Spring 2017

The Effect of Workplace Noise Exposure on Reaction Time

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A dissertation submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Doctor of Audiology

Communication Sciences and Disorders

May 2017

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ACKNOWLEDGEMENTS

I would like to thank my advisor and mentor, Dr. Ayasakanta Rout, for his support and guidance throughout my dissertation project and through my graduate school experience. His friendship has taken me down the path to my dream job in a profession I will always love. I would also like to thank my committee members, Drs. Christopher Clinard and Brenda Ryals, for their support throughout this process and my entire graduate school career. I could not imagine a different graduate school experience; I will carry this experience with me for the rest of my life.

I would like to thank my family, friends, and classmates who have been there for me throughout my eight years of education. I would also like to thank my father for teaching me to always care for others and that audiology is the best profession in the world.

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ABSTRACT

This study examined the effect of listening fatigue on the reaction time of normal hearing listeners, who work in noisy places, at different signal to noise ratios (quiet, +5 and +10 dB). Reaction time was measured using a single task paradigm on twelve male listeners (ages 23-58 years) before and after an eight hour shift at a noisy power plant. The participants in the study also completed a subjective rating questionnaire at two intervals, before and after the fatigue-inducing condition. Results of the study indicated that the reaction time was significantly longer for the most difficult listening condition, indicating the possibility that measurement of the reaction time was confounded by the lack of audibility. A learning effect on this particular reaction time task was also found because the results indicated shorter reaction times in the second session. Participants also subjectively rated significantly higher levels of fatigue on the rating scale after they were exposed to the fatigue-inducing condition. Results from this study indicate that caution should be taken when interpreting reaction time data as a measure of listening fatigue or listening effort. In conjunction with previous studies by Hulvey (2015) and Athey (2016) it is the author's belief that reaction time is affected by signal to noise ratio and not directly by listening fatigue.

Chapter I

INTRODUCTION

Through a degraded and damaged auditory system, individuals with hearing loss often have to exert more cognitive effort because they have to strain to understand speech in various adverse auditory environments throughout the day (Pichora-Fuller & Singh, 2006; Rabbitt, 1991; Rakerd, Seitz, Whearty, 1996). Sensory loss affects cognitive processing during language understanding in quiet and especially in noisy environments. An altered auditory signal to one's cognitive system can result in cognitive and psychosocial declines such as: increased cognitive load, increased mental fatigue, poor memory, difficulty with attention, poorer mental health, and social withdrawal or depression (Beck, Edwards, Humes, Lemke, Lunner, Lin, & Pichora-Fuller, 2012). A common complaint from hearing impaired individuals is that they are fatigued at the end of the day, even if speech is audible enough for them to hear. This fatigue is believed stem from the prolonged strain hearing impaired individuals endure while trying to listen to an auditory signal through a degraded auditory system. The strain derives from the fact that hearing impaired individuals are forced to re-allocate more cognitive resources to understand speech because of their sensory declines.

Literature on listening effort and listening fatigue has increased over the past couple of years, and has expanded into the realm of hearing impaired listeners and hearing aid technology. Research on cognition began to converge with hearing research because researchers felt the need to understand more about how older listeners function in everyday communication situations. The development of more effective assessment and treatment approaches for hearing impaired individuals requires a better understanding of cognition, especially if the fatiguing complaints of patients are to be addressed (Pichora-Fuller et al., 2016). By gaining a greater knowledge of cognition and listening fatigue, an audiologist may be able to provide rehabilitation techniques that reduce listening effort and listening fatigue. It is important for those in the research field to know the definition and difference between listening effort and listening fatigue. Listening effort can be defined as “effort involved in carrying out listening tasks”. Listening effort is the deliberate allocation of resources to overcome demands experienced by the listener. Listening fatigue can be defined as “fatigue resulting from the continued application of effort during difficult listening tasks” (Pichora-Fuller et al., 2016). While both listening effort and fatigue are interrelated, knowing the difference is important in understanding their connection with cognitive load.

