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EFFICACY OF AUTOMATED WIRELESS HEARING TEST SYSTEM IMPLEMENTED IN AN EXERCISE-BASED CANCER REHABILITATION PROGRAM

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ABSTRACT

Cancer patients are at risk of hearing loss due to the ototoxicity of chemotherapeutics and radiation treatments. Gaining clinical access to ototoxic monitoring is a challenge for patients, and physicians are often hesitant to burden their patients with more travel and appointment scheduling to obtain hearing testing. The current pilot study evaluated the feasibility of utilizing the newly developed Creare Wireless Automated Hearing Test System (WAHTS) in an exercise-based cancer rehabilitation center setting. Nine cancer patients were recruited for hearing testing. Hearing tests were conducted using an automated testing algorithm (WAHTS) in an open room and then tested again using manual audiometry conducted in a clinical sound booth test environment. Statistical analysis (t-test) revealed no significant difference between the hearing tests conducted in an open room in the exercise center and those conducted in the clinical setting ($p>.05$). Future research is needed to investigate the implementation of the WAHTS as a means of monitoring cancer patients for ototoxicity while receiving chemotherapeutics or radiation treatments and simultaneously participating in an exercise-based cancer rehabilitation program.

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REVIEW OF THE LITERATURE

Introduction

The term “ototoxicity” quite literally means “ear poison”. Ototoxic drugs are medications that have a negative effect on the auditory and/or vestibular system, causing hearing loss, tinnitus, and/or balance dysfunction. Chemotherapeutic medications, which are used as cancer treatment, causes many side effects that are harmful to the body; in addition, some of these medications cause ototoxicity (Lanvers-Kaminsky et al., 2017). Auditory and vestibular disorders greatly impact a person’s daily life and can cause social isolation, depression, and an overall decrease in their quality of life (Punch et al., 2019). Hearing loss, tinnitus, and a loss of balance can all have adverse consequences on someone’s quality of life, so it crucial for cancer patients to receive ototoxicity monitoring during their chemotherapy (Pearson et al., 2019).

Ototoxicity monitoring is when an audiologist monitors a patient’s hearing before, during and after treatment with ototoxic drugs. Ototoxicity monitoring shows signs of damage to the inner ear so doctors can prevent further damage from happening. Audiologists and oncologists work together and communicate through the monitoring process. Oncologists may need to alter treatment strategies for the patient while audiologists may need to provide the patient with options to help with hearing. Response’s oncologists may take after confirmed exposure of ototoxicity include referring the patient to an audiologist for ototoxic monitoring, reducing the dosage of the drug, stopping the use of the drug and using an alternative drug, providing counseling, increasing intervals between cycles, or increasing the frequency of monitoring if the

patient is already seeing an audiologist (Al-Malky, 2016). Some doctor's fail to mention to their patients the possibility of ototoxicity and these patients may have hearing loss that has not been identified, diagnosed, or treated. The auditory side effects they suffer may impact their daily life (Bartels et al., 2008; Gauvin et al., 2017; Hyams et al., 2018; Mendel et al., 1999; Möhwald et al., 2020; Pearson et al., 2019; Punch et al., 2019; Watts et al., 2018).

Exercise-based therapy is a form of rehabilitation for cancer patients and has been proven to improve their health by increasing physical and mental wellbeing, as well as overall quality-of life (Mishra et al., 2012). It helps reduce negative side effects chemotherapy causes, such as fatigue, anxiety, and depression, while also increasing physical function (Mishra et al., 2012). Exercise training has shown to reduce chances of cancer-specific mortality while also avoiding adverse effects (Samuel et al., 2019; Van Blarigan & Meyerhardt, 2015). Furthermore, a correlation between exercise and hearing levels has been studied (Alessio et al., 2002; Cristell et al., 1998). People who are active tend to have better hearing at older ages than people who do not exercise (Alessio et al., 2002). Not only does exercise-based therapy improve overall health in both a physical and mental aspect, but it can improve and slow down the loss of hearing that comes with older age.

The purpose of this review is to describe the epidemiology of adults with cancer in the U.S., understand which chemotherapeutic agents are associated with ototoxicity in adults, characterize ototoxicity monitoring programs and describe the physical and psychological outcomes of patients who receive exercise-based therapy for cancer rehabilitation. Understanding the importance of these topics can lead to an exploration of

how cancer survivors might enhance their exercise-based cancer rehabilitation experience by identifying, counseling, and referring those with untreated hearing loss and educating the exercise trainers.

Epidemiology of Cancer in the U.S.

Cancer Types

Following heart disease, cancer is the second leading cause of death in the United States today and has been for several years. In 2018, an estimated 16,353,421 people were living with cancer of any site in the United States (SEER*Explorer, 2021). In 2017, the top three most common types of cancer were breast in females with 250,520 new cases, prostate with 207,430 new cases, and lung and bronchus with 221,121 new cases (U.S. Cancer Statistics Working Group, 2020). In 2021, it is estimated that the number of new cancer cases will be 281,550 for breast in females, 248,530 for prostate, and 235,760 for lung and bronchus (Siegel et al., 2021). The risk of cancer can be reduced by sustaining an overall healthy, active lifestyle such as avoiding the use of tobacco, limiting the use of alcohol, maintaining a healthy diet, engaging in consistent physical activity, and reducing exposure to air pollution, radiation, and sunlight (World Health Organization, 2021a). In today's environmental circumstances, these methods of prevention can be difficult to execute: air pollution causes 91% of the world's population to live in areas with air quality levels that exceed World Health Organization (WHO) limits (WHO, 2021b); technology and fast food in today's fast paced society allow for effortless living, which creates a difficult to maintain healthy lifestyle; recreational UV radiation exposure has increased dramatically over the years due to outdoor leisure

activities and the societal trends that have caused people to purposely tan (D'Orazio et al., 2013). Unfortunately, there is no cure for cancer, so the overall number of cases for cancer increase each year since the number of estimated new cases in 2021 exceed the number of recorded new cases in 2017.

Sex and Racial/Ethnic Disparities

According to the Centers for Disease Control and Prevention (CDC), the number of new cancer cases in men in the United States was 861,381, and in women was 839,934 in 2017. In 2021, researchers estimate that the number of new cancer cases in males will be 970,250 and in females will be 927, 910 (U.S. Cancer Statistics Working Group, 2020). From this, it is evident that the number of cases continue to rise in both sexes. Although case numbers appear to be slightly higher in men than in women, it is obvious that cancer can affect anyone, regardless of their sex.

The rate of new cases of cancer per 100,000 people divided up by race and ethnicity in 2017 was 438.8 in whites, 429.1 in blacks, 333.0 in Hispanics, 284.2 in Asian/Pacific islanders, and 269.0 in American Indian/Alaska natives. Rates correlated with population; whites presented the highest rate but also had the highest population compared to the other groups. The differences in the number of cases between sex and race/ethnicity have to do with various factors such as genetics, hormones, environment, socioeconomic status, and location, which can influence health factors (U.S. Cancer Statistics Working Group, 2020). A summary of the number of new cancer cases in 2021 for breast in females, prostate, and lung and bronchus divided by race, ethnicity, and sex can be seen in Table 1. Cancer does not discriminate, and the epidemiological data

exemplifies that anyone can be diagnosed with cancer regardless of sex, race, or ethnicity.

Table 1

Number of New Cancer Cases for Three Prevalent Types of Cancer in the U.S., 2021

Type	Total	Male	Female	White	Black	Hispanic	Asian/Pacific islander	American Indian/Alaska native
Breast in Females	250,520	NA	250,520	204,818	29,274	21,919	11,355	1,428
Prostate	207,430	207,430	NA	158,466	32,750	14,393	5,015	906
Lung and Bronchus	221,121	113,576	107,545	188,149	23,495	9,955	6,586	1,373

Data Source. https://gis.cdc.gov/Cancer/USCS/DataViz.html.

NA: Not Applicable.

Cancer in Colorado

Cancer is the leading cause of death in Colorado, and the CDC reports that there were 24,226 new cases of cancer in Colorado during 2017. The current total number of people living with cancer in Colorado was not reported. Overall, the number of new cases separated into sex and racial/ethnic categories reflect similarly to the United States as a whole; males have a slightly higher number of cases, while whites and blacks lead in the racial/ethnic groups. In general, counties with higher populations, such as Denver, Jefferson, and Larimer County, tend to show a higher rate of new cases. However, as a

whole Colorado has much lower incidence rates when compared to many other states, and in 2019 the cancer mortality rate in Colorado was the second lowest, after Utah (National Center for Health Statistics, 2021). For example, smoking and obesity are much more common in West Virginia, hence a higher incidence rate. The factors of obesity and smoking are less prevalent in Colorado, so the incidence rate of cancer is much lower (U.S. Cancer Statistics Working Group, 2020).

Ototoxicity and Vestibulotoxicity of Chemotherapeutics

When treating cancer, chemotherapy is a common method of intervention. Chemotherapeutic drugs can be taken either by mouth or by injection into the vein. The chemotherapeutic drugs that are used for breast cancer include taxanes (paclitaxel and docetaxel), anthracyclines (doxorubicin and epirubicine), 5-fluoroucil, capecitabine, cyclophosphamide, platinum agents (carboplatin and cisplatin), vinorelbine, capecitabine, gemcitabine, ixabepilone, and eribulin (American Cancer Society, 2019a). For prostate cancer, frequently used chemotherapeutics are docetaxel, cabazitaxel, mitoxantrone, and estramustine (American Cancer Society, 2019b). Lung and bronchi cancer chemotherapeutics consist of etoposide, platinum agents (carboplatin and cisplatin), irinotecan, topotecan, lurbinectedin, paclitaxel, docetaxel, gemcitabine, vinorelbine, and pemetrexed (American Cancer Society, 2020). Commonly, patients are given more than one of these chemotherapeutics to take at one time. Due to the harsh side effects, these drugs are prescribed in cycles in order to give the patient's body time to recover before receiving another dose. There is a long list of side effects caused by chemotherapeutics

including hair loss, nausea and vomiting, diarrhea or constipation, weight changes, mouth sores, fatigue, etc. (American Cancer Society, 2019a, 2019b, 2020).

