or buts"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a blank piece of paper)
1		"Please read this and do what it says" (written instruction is "close your eyes")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (the examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles much be present and the 2 shapes must intersect) 
30		TOTAL

CLOSE YOUR EYES

MMSE (continued)



Appendix E : Background Information Form

1. Date of Birth: ____________
   (mm/yy)

2. Gender:
   - ☐ Male
   - ☐ Female

3. At what age did you begin to notice any difficulty with your hearing?

____

4. Which of the following best describes your current living arrangement?
   - ☐ Living alone
   - ☐ Living together with a partner or others in the same house

5. Which of the following best describes the highest level of education you have completed?
   - ☐ Less than high school
   - ☐ High school diploma
   - ☐ Trade-vocational
   - ☐ Non-university post-secondary
   - ☐ University

Appendix F : Tymanometric Types and Corresponding Middle Ear Characteristics According to the Jerger Classification System (Jerger, 1970).

Type	Tympanometric Peak Pressure (TPP; daPa)	Static Admmittance (SA; mmho)	Middle Ear Function
A	-100 to +50	0.20 – 1.5	Normal
As	-100 to +50	<0.20	Abnormal: - middle ear fluid - ossicular fixation
Ad	-100 to +50	> 1.5	Abnormal: - ossicular disarticulation - tympanic membrane pathology
C	< -100	0.20 – 1.5	Abnormal: - eustachian tube dysfunction
B	No peak	No peak	Abnormal: - middle ear effusion - tympanic membrane perforation - cerumen impaction - probe against canal wall

Note. TPP and SA values reflect adult normative data for conventional tympanometry obtained using a 226 Hz probe tone frequency (Jerger, 1970; Roup et al., 1998; Wiley et al., 1996). TPP = tympanometric peak pressure; SA = static admittance.