Because the effects of hearing loss negatively impact one’s cognitive ability, it has been suggested that hearing aids can improve one’s cognitive ability by improving the quality of the auditory signal. The improved signal will then reach the listener’s cognitive system and be easier to process, compared to the degraded signal that would have been transmitted without the hearing aids (Beck et al., 2012). Researchers have proposed advanced hearing aid technologies, such as digital noise reduction (DNR), that have the ability to reduce the listening effort expended by hearing aid wearers during the day. This reduction in listening effort then results in the wearer having reduced listening fatigue. Because traditional tests, like speech in noise tests, do not access higher and more complex functioning; more complex testing procedures are needed to gain more sensitive measures of cognitive abilities (e.g. listening fatigue, listening effort, or effects of hearing aid technology on auditory processing).

Research test procedures are commonly grouped into three categories: subjective, physiologic, or behavioral. Subjective tests, or opinion based testing, allow for an easy and fast way to assess an individual's perception on his or her effort on a test and have high validity. Physiological tests provide objective information and are beneficial because they do not require behavioral responses, and can be measured continuously while also using other testing procedures. Behavioral tests are performance based where the subject devotes their attention to a specific task. Behavioral tests can be broken into two groups, single or dual task paradigms. Single-task paradigms are tasks that directly measure a dependent variable. Dual-task paradigms consist of a primary task while also simultaneously engaging in a secondary task. By increasing the complexity of the primary task, the secondary task measures the effect of the complexity shown in its performance. Performance in the secondary task is interpreted as an indirect measure of performance in the primary task (i.e. poor performance in the secondary task may indicate increased effort in the primary task) (Bess & Hornsby, 2014).

Several recent studies have attempted to evaluate listening effort by using subjective measures (e.g. Gatehouse and Noble, 2004; Hornsby, 2013), physiological measures (e.g. Zekveld et al., 2010; Richter, 2016), and behavioral measures such as reaction time (e.g. Sarampalis, Kalluri, Edwards, & Hafter, 2009; Hornsby, 2013). Researchers in the past have tried using different physiological and behavioral methods to measure listening effort and listening fatigue, but results vary widely suggesting those methods do not measure the same things. Many of the previous studies have also implemented dual task paradigms, which may not be valid or easily implemented into clinical settings. Dual task paradigms have been noted to document inaccurate results if a subject allocates too many cognitive resources to the secondary task, rather than allocating resources to both tasks (Hicks and Tharpe, 2002). Sarampalis et al. (2009) demonstrated that by increasing the signal to noise ratio through the use of directional technology/digital noise reduction, one can reduce their listening effort, and thus one's cognitive load. Sarampalis et al. (2009) used a dual task paradigm to measure a subject's listening effort which found the reaction times to be significantly shorter with digital noise reduction on, but only at the most difficult SNR condition (-6 dB SNR). Houben et al. (2013) found a single task paradigm consisting of a reaction time test could be effective in measuring a subject's listening effort. The study found that at the lowest signal to noise ratio (- 6 dB SNR), subjects' reaction times increased even with 100% speech intelligibility. Like Sarampalis et al. (2009), Houben et al. (2013) found that only at the hardest test condition (a signal to noise ratio of -6 dB) there can be a change in reaction time. However, these findings raise an important question: is the measured change in reaction time because of a change in the subjects' listening effort or is it because of a change in audibility. For example, the subject found it difficult to understand the signal through the noise and thus took longer to debate if they actually heard the speech signal. This question needed to be answered in order for listening effort to be an indicator of one's listening fatigue.

Hulvey (2015) designed a dissertation study to understand the effect of listening fatigue using a single task reaction time test. Twenty young, normal-hearing listeners were asked to participate in a reaction time task in a quiet both before and after they engaged in a 30-minute effortful listening task at -2 dB SNR. Subjects were included in the study if they had normal hearing thresholds, no reported diagnosis on the ADHD spectrum, no reported consumption of strong medication or alcohol, and no middle ear pathology. Participants were advised to refrain from consuming caffeine the morning of the study as caffeine is considered a stimulant, which could potentially affect their reaction times. The reaction time task consisted of subjects listening to eight sets of seven random nonsense syllables presented at 70 dB SPL in quiet. After the subject heard the nonsense syllable they were asked to respond as quickly and as accurately as they could by matching what they heard with the syllables written on a seven-button Cedrus response pad. The effortful listening task consisted of the subjects listening to thirty minutes of the Connected Speech Test (CST) sentences at 70 dB SPL in eight talker background babble at - 2 dB SNR. During the fatiguing condition subjects were instructed to keep track of the topics they heard in the sentences by writing them down to ensure they maintained attention to the task. Subjects also had to complete a short five-item questionnaire about their level of listening fatigue before and after the effortful listening task.