The drugs mentioned earlier that are ototoxic are mentioned in Table 2 (Ding et al., 2012; Rybak et al., 2007). The platinum-based drugs can cause both auditory toxicity and vestibular toxicity. Cisplatin is more ototoxic than carboplatin and oxaliplatin, however, it is also more commonly used due to its high effectiveness in cancer treatment. Cisplatin causes permanent sensorineural hearing loss, usually bilaterally. Higher dosage and longer duration of the drug will cause the hearing loss to be worsened, and some cases have shown symptoms of tinnitus and vertigo (Lanvers-Kaminsky et al., 2017). Vincristine and vinorelbine can also cause irreversible, bilateral sensorineural hearing loss and tinnitus, and vinblastine can lead to permanent sensorineural hearing loss as well as tinnitus. Tinnitus from vinblastine will last several days after each round of treatment, but eventually subsides before the next round (Rybak et al., 2007).

Table 2

Commonly Used Chemotherapy Drugs for Three Common Cancer Types in U.S.

Cancer Type	Common Chemotherapeutics	Ototoxic Chemotherapeutics
Breast in Females	taxanes (paclitaxel and docetaxel), anthracyclines (doxorubicin and epirubicine), 5-fluoroucil, capecitabine, cyclophosphamide, platinum agents (carboplatin and cisplatin), vinorelbine, capecitabine, gemcitabine, ixabepilone, and eribulin	Paclitaxel, doxorubicin, carboplatin, and cisplatin
Prostate	docetaxel, cabazitaxel, mitoxantrone, and estramustine	NA
Lung and Bronchus	etoposide, platinum agents (carboplatin and cisplatin), irinotecan, topotecan, lurbinectedin, paclitaxel, docetaxel, gemcitabine, vinorelbine, and pemetrexed	Carboplatin, cisplatin, and paclitaxel

Sources. American Cancer Society, 2019a, 2019b, 2020; Ding et al., 2012; and Rybak et al., 2006.

NA: Not Applicable.

Effects of Auditory Disorders on Quality of Life

People who suffer from hearing loss and tinnitus are more likely to have a lower quality of life compared to those who do not. Hearing loss and tinnitus have been shown to correlate with poor mental health as well as depression (Pearson et al., 2019). Hearing loss can have a large impact on a person's social life and can cause burden in communicating in public and with family. Utilizing interviews and focus groups, the study done by Pearson et al. discussed with hard-of-hearing individuals the impact of their hearing abilities on their daily life. The inclusion criteria included adult individuals who had a bilateral sensorineural hearing loss of any degree, despite its cause. Pearson et al. reported that a significant impact due to hearing loss is the inability to participate in group discussions. Further, this prompts negative emotions due to the insecurities created from having to ask people to repeat so often (Punch et al., 2019). The most common complaint associated with hearing loss was the public being uninformed and insensitive to people with hearing loss. The participants expressed a desire for people to be better educated on this topic (Punch et al., 2019). Overall, these issues lead to an increased risk of social isolation and depression, lowering a person's quality of life. Hyams et al., (2018) evaluated the mental health of participants with a hearing loss who do not use hearing aids compared to participants with a hearing loss who do use hearing aids and found that hearing loss associated risks such as social stressors and depression were lower in individuals with hearing aids, and these individuals had an increased quality of life (Hyams et al., 2018).

Tinnitus can have varying effects on individuals; for some people it may not be as apparent and causes little disturbance of someone's daily life, but in others, it can be

severe and greatly impacts someone's well-being. Tinnitus has been shown to be associated with anxiety and depression, therefore a poorer quality of life (Bartels et al., 2008). In some cases, it can lead to a maladaptive coping method, which involves thinking about the negative consequences of tinnitus, avoiding social situations, and increased phycological distress, which in the end worsens the anxiety and depression (Bartels et al., 2008). The constant ringing or buzzing sound can also cause symptoms such as insomnia and difficulty concentrating, which also factor into a decreased quality of life (Watts et al., 2018). In addition, Watts et al. found that people who suffer from tinnitus were found to experience more insecurity, fear, and worry stemming from the fear of tinnitus itself, the future of their tinnitus, and activities that could provoke the tinnitus to worsen (Watts et al., 2018).

Overall, auditory disorders can elicit negative side effects which cause difficulties in someone's everyday life, decreasing the quality of life in that individual. Although these studies were not specific to ototoxicity, the negative effects that are associated with auditory disorders and decrease quality of life are possible in any individual with a hearing loss or tinnitus, despite if it is ototoxic-induced, noise-induced, age-related, etc.

Effects of Vestibular Dysfunction on Quality of Life

Vestibular dysfunction causes balance disorders, which include dizziness and vertigo, and can ultimately lead to imbalance, nausea, and vomiting. This also means that someone who suffers from vestibular dysfunction is highly sensitive to motion, such as movement of their own body or movement of other objects (Gauvin et al., 2017). Maintaining balance is important in everyone's everyday life and struggles with this can

make simple activities challenging. The side effects brought on by vestibular disorders undoubtedly cause a poorer quality of life. Vertigo has been reported to cause feelings of light-headedness, swimmy or giddy, and unsteadiness. The unsteadiness can be so severe that falling occurs frequently (Mendel et al., 1999). The feeling of dizziness causes physical restrictions thus affecting social interactions due to worry and lack of confidence. As a result, anxiety, depression, and/or panic disorders can take place (Möhwald et al., 2020). Ototoxicity and vestibulotoxicity can happen in the same person from the same drug as well, so hearing loss and tinnitus can also occur with vestibular dysfunction symptoms. All in all, these side effects can lead to social avoidance and withdrawn behaviors, causing disturbances in someone's social, family, and professional life.

Patient Awareness

The symptoms caused by ototoxicity, which include hearing loss, vertigo, balance disorder, and tinnitus, are not mentioned as frequently or consistently as the other side effects (nausea and vomiting, hair loss, mouth sores, loss of appetite, diarrhea, fatigue, easy bruising, increase chance of infection) by the American Cancer Society. The American Cancer Society website pages for chemotherapy for ovarian cancer, bone cancer, and testicular cancer mention the occurrence of ototoxic symptoms, however, ototoxic symptoms are not mentioned for breast cancer in females and lung and bronchus cancer in both sexes (American Cancer Society, 2018a, 2018b, 2018c, 2019a, 2020). The pages for breast cancer in females and lung and bronchus cancer both list ototoxic drugs but fail to mention the possibility of ototoxic side effects. Some chemotherapeutics can

cause auditory and/or vestibular toxicity by targeting the hearing and balance system sensory cells in the inner ear (Cone et al., 2020). Sometimes, these side effects are irreversible and will remain present after chemotherapy and in other instances, the symptoms are temporary (Lanvers-Kaminsky et al., 2017). The fact that this is not discussed on all chemotherapy pages for cancer.org where ototoxic drugs are mentioned shows that ototoxicity is not communicated enough to patients by doctors when prescribing chemotherapeutics (Al-Malky, 2016; Ganesen et al., 2018; Garinis et al., 2018; Maru & Malky, 2018).

Prevention and Intervention Strategies

Ototoxicity Monitoring

During chemotherapeutic treatment with ototoxic medications, is it important for audiologists to monitor the patient's hearing. The purpose of ototoxicity monitoring is to prevent or inhibit damage to the inner ear from occurring when a patient is on a chemotherapeutic treatment. The audiologist uses this to spot signs that damage to the inner ear is developing. If so, the doctor can provide a treatment modification for the patient to prevent severe and permanent damage (Landier, 2016). If the damage is caught too late, ototoxicity monitoring can still provide reason for intervention (Landier, 2016). Both the American Speech-Language-Hearing Association (ASHA) and the American Academy of Audiology (AAA) have guidelines as to how ototoxicity monitoring is carried out (Durrant et al., 2009; Konrad-Martin et al., 2005).

Ototoxicity monitoring protocol often includes: "comparing the auditory test results during the course of drug therapy, early identification of change in hearing, need

for potential alterations of drug therapy, prevention of debilitating ototoxic-induced hearing loss if therapy is changed, and auditory rehabilitation to minimize the negative impact of ototoxicity" (Ganesan et al., 2018).

According to ASHA's guidelines, ototoxicity monitoring begins with a baseline evaluation. This takes place no later than 24 hours after the chemotherapeutic drug(s) are administered to the patient. The baseline evaluation is particularly important because otherwise, it is difficult to interpret future results in terms of whether or not it is caused by an ototoxic agent (Durrant et al., 2009). The following monitoring evaluations after the baseline take place at times which depend on the scheduled treatment of chemotherapy. Typically, each evaluation happens prior to the next round of treatment. In addition to the regularly scheduled evaluations, other evaluations are necessary when the patient is experiencing hearing difficulties, tinnitus, aural fullness, and/or dizziness (Konrad-Martin et al., 2005).

During each evaluation, pure-tone audiometry and extended high frequency audiometry are utilized to record the patients hearing. The results for each audiometry test can be compared to previous evaluations to detect signs of ototoxicity. The AAA's guidelines emphasize the importance of using high frequency audiometry alongside of conventional audiometry since ototoxic drugs cause a hearing loss in the high frequency region of the cochlea first (Durrant et al., 2009). Table 3 shows the criteria for extended high frequency audiometry for ototoxicity. Cisplatin ototoxicity appears to be triggered by reactive oxygen species (ROS) that initiate a cascade of molecular events that lead to apoptosis of outer hair cells (Rybak et al., 2007). The cochlea is organized tonotopically, meaning the basal end registers high frequencies and the apex end registers low

frequencies. The outer hair cells in the basal end are damaged initially followed by the mid and low frequencies. High frequency audiometry will monitor the ultra-high frequencies to detect the onset of ototoxicity. The use of high frequency audiometry is described further below.

Table 3

Ototoxicity Criteria with Inclusion of Extended High Frequency Audiometry

Grade	Chang Grading System	Tune Grading System
0	≤20 dB at 1, 2, and 4 kHz	No hearing loss
1a	≥40 dB at any frequency 6 to 12 kHz	Threshold shift ≥10 dB at 8, 10 and 12.5 kHz
1b	>20 and <40 dB at 4 kHz	Threshold shift ≥10 dB at 1, 2 and 4 kHz
2a	≥40 dB at 4 kHz and above	Threshold shift ≥20 dB at 8, 10 and 12.5kHz
2b	>20 and <40 dB at any frequency below 4 kHz	Threshold shift ≥20 dB at 1, 2 and 4 kHz
3	≥40 dB at 2 or 3 kHz and above	≥35 dB HL at 1, 2 and 4 kHz
4	≥40 dB at 1 kHz and above	≥70 dB HL at 1, 2 and 4 kHz

Source. Ganesan et al., 2018.

Tinnitus Monitoring

Tinnitus is a persistent, high-pitched ringing or buzzing sound that can occur either unilaterally or bilaterally. Ototoxic chemotherapy agents increase the risk of a patient developing tinnitus; cisplatin increases the risk by 5.53 times and carboplatin increases the risk 3.75 times (Dille et al., 2010). It can be as common as hearing loss in ototoxicity as well as possibly the first indication of ototoxicity (Lesar, 1993; Seligmann et al., 1996). Patients who are older or have a hearing loss prior to chemotherapy treatment are at a higher risk of developing tinnitus (Dille et al., 2010). Once treatment ends, it is possible for symptoms to eventually subside, but they may also persist for several years (Rybak, 2005). As stated by the AAA guidelines, tinnitus is a common side effect of ototoxic drugs, however, unfortunately there is no way to monitor it. Severe tinnitus is rare in these cases, and often times the patients are overwhelmed with other symptoms that tinnitus is not a substantial concern (Durant et al., 2009).

Vestibulotoxicity Monitoring

As far as vestibulotoxicity monitoring, there are no widely accepted guidelines. Not only is the laboratory equipment necessary to monitor vestibular function an expense, but a formal evaluation can be difficult to endure for patients who are already ill from chemotherapy. However, there are many tests that can be run to assess vestibular reflexes: dynamic visual acuity testing, head thrust testing, head shaking nystagmus, postural control, electronystagmography, videonystagmography, rotational testing, static balance/posturography, video head impulse, and vestibular-evoked myogenic potential

(Durrant et al., 2009; Handelsman, 2018). A battery of these tests helps to evaluate and identify the specific vestibular systems that may or may not be working properly.

Intervention Strategies for Ototoxicity

If ototoxicity is confirmed in a patient, an oncologist's response will be to stop and use an alternative drug, reduce the dosage of the current drug, refer the patient to an audiologist if they have not been already, increase the frequency of monitoring by an audiologist, provide counseling, increase intervals between cycles of treatment, or potentially do not know what to do and continue with the current treatment plan (Al-Malkey, 2016). Most commonly, oncologists will choose to stop use of the current drug and use an alternative drug or reduce the dosage of the current drug. Ideally, patients should be referred to an audiologist for ototoxic monitoring prior to treatment if the patient is taking a chemotherapeutic known to cause ototoxicity. This is because during ototoxicity monitoring, if ototoxicity is observed, the priority of the audiologist is to inform the oncologist in order to potentially prevent it from progressively getting worse. The severity of ototoxicity that can occur depends not only on the chemotherapeutic, but on the dosage level and the frequency received. A higher dose and less time between treatments is going to induce a higher risk of ototoxicity (Laurell, 2019). If the dose is changed, however, there is a balance between preventing ototoxicity while still allowing the chemotherapeutic to continue being an effective treatment. The dosage that meets this balance depends on the drug, and it is important for the doctors and audiologists involved to keep this in mind (Hammill & Campbell, 2018). Nonetheless, this may not be possible due to the condition of the patient. If the ototoxicity has begun to make changes in the

patient's hearing to the point that their understanding of speech is being affected, the audiologist should offer aural rehabilitation (Ganesan et al., 2018). Drug-induced hearing loss is typically permanent, so this is when counseling occurs; the patient should consider amplification devices, cochlear implants, or assistive listening devices in conjunction with the implementation of compensatory communication strategies (Ganesan et al., 2018).

For patients who suffer from vestibulotoxic side effects such as dizziness and vertigo, vestibular rehabilitation is an option. With a loss of vestibular function, patients are negatively impacted in their vision and mobility (Handelsman, 2018). During rehabilitation, the patient learns to adapt to the symptoms by learning to coordinate their movement with the vestibular imbalance. The vestibular rehabilitation activities stimulate the patients sensory, motor, cognitive, and neurologic systems to counteract vestibular dysfunction. This compensates the patient for a vestibular loss, so that the symptoms can become more manageable. Sessions happen repeatedly in order to create habituations that will limit the motion symptoms due to vestibular imbalance (Handelsman, 2018).

Audiometry

Conventional Audiometry

Pure-tone audiometry involves testing an individual's hearing by measuring their threshold of hearing with multiple single frequency sounds (pure tones) with an audiometer. This is performed for both air and bone conduction and must be completed in sound-resistant booths in order to prevent interference of any surrounding sounds. Air conduction is performed with supra-aural, circumaural or insert earphones. Audiometry

allows for testing the entirety of the auditory system: outer ear, middle ear, and inner ear. The patient wears earphones while sitting in the sound-isolated booth. The audiologist sits outside the patient booth, with a window between the rooms so the patient and audiologist can see each other. Utilizing the audiometer, the audiologist sends pure tone sounds through the earphones, one ear at a time, starting with 1000 Hz, then 2000 Hz, 4000 Hz, 8000 Hz, then back to 1000 Hz, and finally down to 500 Hz, and 250 Hz (American Speech-Language-Hearing Association, 2005). For each frequency sound, the audiologist finds the lowest hearing threshold the patient responds to 50% of the time, starting at what is considered a normal hearing level in decibels (dB HL). The patient responds by pressing a button, which is indicated by a light on the audiometer for the audiologist to see. The Hughson-Westlake method allows for the most accurate response (Carhart & Jerger, 1959). For example, when finding the hearing threshold of a patient for 1000 Hz, the audiologist will initially present it at 30 dB HL. If there is no response, the audiologist should then increase the amplitude by increments of 10 dB HL, and if there is a response, they should decrease the amplitude by increments of 5 dB HL. The lowest dB of that frequency that the patient responds to 50% of the time is recorded on an audiogram, a graph which summarizes the hearing threshold of each frequency in each ear of the patient (American Speech-Language-Hearing Association, 2005; Carhart & Jerger, 1959). This is repeated for the remainder of the test frequencies, which are collectively analyzed to determine the patient's threshold in each ear.

During bone-conduction audiometry, the same process is completed as the air-conduction audiometry, but instead is utilizing a bone-conductor vibrator that is placed on the mastoid or forehead of the patient. The bone vibrator allows for testing the hearing

of the inner ear directly by vibrating the skull, it bypasses the outer and middle parts of the auditory system and stimulates the cochlea directly (American Speech-Language-Hearing Association, 2005). Bone conduction measures hearing by testing the same frequencies as air conduction: starting at 1000 Hz, 2000 Hz, 4000 Hz, then back to 1000 Hz, and down to 500 Hz, and 250 Hz. Bone conduction does not test for 8000 Hz. The same Hughson-Westlake threshold measurement method is used for bone conduction as air conduction. The audiologist increases the amplitude by increments of 10 dB HL when there is no response made by the patient and decreases the amplitude by increments of 5 dB HL when there is a response (Carhart & Jerger, 1959). The lowest hearing threshold requires the patient to respond at least 50% of the time.

Extended High Frequency Audiometry

In pure-tone audiometry, 250 Hz – 8000 Hz is the conventional range of frequencies typically used to test someone's hearing because the frequencies produced by speech generally fall into that range. However, the human ear is able to hear sounds as low as 20 Hz to sounds as high as 20,000 Hz. Extended high frequency audiometry tests the sounds above 8000 Hz (American Academy of Audiology, 2014). During ototoxicity monitoring, it is important to measure the patient's response to the higher frequencies because ototoxic drugs tend to target the basal part of the cochlea, which registers high frequency sounds, first (American Academy of Audiology, 2014). However, if ototoxic drugs are continuously used without monitoring and intervention, the hearing loss will progress to lower frequencies. Eventually, it will impact a person's ability to hear speech. Extended high frequency audiometry is especially important in ototoxicity monitoring

because catching the beginning stages of ototoxicity will be easier since the high frequencies are affected initially.

Boothless Audiometry

Ambient noise is background noise pollution that is not meant to be monitored during audiometric testing. An excess of ambient noise can cause invalid hearing test results; thus, audiometry is generally performed in a sound-resistant booth to reduce the ambient noise as much as possible. The American National Standards Institute (ANSI S3.1-2013) set a criterion for Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (MPANL) to ensure accuracy in hearing testing practices (Frank et al., 1993; Lankford et al., 1999; Meinke et al., 2017). However, audiometry in a soundless booth is not always accessible. Mobile audiometry allows hearing tests to be performed in locations outside of a soundless booth. Ambient noise becomes more difficult to control in these situations. Studies show is it possible for valid diagnostic air-conduction and bone-conduction pure-tone hearing thresholds to be recorded using mobile audiometer without a sound booth or a sound-controlled environment (Brennan-Jones et al., 2016; Maclennan-Smith et al., 2013; Swanepoel et al., 2013).