Hulvey's (2015) results showed that exposing young, normal hearing subjects to thirty minutes of continuous speech at the -2 dB SNR did not result in a change in their reaction times before vs after. This finding could be because the reaction time task was not an accurate measure of listening effort, the thirty minutes of effortful listening could not have been long enough to cause fatigue, or the reaction time task in quiet was too easy. While objectively there was no significance, subjectively the subjects reported they were more fatigued post-test vs pre-test.

Athey (2016) aimed to assess if the reaction time task in quiet was too simple of a task to assess a subjects listening effort. As an extension of Hulvey (2015), Athey (2016) used the same fatigue inducing condition, and reaction time task using the nonsense syllables. However, Athey (2016) tested subjects at different signal to noise ratios. Through a pilot study Athey was able to select +5 and +10 SNRs to try and make the reaction time task harder than when subjects were assessed in quiet. To obtain the different SNRs for her reaction time task, the nonsense syllables were preprocessed offline in four talker babble to generate the stimuli at +5 and +10 SNRs. The speech noise preceded the nonsense syllable by 500 milliseconds (ms) and continued an additional 50 ms after the nonsense syllables. Her study consisted of twenty young normal hearing adults, with no reported diagnosis of an ADHD spectrum disorder, no reported consumption of strong medication or alcohol, and no middle ear pathology. Her results showed that the twenty subjects' mean reaction time for the +5 SNR was significantly longer than the reaction time for the +10 SNR task ($f_{1,\ 19} = 13.1$; $p < .005$). The mean reaction time at the +5 SNR (the most difficult condition) was 52 ms longer than the reaction time at the +10 SNR. The difference between the reaction times for the pre and post fatigue inducing task was found to be nonsignificant ($f_{1,19} = 0.002$; $p > .05$). There was no interaction observed between the two SNRs and the pre and post tests. The results from her study can be found in figure 1. All participants indicated a higher level of fatigue rating on the subjective questionnaire following the effortful listening task. Athey (2016) found that while there was no overall change in reaction time after the fatiguing condition, the subjects did show a significant effect of signal to noise ratio. Her study showed that the fatigue inducing condition did affect listening effort, and that a reaction time task can be a measure listening effort as shown in the significant difference between the SNRs tested. Based on the results of Athey's study a question was left to answer: was the thirty minutes of effortful listening long enough to cause fatigue?

To answer this question, this study was undertaken as an extension of Hulvey (2015) and Athey's (2016) studies where subjects would be tested at different signal to noise ratios before and after an effortful listening task of working in a noisy environment. Because Athey's +5 and +10 SNRs were found to have an effect on listening effort, those two signal to noise ratios were used as well as a quiet condition. Also, the researchers wanted to extend the eight talker babble background noise encompassing the nonsense speech, thinking that the burst of the babble may have an effect on the interpretation of the nonsense syllable. This study used a continuous background noise of eight talker babble that was preprocessed offline to generate the +5 and +10 signal to noise ratios (the nonsense syllables were presented at 70 dB SPL). We decided to also run two trials at each of the three signal to noise ratios tested in order to gain more data points for statistical analysis when outlier reaction times were removed.