Creare Inc.'s wireless automated hearing test system (WAHTS) is a wireless audiometric headset used to test people's hearing in environments outside of a sound booth, where ambient noise is much higher. Meinke et al. (2017) states the WAHTS was designed to 1) maximize passive attenuation, while keeping the headset comfortable enough to wear for the duration of a hearing test, 2) leverage mobile technologies and eliminate cables, and 3) meet ANSI S3.6 and IEC 60645-1 standards for (Type 4)

audiometers (Meinke et al., 2017). The WAHTS is reliable to be utilized for mobile audiometry outside of a sound booth but is not going to be as accurate as audiometric testing in a sound booth.

Classification of Hearing Loss

The results recorded on an audiogram from pure-tone audiometry can show if someone has a hearing loss, and the degree of hearing loss. According to ASHA, the classifications of hearing loss are normal hearing, slight hearing loss, mild hearing loss, moderate hearing loss, moderately severe hearing loss, severe hearing loss, and profound hearing loss (Clark, 1981). On an audiogram, the average hearing threshold levels for each classification is -10.0 to 15 dB HL for normal hearing, and 16 to 25 dB HL for a slight hearing loss, 26 to 40 dB HL for a mild hearing loss, 41 to 55 dB HL for a moderate hearing loss, 56 to 70 dB HL for a moderately severe hearing loss, 71 to 90 dB HL for a severe hearing loss, and 91+ dB HL for a profound hearing loss (Clark, 1981). Hearing loss can be either bilateral, present in both ears, or unilateral, present in one ear.

Hearing Handicap Inventory

Clinical evaluations utilize audiometry to determine the severity of a hearing loss and understand areas of difficultly in speech-recognition someone may have. However, these tests do not evaluate the impact a hearing loss has on a person's day-to-day life. While audiometry uses pure-tone thresholds to elicit a response and diagnose a hearing loss, patient-reported outcome measures (PROM) can be used to assess each individual's experience with a hearing loss (Cassarly et al., 2020). This allows for more specific

information for each person, and aids in providing the best intervention for them (Cassarly et al., 2020).

The Hearing Handicap Inventory for the Elderly (HHIE) (Ventry & Weinstein, 1982) and the Hearing Handicap Inventory for Adults (HHIA) (Newman et al., 1991) were PROMs developed to assess self-perceived hearing handicap in relation to emotional consequences and social/situational effects (Cassarly et al., 2020). Each version of the HHI includes 25 questions asking about the ways their hearing problem impacts their quality of life in their day-to-day life, how certain social situations that are affected by their hearing problem make them feel, and their emotions correspond to their hearing problem. The 25 HHIE and HHIA responses are scored into two sub-scales (social and emotional).

Cassarly et al. (2020) evaluated the HHIE and the HHIA using Mokken scale analysis (MSA), a type of nonparametric item response theory, and develops updated tools with optimal psychometric properties. A longitudinal study of 1447 adults completed the HHIE/A and audiometric testing at baseline. These researchers noted that the all the items of the HHIE/A form a strong unidimensional scale measuring self-perceived hearing handicap but lacked the ability to discriminate the two distinct sub-scales of social and emotional. A psychometric analysis was performed to determine which questions were the most effective and which ones could be removed. The final 18 questions from both HHIE/A were evaluated for sensitivity versus specificity so that the scores of the questionnaire could predict a hearing loss and the areas of difficulty for that specific person. Hence, this analysis resulted in the creation of the Revised Hearing Handicap Inventory (RHHI) that can be used for both adults and the elderly. To score the

RHHI each question, the patient responds with a “yes”,” no”, or “sometimes”. A “no” is score 0 points, “sometimes” is scored 2 points, and a “yes” is scored 4 points. Individuals who score >6 points are considered to have a hearing handicap and the higher the score the greater the self-reported hearing handicap.

Exercise Training for Cancer Rehabilitation

With an increasing rate of cancer in the United States each year and yet no cure, exercise training is an important resource for cancer rehabilitation. Chemotherapy causes harsh side effects that can put a physiological and physical strain on the body in addition to the cancer. Not only is physical function dramatically impacted, but mental wellbeing is also negatively affected. Overall, cancer patients endure a decrease in quality of life (Mishra et al., 2012). Mishra et al.’s systematic review analyzed the findings of 56 studies looking at the effects of exercise-based therapy on cancer survivors. The participants had either had cancer treatment in the past, were currently undergoing cancer treatment, or were scheduled for cancer treatment. Mishra et al. found that exercise interventions create a positive impact on health-related quality of life (Mishra et al., 2012). Physical function and social function were increased, while fatigue, anxiety, depression, and sleep disturbances were decreased. Results also showed that higher intensity exercise interventions had a more pronounced positive increase in quality of life compared to less intense exercise interventions (Mishra et al., 2012). This evidence is important for cancer patients to be aware of, as taking part in exercise cancer rehabilitation can help to alleviate many of the symptoms arising from cancer and cancer treatment.

Hwang et al. did a study to determine if 8 weeks of exercise training improve exercise capacity along with physical function. Participants were 24 non-small cell lung cancer patients at advanced stages who were either placed into a control group, who did not participate in the 8-week exercise training, and an exercise group, who did participate in the 8-week exercise training. They assessed exercise capacity and physical function by measuring VO_{2peak}, muscle strength and endure of the right quadriceps muscle oxygenation during exercise, insulin resistance, high- sensitivity C-reactive protein, and quality of life before and after the 8 weeks. The results determined that the exercise group benefited significantly in exercise capacity with improvements in circulatory, respiratory, and muscular functions. The control group showed no changes in terms of exercise capacity or physical functions (Hwang et al., 2012).

Evidence also shows that routine exercise in general leads to a 30-50% reduction in the risk of cancer-specific mortality along with mortality in general when compared to physically inactive individuals (Van Blarigan & Meyerhardt, 2015). Not only does exercise-based therapy increase quality of life, but it is also a method of rehabilitation that causes no adverse effects (Samuel et al., 2019). This is crucial for cancer patients because chemotherapy is already hard on the body, so avoiding further side effects is an important factor to consider.

University of Northern Colorado Cancer Rehabilitation Institute Exercise Program

Dr. Reid Hayward is the director of the University of Northern Colorado Cancer Rehabilitation Institute (UNCCRI), a program which conducts and researches exercise-based therapy for cancer patients in order to improve the quality of life for cancer

survivors. The program consists of four phases that are either one-on-one with a trainer or in group sessions depending on the phase the client is in. Sessions occur two to three times a week and last about 60 minutes. Each session focuses on cardiovascular exercise, resistance training, balance activities, flexibility, and stretching (UNCCRI, 2020a). The UNCCRI offers exercise prescriptions which vary based each patient's specific needs including medical and cancer evaluations as well as initial physical and psychological assessments. After these evaluations, patients are placed in a certain phase of the program. See Table 4 for more detailed information about each phase.

Table 4

Phases of UNCCRI Exercise Program

Description	Phase 1	Phase 2	Phase 3	Phase 4
Who	Cancer survivors who are currently undergoing chemotherapy and/or radiation treatments	Cancer survivors who have completed phase one or clients who have had surgery and/or hormonal treatment, and have not had chemotherapy or radiation	Cancer survivors who have completed phase 2	Cancer survivors who have completed phase 3
Duration	During cancer treatment or for 3 months	3 months	3 months	No time period
Goal	To alleviate the severe side-effects of chemotherapy and/or radiation treatment	To reduce the physical and functional limitations caused by cancer treatment.	To improve physiological and psychological values beyond baseline; clients should be back to functional health after this phase	To maintain improvements in physiological and psychological parameters and to encourage and develop habits of lifetime physical activity
Training	Low intensity and one-on-one	Low-to-moderate intensity, one-on-one, incorporates foundational, technique- oriented exercises	Moderate intensity and one-on-one	Moderate-to-high intensity and option of working out on their own, attending a group exercise session, or continuing to work out one-on-one with a Clinical Cancer Exercise Specialist.

Note. Adapted from

https://www.unco.edu/nhs/cancerrehabilitationinstitute/pdf/unccri_program_brochure.pdf

Hsieh et al. conducted a study at the UNCCRI on breast cancer patients. Prior to beginning each session, cancer exercise specialists communicated with patients how they were feeling, such as any soreness or specific physical problems, as well as any changes in medication or treatment. Exercise prescriptions were altered based on the patients' needs if necessary (Hsieh et al., 2008). Taking this into consideration as well as the fact that each session is either individualized one-on-one or within a group, communication is an important factor during exercise rehabilitation. Cancer exercise specialists need to be able to provide patients with instruction and verbal guidance for each exercise, while patients need to be able to communicate their needs and comfort levels through each exercise. This communication aspect applies outside of the exercises as well: appointments booked over the phone or in person, evaluations, and socializing with others in group trainings. Communication is a key factor for exercise rehabilitation to be highly beneficial for the patient.

Effects of Exercise on Hearing

Studies show that people who live a more physically active lifestyle tend to have better hearing compared to those who are not physically active (Alessio et al., 2002; Cristell et al., 1998; Kawakami et al., 2021; Loprinzi et al., 2012). Just like other organs of the body, the inner ear is a vascular organ and requires a healthy blood supply to work as efficiently as possible. Reduction in blood circulation correlates to worsened hearing over time. Variations in blood flow affect the availability of oxygen and glucose, and during sound stimulation, oxygen and glucose are metabolized faster. This becomes

increasingly difficult for the cochlea if poor circulation is causing less blood flow, therefore less access to oxygen and glucose (Alessio et al., 2002).

Similarly, Loprinzi et al. (2012) completed a study examining the association between cardiorespiratory fitness and hearing sensitivity and found that people with higher cardiorespiratory fitness levels preserve hearing sensitivity over time. An increase in cardiorespiratory fitness has many positive effects on the cardiovascular system including increase venous circulation, decreased resistance to blow flow, and improved endothelium-mediated vasodilatation which all increase the delivery of oxygen to the cochlea (Loprinzi et al., 2012). Another study done by Kawakami et al. investigated the correlation between muscular and performance fitness and hearing loss incidence, and the results showed that a higher muscular and performance fitness was associated with a lower risk of hearing loss (Kawakami et al., 2021).

A study by Cristell et al. (1998) was conducted to find whether improvements in both cardiovascular fitness and hearing sensitivity occurred after an 8-week aerobic exercise training program. The participants were 17 moderately low fit young adults. Each participant tested to have normal hearing on a Beltone 2000 pure-tone audiometer and did not indicate any history of middle-ear disease or previous significant noise exposure. VO_2 peak levels indicated fitness levels and were measured as a baseline using a graded exercise test on a Monark bicycle ergometer. A baseline for heart rate, blood pressure, and core temperature were also recorded. Heart rate was measured by a UNIQ model 8799 heart watch, blood pressure was measured by a certified physician assistance using a manual sphygmomanometer, and tympanic core was measured using a First Temp thermometer (Cristell et al., 1998). Participants were separated into a control

group, who did not participate in the exercise training program, and an experimental group, who did participate in the exercise training program. The experimental group did an 8-week aerobic exercise training program, where they cycled on a bicycle ergometer at least twice a week, 30 minutes a day. The control group took this time to learn about health-related benefits of regular exercise (Cristell et al., 1998). Results showed that the experimental groups VO_2 peak levels improved by 25% with an enhanced hearing ability, while the control group remained the same. Cristell et al. (1998) hypothesized that higher cardiovascular fitness may increase blood flow and oxygen delivery to the hearing organ. The authors concluded that cardiovascular function and hearing ability are able to improve after an 8-week moderate intensity exercise training routine. Limitations to this study include differences in tone presentation techniques, patient response patterns, and equipment and testing environment during the hearing tests. However, conventional automatic audiometry was found to be reliable using the test versus retest model (Cristell et al., 1998).

Summary

Cancer statistics illustrate that the rate of new cases increases each year and can affect anyone despite their sex, race, and ethnicity. Anyone is at risk of cancer and millions of people in the United States live with cancer each year. Thus, many people are exposed to risks of ototoxicity. Several common chemotherapeutics have the ability to induce ototoxicity, which damage the auditory and the vestibular systems. It is important to understand that the auditory and vestibular side effects of ototoxic drugs can dramatically impact a person's day-to-day life and cause an overall decreased quality of

life. There are methods to monitor and prevent with ototoxicity which may help prevent these negative effects.

Exercise-based cancer rehabilitation is important for cancer patients to participate in because it can create positive results and allow cancer treatment and recovery to be a smoother process by reducing symptoms. During exercise therapy at UNCCRI, communication is important between the cancer patient and the cancer exercise specialist so that the patient can be guided verbally during each session and, by the end of all four phases, ensured physiological and psychological improvements. However, due to the implications of ototoxicity, it is possible that hearing loss may be a barrier in the necessary communication. UNCCRI requires communication in both group environments and one-on-one sessions with specialists. Patients need to be able to talk about chemotherapy and discomfort they experience, while specialists must provide patients with direction during exercises. Poor communication could cause problems during exercise therapy and lead to physical injury if instructions are misunderstood therapy.

With further research, it is possible to characterize the hearing status of cancer patients participating in exercise-based cancer rehabilitation. If hearing loss is common amongst these patients, then there may be a need to educate the exercise trainers and office staff regarding communication strategies and hearing devices. There may also be a need to educate cancer patients regarding the status of their hearing and identify any need for medical/audiological referral and intervention to treat their hearing disorder. Determining the feasibility of the WAHTS at the UNCCRI is a crucial step to facilitate this possibility. In addition, this study will compare the hearing thresholds of cancer

patients obtained with the automated WAHTS used in a room at the UNCCRI to hearing thresholds obtained manually using a clinical audiometer in a sound-treated booth?

METHODS

Participants

Adult cancer patients who had received chemotherapeutics and/or radiation treatment for cancer and were receiving exercise-based therapy at UNCCRI were recruited for participation in the study. Consent and experimental procedures were conducted in compliance with the approved UNC Institutional Review Board (IRB) protocol (see Appendix A).

Additional inclusion criteria consisted of the following:

- Male or female aged 18+ years
- Ability to give informed consent
- Subject was agreeable to the conditions of study and signed consent form
- Ability to understand the hearing test instructions and respond accordingly
- Normal otoscopic examination

Study exclusion criteria included the following:

- Implantable hearing device
- Physical condition that prevents the placement of the clinical headphones or the WAHTS headset
- Any piercings or a non-removable head dressings that would interfere with the placement of the headset or headphones
- Physical condition that prevents routine operation of the WAHTS (e.g., impaired dexterity or visual impairment)

Instrumentation and Procedures

Creare Wireless Automated Hearing Test System

The Creare Wireless Automated Hearing Test System (WAHTS) is a wireless audiometric headset which connects to a mobile device (tablet or smartphone) through Bluetooth. The electronics inside the headset are like a very small computer and process the sounds going to the speakers inside the headset automatically. This is essentially equivalent to the electronics that are inside an audiometer, except in the WAHTS the electronics were made small enough to fit inside the high attenuation earcups. The electronic includes a CODEC (Coder/Decoder) that provides analog-to-digital and digital-to-analog encoding for each of the speakers and microphones (left and right) in the ear cups. The CODEC is part of an electronic circuit that includes a digital signal processor (DSP), a memory chip, a communication module for Bluetooth communication, and a power module to regulate the power (3.3V) provided by a lithium-ion battery (similar to the batteries found in cell phones). The power module drives the speakers, the microphone bias, the DSP, and the memory. The DSP generates the waveforms to be played in the ear canal according to an algorithm that is implemented in the chip itself. Calibration data is also stored in permanent memory on the board. The tablet computer serves as a user interface for the measurement protocol. The user can enter the parameters associated with the specific protocol of interest (frequencies to be tested, etc.), and the results of the on-chip computations are returned to the software on the tablet for storage. Automated algorithms are specific to the type of test being performed including audiometric thresholds according to either the Modified Hughson-Westlake technique or the Bekesy tracking technique.

Figure 1

Creare Wireless Automated Hearing Test System (WAHTS)

Note: Picture courtesy of Ashley Stumpf.

Clinical Audiometry

Manual air conduction hearing testing was conducted using three clinical audiometers equipped with circumaural earphones (HDA-200 or DD450) within a double-walled sound booth located in the University of Northern Colorado Speech-language Pathology and Audiology Clinic. Table 5 presents the make, model, serial number and earphone type used in the study. All audiometers had passed annual calibration and output calibrations were obtained daily as part of routine clinic operating procedures.

Table 5

Audiometer Information

Make/Model	Serial Number	Headphone Model
GSI AudioStar Pro	GS0085882	HDA-200 or DD450
GSI AudioStar Pro	GS0086087	HDA-200 or DD450
GSI 61	AA094905	HDA-200 or DD450

Note. Make/model, serial number, and headphone model of each audiometer that was used to test participants in the clinical setting.

Ambient Noise Level Measurements

Ambient noise levels within the clinical sound booth and the UNCCRI exam room complied with the maximum permissible ambient noise levels specified in ANSI S3.1-1999 (R2018) for testing to 0 dB HL (decibels hearing level).

Data Collection Procedures

Otoscopy

Appropriate subject consent forms were to be completed prior to beginning data collection. The researcher performed brief otoscopic exam to determine if the ear canal was clear and normal landmarks were visible. No participants were excluded due to abnormal otoscopy.

Survey Instrument

Prior to testing their hearing, each participant took a survey answering questions about their cancer, hearing, and exercise status (see Appendix B). The survey was administered on the tablet computer and the participant's responses were logged in Qualtrics using a unique identifier for each subject that could not be linked to any personally identifiable information. The Revised Hearing Handicap Inventory for the Elderly and Adults was also administered electronically using Qualtrics (Cassarly et al., 2020).

Audiometry

The hearing test protocols consisted of air-conduction threshold measurements at the conventional test frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in both ears. Extended high frequency (EHF) thresholds were also measured at 9000, 10000, 11200, 12500, 14000, and 16000 Hz in both ears. Hearing thresholds were measured in accordance with the ANSI S3.21-2004 (R2009) using a clinically appropriate 5 dB step size. Both ears were occluded by the same earphone type during air conduction testing. Both hearing test systems were calibrated beforehand to assure accurate stimulus levels.

The participants were debriefed with a copy of their hearing tests obtained with the clinical audiometer, counseled regarding the otoscopy and hearing test results, and each had an opportunity to ask questions about their hearing status. Participants were referred to their personal physician and/or an audiologist for follow-up hearing care when

hearing loss was identified. All testing and patient debriefing was completed under the supervision of an experienced audiology graduate student.

Data Analysis

Survey responses were then download into Excel for descriptive analysis and scoring of the RHHI as indicated in Cassarly et al. (2020). Hearing thresholds were exported from the WAHTS and analyzed using Excel (v16.59) Descriptive and analytical comparison of hearing threshold values were obtained for each experimental test condition (in sound booth with clinical audiometer and outside sound booth at the UNCCRI with WAHTS). The average hearing thresholds were obtained for each test frequency and test ear for each condition. Student's t-test was utilized to compare hearing thresholds obtained in an exam room at UNCCRI with the hearing thresholds measured in a clinical setting. Statistical significance referenced an alpha of .05. The clinical significance of any differences referenced a ±10 dB test-retest reliability (Schmuziger et al., 2004).