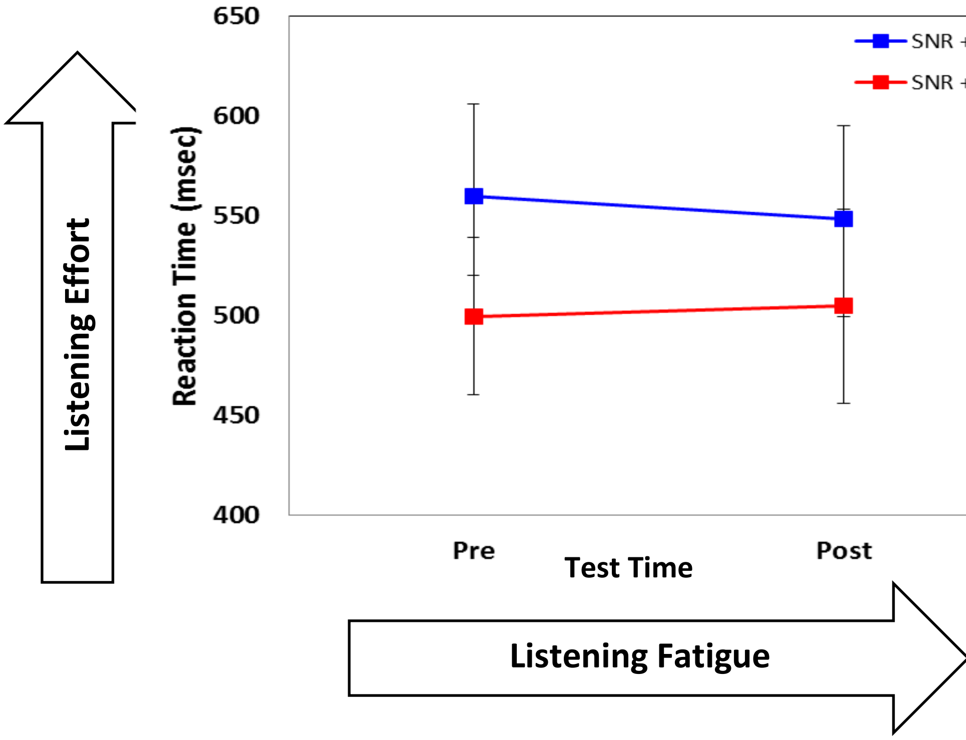

Figure 1. Athey (2016) results for mean reaction time in milliseconds (msec) for before and after exposure to the fatigue-inducing listening task. Error bars indicate ±1 SEM.

Research Questions

As a follow up to Hulvey (2015) and Athey (2016), this study examines the effect of long-term listening fatigue on reaction time. The following research questions are being posed in his study:

1. Is the reaction time to identify nonsense syllables in noise longer after normal hearing subjects are engaged in an effortful listening task consisting of an 8 hour work day?
2. Do the same subjects report a higher level of listening fatigue on a subjective rating scale?

Hypothesis

Based on the above questions the following null hypotheses are being put to test in this study:

1. There will be no significant difference in the measured reaction time between pre and post fatigue measures at the three signal to noise ratios.
2. There will be no significant difference between the self-reported level of listening fatigue before and after the fatigue inducing listening

Chapter 2

LITERATURE REVIEW

The Cognition and Audition Connection

It is important, in the field of audiology to understand the connection betw een cognition, listening, and amplification. This connection is important because hearing healthcare professionals need to incorporate this knowledge into aural rehabilitation, hearing aid programming, and counseling to better treat the needs of their patients. Cognitive functions that are important for listening consist of working memory, speed of processing, and attention control. Beck and Flexer (2011) stress that the goal of hearing healthcare professionals is to not just be make sounds louder, but to improve a patient's *listening*. *Listening* is referred to as hearing with intention and attention for purposeful activities. *Listening* demands an expenditure of mental effort involving short-term memory, working memory, allocation of attention, and higher cognitive processes. *Listening* is where hearing meets the brain and where cognitive processing begins. *Listening* is an active process that takes attention, and attention directs one's cognitive system to focus effort on a certain matter of interest (Beck & Flexer, 2011).

One of the main principles involving audition and cognition is that there is a limited capacity of mental resources that can be used for tasks. Cognition is finite, and there are vast differences in cognitive abilities across individuals. The amount of capacity allocated to tasks increases as tasks become more effortful or demanding. When an individual has hearing loss, or there is background noise present, the effort needed for successful interpretation of speech reduces cognitive resources. Thus, due to this effortful listening, there may be insufficient cognitive resources for interpreting and encoding sounds into stored memory (Pichora-Fuller et al., 2016). Having normal hearing thresholds is a precursor for successful auditory recognition, because the quality of the incoming acoustic signal is better, which allows for a better chance at successfully understanding speech (Beck et al., 2012). Listening effort can thus be connected to principals involving cognitive capacity.

Hearing Impairment and Cognitive Energy

When one has hearing loss, he or she is receiving less sound to the brain, which causes them to concentrate more and use up more cognitive resources to try and make sense of the sound coming in. The extra effort a hearing impaired listener uses leaves less mental resources for putting towards other necessary cognitive functions. The increased cognitive load causes the hearing impaired person to feel more tired after engaging in a conversation because of the increased strain on their mental system. This is detrimental to someone with hearing loss because, after feeling fatigued, many withdraw from conversations because they are exhausted from exerting such effort. Research has shown that listeners with hearing loss, who have more success interpreting speech signals, have larger working memories and hence greater cognitive functions. While a patient might have a very treatable hearing loss with hearing aids, we do not know the cognitive capacity of that individual. That individual might be able to listen but not interpret the acoustical signal due to absence of cognitive function. Measures of cognitive spare capacity can inform researchers and hearing health care specialists about listening effort.