RESULTS

Participants

Nine participants were recruited and ranged in age from 52 to 81 years with a mean age of 66.2 (±8.6) years. One participant was male and the remaining eight were female. All subjects were white. Each participant had been diagnosed with at least one type of cancer which included ovarian, breast, head and neck, colon/rectum, kidney/renal pelvic, and skin. Four (44%) of the participants had undergone chemotherapy in the past five years, one (12%) participant was currently undergoing chemotherapy treatments, and four (44%) participants had not undergone chemotherapy in the past five years. The chemotherapy drugs with side effects of hearing loss and/or tinnitus that had been prescribed to the participants in the past five years included Carboplatin and Folfox (rarely <1% ototoxic) (Cancer Research UK, 2019). Three of the five (60%) participants said their doctors and nurses did not inform them that chemotherapy could potentially damage hearing. Of these, one participant was informed through their pre-treatment paperwork, and two were unsure of how they were notified.

Survey Results

Three (33.3%) of the participants noted hearing loss in both ears and one (11.1%) had a unilateral hearing loss. Three (33.3%) participants were unsure of their hearing status. Two (22.2%) said they did not have a hearing loss. Of these, one participant reported wearing hearing aids and that they had them for both ears. None of the participants used any type of listening device while exercising at the UNCCRI. When

asked if they had difficulty hearing their trainer during exercise sessions or assessments at the UNCCRI, six (66.6%) of the participants stated they did not, two (22.2%) of the participants stated they had trouble hearing during both the exercise sessions and physical assessments, and one (11.1%) participant stated they had trouble hearing during the exercise sessions only. Seven (77.8%) of the participants said their hearing did not affect their exercise sessions, and two (22.2%) of the participants reported that their poor hearing effected their exercise sessions sometimes. When asked how often they needed to ask their trainer to repeat, four (44.4%) of the participants said "sometimes", two (22.2%) participants said "rarely", and three (33.3%) of participants said "never."

Revised Hearing Handicap Inventory

The 18 questions from the RHHI along with number and percentages of responses are detailed in Table 6. The participants' survey scores ranged from 0, indicating the participant has no self-reported hearing handicap, to 52, indicating that the participant has a greater hearing handicap. Five (55.6%) of participants exceeded the ≥ 6 cut-off score as an indication of hearing impairment. The mean RHHI score was 16 (±17).

Table 6

Summary of Revised Hearing Handicap Inventory Responses

Question	Yes	No	Sometimes
	% (n)	% (n)	% (n)
(RHHI-1) Does a hearing problem cause you difficulty when listening to TV or radio?	22.2 (2)	44.4 (4)	33.3 (3)
(RHHI-2) Does a hearing problem cause you difficulty when attending a party?	11.1 (1)	44.4 (4)	44.4 (4)
(RHHI-3) Does any problem or difficulty with your hearing upset you at all?	22.2 (2)	33.3 (3)	44.4 (4)
(RHHI-4) Does a hearing problem cause you to feel frustrated when talking to members of your family?	11.1 (1)	44.4 (4)	44.4 (4)
(RHHI-5) Does a hearing problem cause you to feel left out when you are with a group of people?	11.1 (1)	44.4 (4)	44.4 (4)
(RHHI-6) Does a hearing problem cause you difficulty when visiting friends, relatives or neighbors?	11.1 (1)	44.4 (4)	44.4 (4)
(RHHI-7) Do you feel handicapped by a hearing problem?	11.1 (1)	44.4 (4)	44.4 (4)

Question	Yes	No	Sometimes
	% (n)	% (n)	% (n)
(RHHI-8) Do you feel that any difficulty with your hearing limits or hampers your personal or social life?	22.2 (2)	55.6 (5)	22.2 (2)
(RHHI-9) Does a hearing problem cause you to feel uncomfortable when talking to friends?	11.1 (1)	55.6 (5)	33.3 (3)
(RHHI-10) Does a hearing problem cause you to avoid groups of people?	0 (0)	77.8 (7)	22.2 (2)
(RHHI-11) Does a hearing problem cause you to use the phone less often than you would like?	0 (0)	66.7 (6)	33.3 (3)
(RHHI-12) Does a hearing problem cause you to be nervous?	0 (0)	77.8 (7)	22.2 (2)
(RHHI-13) Does a hearing problem cause you to listen to TV or radio less often than you would like?	0 (0)	77.8 (7)	22.2 (2)
(RHHI-14) Does a hearing problem cause you to talk to family members less often than you would like?	0 (0)	77.8 (7)	22.2 (2)
(RHHI-15) Does a hearing problem cause you to want to be by yourself?	0 (0)	77.8 (7)	22.2 (2)

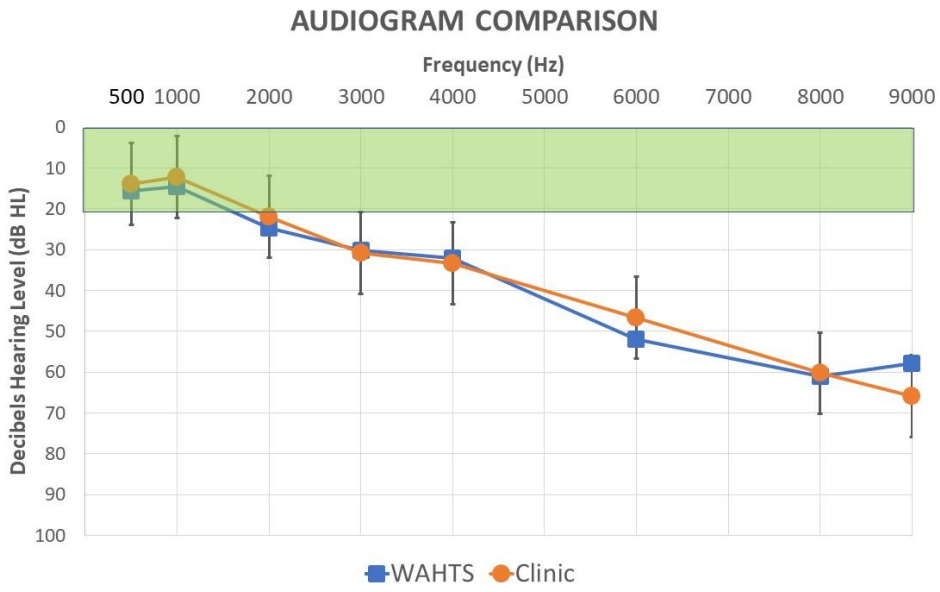
Question	Yes	No	Sometimes
	% (n)	% (n)	% (n)
(RHHI-16) Does a hearing problem cause you to feel depressed?	0 (0)	88.9 (8)	11.1 (1)
(RHHI-17) Does a hearing problem cause you to visit friends, relatives or neighbors less often than you would like?	0 (0)	88.9 (8)	11.1 (1)
(RHHI_18) Does a hearing problem cause you to go shopping less often than you would like?	0 (0)	77.8 (7)	22.2 (2)

Hearing Status

Individual audiograms showed that there is a 100% incidence of hearing loss (at least one hearing threshold >20 dB HL) among the participants in this study. The participant's mean audiograms showed that the participants had normal hearing thresholds (≤20 dB HL) at 500 Hz and 1000 Hz and mild sloping to severe high frequency hearing loss for the higher frequencies (2000-9000 Hz). Mean hearing thresholds are plotted on the audiogram in Figure 1 for the WAHTS as compared to the clinical exam. The error bars represent the typical test-retest reliability (±10 dB) for hearing threshold measurements 500-9000 Hz with circumaural headphones in the clinical setting.

Figure 2

Mean Hearing Thresholds for all Participants



Note. Error bars reflect clinical test-retest reliability (±10 dB).

WAHTS Versus Clinical Testing

Hearing thresholds were not statistically different (α = .05) between ears with either the WAHTS (*p*=0.81*)* or the clinical audiometer (*p*=0.69*)* and so hearing thresholds for both ears were combined for statistical comparison of test locations/audiometers. There was no significant difference (*p*=0.62) between the hearing thresholds obtained using automated testing in a room in the exercise center and those conducted in the clinical setting within a sound booth at any test frequency.

Summary

All of the subjects (100%) had hearing loss as measured with pure-tone audiometry. The RHHI scores indicated that 55.6% of the participants had a hearing

handicap. 22.2% of the participants stated their hearing loss had an impact on communication during exercise sessions. Since there was no significant difference between the hearing thresholds measured with the WAHTS as compared to thresholds measured with the clinical audiometer. These preliminary results suggest that there is potential for the WAHTS technology to be used to test the hearing of cancer patients. undergoing exercise rehabilitation at UNCCRI.

DISCUSSION

Implementation of the WAHTS in a Cancer Exercise Center

Feasibility of using the WAHTS was established by comparing hearing thresholds obtained at the UNCCRI using the WAHTS to hearing thresholds measured by clinical audiometers in a traditional clinical setting. The results of this study are consistent with other studies investigating the use of WAHTS in out-of-booth locations. The Stumpf (2019) study found the WAHTS provided sufficient attenuation of ambient noise and enabled valid hearing thresholds measurements to 5 dB HL for 250-20,000 Hz in two outpatient chemotherapy treatment settings in northern Colorado. Meinke et al. (2017) showed that the WAHTS obtained equivalent hearing thresholds in six different workplace locations as the computer-controlled audiometry obtained in a mobile trailer sound booth at 1000, 2000, 3000 and 8000 Hz, and thresholds within ±5 dB at 500, 4000, and 6000 Hz. The current study shows testing was valid and there was no significant difference between test locations.

In addition, the WAHTS was easily operated by a researcher who is not a trained audiologist. The automated hearing test protocol implemented in the WAHTS enabled testing to be conducted by a person with less training. In addition, there were no malfunctions or challenges with using the WAHTS in the experimental setting.

Hearing Loss in Cancer Patients Enrolled in Cancer Exercise Program

The prevalence of hearing loss among the participants of this study was 100%. Eight (88.9%) of the participants were taking or had taken chemotherapeutics and/or

radiation treatments. The participants were of an older population with a mean age of 66.2 (±8.6) years, which studies show hearing loss is more prevalent (45.9% - 63.1%) in older individuals (48 years and older) than in younger individuals (Cruickshanks et al., 1998; Homans et al., 2017; Lin et al., 2011). The degree and configuration of the mean hearing loss is typical for the participant's demographics (Ganesan et al, 2018, Vaden et al., 2017). However, there is no way to tell if the participants' hearing loss was caused by ototoxicity, presbycusis, and/or other factors since diagnostic testing was not completed.

Self-Report of Hearing Loss

Four (44.4%) of the participants stated they had a hearing loss. All (100%) of participants had a hearing loss, which suggests that the participants self-report severely under-estimated their actual hearing loss. This is consistent with the findings of studies that have looked at the under reported discrepancies between self-reported hearing loss and pure-tone air conduction audiometry (Nondahl et al., 1998; Sinhusake et al., 2001). When asked, "do you feel you have a hearing loss?", overall estimated prevalence was within 3.2% of actual prevalence. This question had the highest sensitivity compared to other hearing related questions asked and the Hearing Handicap Inventory for the Elderly: Screening version (HHIE-S) (Nondahl et al., 1998; Sinhusake et al., 2001).

Revised Hearing Handicap Inventory

Hearing impairment is calculated based on hearing threshold measurements, whereas hearing handicap is the disadvantage imposed by a hearing impairment on a person's performance in the activities of daily living. Therefore, comparisons between

self-reported hearing status, RHHI and hearing impairment based upon the audiogram will reflect different aspect of a person's hearing status. Five (55.6%) of the participants had RHHI scores >6, suggesting that they have a hearing impairment, slightly higher than the self-report demographic question (44.4% affirmative). In these instances, the audiograms show that the RHHI accurately predicted the presence of a hearing impairment (Cassarly et al., 2020). Four (44.4%) of the participants had RHHI scores <6, indicating they did not have a hearing impairment (Cassarly et al., 2020). These scores did not accurately predict the participants hearing because their audiograms showed they all had a hearing loss. However, when taking a closer look at their scores, participants who had lower RHHI scores tended to have a less severe hearing loss than those with higher RHHI scores. The participant with the lowest RHHI score of 0 had normal hearing at 500 – 4000 Hz and thresholds in the moderately severe range at 6000 – 9000 Hz which likely explains the discrepancy between RHHI categorization and self-report. The participant with the highest RHHI score of 52 had normal hearing at 500 – 2000 Hz with thresholds sloping downward to a profound hearing loss at 9000 Hz. Survey responses and RHHI outcomes indicated that some participants had difficulty communicating at their exercise sessions at the UNCCRI, as well as in their daily life. This could impact ease of communication between patients and their trainers during their exercise sessions and physical assessments.

Auditory Rehabilitation Needs

Due to the 100% prevalence of hearing loss among the participants, some participants might benefit from assistive listening devices and/or amplification devices

dependent on the frequencies involved in the hearing loss. This would need to be further evaluated using clinical diagnostics and speech testing. One (11.1%) of the participants stated they wore hearing aids. This same participant obtained the highest score from the RHHI, which suggests the RHHI outcomes may accurately stratify the degree of hearing impairment. Eight (88.9%) participants stated they did not utilize a hearing aid, and some may be candidates for amplification depending upon further testing by an audiologist. This type of referral is important since, individuals with a hearing loss who use hearing aids have a higher quality of life than those with a hearing loss who do not use hearing aids (Hyams et al., 2018).

Implications for Exercise Training

Exercise training requires communication between the trainer and the patient. Ambient noise in the exercise room and/or exercise positions that require patients to face away from the trainer may increase difficulty in hearing instructions from the trainer, especially for those with a hearing loss. Missing important information during instruction could lead to improper exercise and perhaps physical injury. Two (22.2%) of the participants stated they had trouble hearing during both the exercise sessions and physical assessments, and one (11.1%) participant stated they had trouble hearing during the exercise sessions only. During exercise sessions, communication is a means of motivating and encouraging the patient during exercises while keeping them focused and coaching them to do their best. Communication is also important during assessments, which determine the patients physical and physiological status. A miscommunication during these assessments could lead to formulation of an inappropriate exercise plan for

the patient. Communication is not only important during exercises, but before, after, and outside of exercise sessions to communicate physical discomfort, current treatment plans, and scheduling appointments.

Implementation of WAHTS into Exercise Rehabilitation for Cancer Patients

The WAHTS hearing testing could be implemented into UNCRRI as part of intake exam to identify need for communication accommodations during assessment and training. Screening for potential ototoxic drug exposure during intake exams if the patient has not initiated chemotherapy yet to assure appropriate referral for ototoxicity monitoring. Whether or not the patient decides to see an audiologist and obtain amplification, trainers can provide ways to accommodate to patients with hearing loss. Visuals are an immense aid in communication: when possible, trainers should stand in front of the patients so their facial expressions and lips are visible, trainers should face the patients when they speak prior to moving to spotting positions, lighting should be sufficient for patients to be able to see the trainers face (Farage et al., 2012). Maximizing the use of verbal communication is also important: trainers should speak clearly and concisely, if asked to repeat more than once, trainers should reword what they said, trainers should ask questions to make sure their patient is hearing and understanding correctly (Farage et al., 2012). The signal-to-noise ratio can also be maximized by eliminating background music/noise and communicating in quieter environments when feasible. In cases of moderate to severe hearing loss, the patients may need to utilize their hearing aids or assistive listening devices to facilitate communication. Audiologists can

collaborate with exercise trainers to address any unique communication/exercise situations.

Study Limitations

The sample size of this pilot study was small, which reduces the generalizability of this study. The number of participants in the current study was less than other studies regarding the feasibility of the WAHTS, the Meinke et al. (2017) study (n=20) and the Stumpf (2019) study (n=21). Recruiting participants was difficult due to the state of their health, general availability, and scheduling challenges. These challenges were similar to those reported for ototoxicity monitoring. It is important for cancer patients who are at risk of ototoxicity to be referred to an audiologist for ototoxicity monitoring, which requires multiple appointments to monitor the patients hearing during their treatment and is a significant barrier to hearing healthcare (Landier, 2016). The difficulty in scheduling participants for a clinical evaluation observed during this study supports the need for onsite testing using the WAHTS at the UNCCRI. Testing onsite could ease the inconvenience caused by arranging clinical appointments at a separate facility.

Ambient noise was only measured one time at the UNCCRI but should have been tested continuously during each hearing test. Noise levels subjectively varied throughout testing due to people talking outside of the room, which was not captured through sound level meter measurements during the experiment/ However, the hearing thresholds were consistent between both test locations which suggests that ambient noise was not a problem when testing with the WAHTS. Meinke et al. (2017) recommends future

research to utilize the microphones placed in each ear cup of the WAHTS to detect noise levels too high and testing pauses or repeats to ensure accurate thresholds.

Future research

Future research should investigate if exercise trainers can administer the WAHTS hearing test and obtain valid results. Future research should also explore what type of audiometric technician training the exercise trainers may need in order to perform automated audiometry with the WAHTS. It is also important for future research to assess the use of hearing aids and/or cochlear implants during exercise sessions to answer the following questions: would they need the use of assistive listening devices such as remote microphone capabilities?; what programming features might be best for this setting, e.g. omni-directional microphone, or "backseat" program?; can the devices stay in position during exercise movements?; is there a concern for perspiration? etc. In addition, future research should investigate the use of the WAHTS as a means of ototoxic monitoring, and if it can be integrated with the exercise rehabilitation program for cancer patients beginning ototoxic treatments.

Summary

Hearing thresholds can be measured accurately with the WAHTS in a cancer exercise center exam room and are comparable to those measured in clinical setting. There was no significant statistical difference (p=0.62) in thresholds measured by the WAHTS at the cancer exercise center and the clinical audiometer in the speech-language pathology and audiology clinic. Cancer patients participating in exercise rehabilitation

program may have hearing loss and need accommodations to facilitate communication during exercise sessions.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date:	09/20/2021
Principal Investigator:	Cecilia Talarico
Committee Action:	**Expedited Approval - New Protocol**
Action Date:	09/20/2021
Protocol Number:	2108028848
Protocol Title:	Hearing profiles of cancer patients attending an exercise-based cancer rehabilitation program
Expiration Date:	

The University of Northern Colorado Institutional Review Board has granted approval for the above referenced protocol. Your protocol was approved under expedited category (4) as outlined below:

Category 4: Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

All research must be conducted in accordance with the procedures outlined in your approved protocol.

If continuing review is required for your research, your project is approved until the expiration date listed above. The investigator will need to submit a request for Continuing Review at least 30 days prior to the expiration date. If the study's approval expires, investigators must stop all research activities immediately (including data analysis) and contact the Office of Research and Sponsored Programs for guidance.

If your study has not been assigned an expiration date, continuing review is not required for your research.

For the duration of the research, the investigator(s) must:

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Institutional Review Board

- Submit any change in the research design, investigators, and any new or revised study documents (including consent forms, questionnaires, advertisements, etc.) to the UNC IRB and receive approval before implementing the changes.
- Use only a copy of the UNC IRB approved consent and/or assent forms. The investigator bears the responsibility for obtaining informed consent from all subjects prior to the start of the study procedures.
- Inform the UNC IRB immediately of an Unanticipated Problems involving risks to subjects or others and serious and unexpected adverse events.
- Report all Non-Compliance issues or complaints regarding the project promptly to the UNC IRB.

As principal investigator of this research project, you are responsible to:

- Conduct the research in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorizations using the currently approved forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any unanticipated problems involving risks to subjects or others and serious and unexpected adverse events.
- Maintain accurate and complete study records.
- Report all Non-Compliance issues or complaints regarding the project promptly to the IRB.

Please note that all research records must be retained for a minimum of three (3) years after the conclusion of the project. Once your project is complete, please submit the Closing Report Form.

If you have any questions, please contact Nicole Morse, Research Compliance Manager, at 970-351-1910 or nicole.morse@unco.edu. Please include your Protocol Number in all future correspondence. Best of luck with your research!

Sincerely,

Michael Aldridge
IRB Co-Chair, University of Northern Colorado: FWA00000784

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Silvia Correa-Torres
IRB Co-Chair, University of Northern Colorado: FWA00000784

APPENDIX B

ELECTRONIC SURVEY WITH RHHI

Start of Block: Demographics Base/Universal

Q17 UnderGrad and Grad Student Initials

_____

Q8 Enter Subject Number

_____

Q10 What is your year of birth?

_____

Q13 Are you Spanish, Hispanic, or Latino or none of these?

- ○ Spanish (1)
- ○ Hispanic (2)
- ○ Latino (3)
- ○ None of these (4)

Q14 Choose one or more races that you consider yourself to be:

- ☐ White (1)
- ☐ Black or African American (2)
- ☐ American Indian or Alaska Native (3)
- ☐ Asian (4)
- ☐ Native Hawaiian or Pacific Islander (5)
- ☐ Other (6) _____

Q15 What is your sex?

- ○ Male (1)
- ○ Female (2)
- ○ Prefer not to answer (3)

End of Block: Demographics Base/Universal

Start of Block: Cancer Questions

Q18 What type of Cancer(s) were you most recently diagnosed? (past 5 years). Select all that apply.

- ☐ Breast (1)
- ☐ Prostate (2)
- ☐ Lung / Bronchus (3)
- ☐ Colon / Rectum (4)
- ☐ Melanoma (6)
- ☐ Bladder (7)
- ☐ non-Hodgkin Lymphoma (8)
- ☐ Kidney / Renal Pelvic (9)
- ☐ Endometrial (10)
- ☐ Leukemia (11)
- ☐ Pancreatic (12)
- ☐ Thyroid (13)
- ☐ Liver (14)
- ☐ Other (16) _____

Q19 Have you been prescribed chemotherapy drug treatments in the past 5 years?

- ○ Yes, I am taking chemotherapy NOW (1)
- ○ Yes, I took chemotherapy treatments in the past 5 years (2)
- ○ No, I have not had chemotherapy drug treatments in the past 5 years (3)
- ○ Unsure (4) _____

Skip To: Q1 If Have you been prescribed chemotherapy drug treatments in the past 5 years? = Yes, I am taking chemotherapy NOW

Skip To: Q21 If Have you been prescribed chemotherapy drug treatments in the past 5 years? = Yes, I took chemotherapy treatments in the past 5 years

Skip To: End of Block If Have you been prescribed chemotherapy drug treatments in the past 5 years? = No, I have not had chemotherapy drug treatments in the past 5 years

Skip To: End of Block If Have you been prescribed chemotherapy drug treatments in the past 5 years? = Unsure

Q1 What are the names of the chemotherapy drug treatments you are taking now?

_____

Q21 What were the names of the chemotherapy drug treatments that you were given in the past 5 years?

_____

Q22 Did your doctors or nurses ever tell you that your chemotherapy drug(s) might damage your hearing?

- ○ Yes (1) _____
- ○ No (2) _____
- ○ Unsure (3) _____

Q2 Have you noticed any differences in your hearing since starting chemotherapy?

- ○ Yes, both ears (7) _____
- ○ Yes, one ear (8) _____
- ○ No (11) _____
- ○ Unsure (12) _____

End of Block: Cancer Questions

Start of Block: Hearing Status

Q43 Do you have a hearing loss?

- ○ Yes, both ears (1)
- ○ Yes, one ear (2)
- ○ No (3)
- ○ Unsure (4)

Skip To: Q45 If Do you have a hearing loss? = No
Skip To: Q45 If Do you have a hearing loss? = Unsure

Q44 If Yes, do you wear one of the following devices?

- ○ Hearing Aids, both ears (1) _____
- ○ Hearing Aid, one ear (2) _____
- ○ Cochlear Implant, both ears (3) _____
- ○ Cochlear Implant, one ear (4) _____
- ○ Other implantable device (5) _____

Q45 Do you wear a hearing aid, cochlear implant or other listening device while exercising at UNCCRI?

- ○ Yes (1) _____
- ○ Sometimes (2) _____
- ○ No (3) _____

Q4 Have you ever noticed a difficulty hearing your trainer during your exercise sessions or assessments at the UNC Cancer Rehabilitation Institute? Please describe further if possible.

- ○ Yes, during exercise sessions AND assessment sessions (1) _____
- ○ Yes, during exercise sessions only (2) _____
- ○ Yes, during assessment sessions only (6) _____
- ○ No (7) _____
- ○ Unsure (8) _____

Q7 Do you feel that your hearing effects your exercise sessions at the UNC Cancer Rehabilitation Institute?

- ○ Yes (1)
- ○ Sometimes (5)
- ○ No (3)

Q6 How often do you find yourself having to ask your exercise trainer to repeat?

- ○ Very often (1)
- ○ Sometimes (2)
- ○ Rarely (3)
- ○ Never (4)

End of Block: Hearing Status

Start of Block: Revised Hearing Handicap Inventory Questions

Q24
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. Do not skip a question if you avoid a situation because of your hearing problem. *If you use a hearing aid or implant, please answer the way you hear* ***without the aid or implant****.*

(RHHI-1) Does a hearing problem cause you difficulty when listening to TV or radio?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q25 (RHHI-2) Does a hearing problem cause you difficulty when attending a party?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q26 (RHHI-3) Does any problem or difficulty with your hearing upset you at all?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q27 (RHHI-4) Does a hearing problem cause you to feel frustrated when talking to members of your family?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q28 (RHHI-5) Does a hearing problem cause you to feel left out when you are with a group of people?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q29 (RHHI-6) Does a hearing problem cause you difficulty when visiting friends, relatives or neighbors?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q30 (RHHI-7) Do you feel handicapped by a hearing problem?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q31 (RHHI-8) Do you feel that any difficulty with your hearing limits or hampers your personal or social life?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q32 (RHHI-9) Does a hearing problem cause you to feel uncomfortable when talking to friends?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q33 (RHHI-10) Does a hearing problem cause you to avoid groups of people?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q34 (RHHI-11) Does a hearing problem cause you to use the phone less often than you would like?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q35 (RHHI-12) Does a hearing problem cause you to be nervous?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q36 (RHHI-13) Does a hearing problem cause you to listen to TV or radio less often than you would like?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q37 (RHHI-14) Does a hearing problem cause you to talk to family members less often than you would like?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q38 (RHHI-15) Does a hearing problem cause you to want to be by yourself?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q39 (RHHI-16) Does a hearing problem cause you to feel depressed?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q40 (RHHI-17) Does a hearing problem cause you to visit friends, relatives or neighbors less often than you would like?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

Q41 (RHHI_18) Does a hearing problem cause you to go shopping less often than you would like?

- ○ Yes (1)
- ○ Sometimes (2)
- ○ No (3)

End of Block: Revised Hearing Handicap Inventory Questions

APPENDIX C

HEARING THRESHOLD DATA

Raw hearing threshold data obtained with the WAHTS (dB HL)

		Test Frequency (Hz)							
Subject	Ear	500	1000	2000	3000	4000	6000	8000	9000
1	R	10	15	20	25	30	55	65	65
	L	10	15	20	10	5	35	40	40
2	R	30	5	10	20	10	20	30	20
	L	10	5	10	15	20	25	40	30
3	R	10	20	10	20	45	75	75	75
	L	0	5	20	15	35	75	80	75
4	R	10	10	10	15	15	50	65	50
	L	10	10	15	10	5	45	70	60
5	R	25	20	45	50	65	75	70	75
	L	30	40	50	55	70	80	75	65
6	R	25	20	35	60	65	75	75	70
	L	20	20	55	60	70	75	80	75
7	R	30	40	35	35	35	35	35	40
	L	15	20	20	40	30	50	65	50
8	R	10	5	15	25	20	40	45	70
	L	5	5	10	35	25	40	60	65
9	R	5	0	20	15	10	35	65	55
	L	25	5	45	40	20	50	65	60
M		15.6	14.4	24.7	30.3	31.9	51.9	61.1	57.8
(SD)		(9.7)	(11.5)	(15.3)	(17.2)	(22.3)	(19.4)	(16.0)	(16.5)

Raw hearing threshold data obtained with the clinical audiometer (dB HL).

		Test Frequency (Hz)							
Subject	Ear	500	1000	2000	3000	4000	6000	8000	9000
1	R	5	10	10	5	0	25	65	75
	L	0	15	15	20	30	50	40	45
2	R	25	0	10	15	15	15	30	40
	L	10	5	10	10	20	25	40	50
3	R	10	20	10	30	50	70	80	95
	L	5	5	15	20	40	70	85	90
4	R	10	10	5	20	20	55	60	55
	L	10	10	15	15	15	50	65	70
5	R	30	30	50	55	70	80	85	75
	L	25	20	45	55	65	75	75	80
6	R	25	20	30	60	70	65	75	80
	L	25	20	55	70	75	65	75	80
7	R	25	30	30	40	35	35	40	40
	L	15	20	25	40	35	35	45	50
8	R	5	0	10	25	25	30	40	75
	L	10	5	10	35	20	35	65	70
9	R	5	0	15	10	5	25	60	55
	L	10	0	35	30	10	35	60	60
M		13.9	12.2	21.9	30.8	33.3	46.7	60.3	65.8
(SD)		(9.3)	(10.0)	(15.4)	(19.0)	(23.6)	(20.3)	(17.4)	(16.9)