Mary Rudner (2016) has proposed three different tests to measure cognitive spare capacity. The Sentence-Final Word Identification and Recall Test (SWIR) consists of subjects listening to Hearing in Noise Test (HINT) sentences, and they are then prompted to report the final words of all the sentences in any order they remember them in. The sentences are fully audible but different internal and external variables are changed. Results using this test have shown that background noise consisting of four talkers significantly reduces recall of spoken words for listeners with hearing loss. This supports previous findings that quality of the auditory signal influences the amount of information that can be held in a listener's working memory (Rudner, 2016).

The Cognitive Spare Capacity Test (CSCT) assesses a listener's ability to process spoken information in different combinations of internal and external factors. CSCT is based on the processing of two-digit numbers. The subject is asked to listen to lists of numbers, and then is instructed to remember and then report two numbers, depending on which task it is. Researchers found that when background noise was added to the test, listeners' performance was reduced. For subjects that were older and had documented hearing loss, steady state and speech-like background noise both decreased performance, however, young adults with normal hearing were only affected by steady state background noise. It is believed that since hard of hearing adults showed a vulnerability to stimulus degradation and load it is probably due to a greater allocation of resources to solve a task at hand (Rudner, 2016; Peterson et al., 2015).

The third test developed is the Auditory Inference Span Test (AIST). This test is designed to look at the ability of a subject to process the content of audible sentences, depending on different combinations of internal and external factors. AIST is based on using Hagerman Sentences, which are sentences that have the same grammatical structure across each and every sentence. In Rudner's study, the subject is asked to listen to sets of three sentences. After each sentence, the subject answers a question about the sentence he or she just heard. After hearing all three sentences, the subject answers three questions tapping into his or her memory load. Results showed that the number of correct answers decreased with an increase in memory load. She also found that performance decreased with a decrease in the signal to noise ratio (Rudner, 2016).

The implications of Rudner's studies suggest three things. First, that increasing cognitive processing demands decreases cognitive spare capacity. Second, increasing memory load reduces one's cognitive spare capacity, which is seen more in adults with hearing loss. Third, background noise can reduce one's cognitive spare capacity even when speech intelligibility is maintained for the listener. Rudner's results support results by Pichora-Fuller et al. (2016) which state that listening becomes more effortful and depletes cognitive resources when there is a disconnection between what is being heard and what is stored in long term memory (Rudner, 2016).

The success of those with hearing loss interpreting incoming auditory signals will depend on the deployment of more cognitive energy. The allocation of more cognitive resources is necessary when the quality of the speech signal to the hearing impaired listener is suboptimal. Because listening every day through a damaged system demands a lot of effort, a listener can develop chronic stress and withdraw from social activities, which can negatively affect their health and quality of life.

Psychological Factors that Affect Cognition and Listening Effort

Performance on auditory and cognitive measures can be mediated by multiple factors such as: stress, attention, arousal, social support, social stigmas, self-perceived abilities to meet social demands, and motivation. Variations of physiological factors directly influence variations in one's effort. Multiple studies have investigated listening effort using subjective ratings, physiologic responses (hormone levels, heart rate, skin temperature, skin conductance, electromyographic activity, pupil dilation), and behavioral methods (functional magnetic response imaging, electroencephalography, magnetoencephalography) (Pichora-Fuller et al., 2016). While these studies are important to assess a listener's listening effort, other factors must be taken into account.

Listening effort depends not only on one's hearing thresholds, but also on his or her motivation to expend or use their mental effort in difficult environments (poor audition, poor signal to noise ratio, poor cognitive abilities, etc.). Even if a listener has sufficient cognitive capacity to meet the demands needed in a difficult environment, cognitive resources may not be allocated depending on the listener's evaluation and willingness to use the effort needed for the demanding environment (Pichora-Fuller, 2016). Richter's study (2016) investigated listening effort by looking at a participant's cardiovascular measures (heart rate, systolic blood pressure, diastolic blood pressure, and the pre-ejection period), because research has shown that effort is reflected in the effect of the sympathetic system on the heart. His study consisted of participants performing four blocks of auditory discrimination tasks, each differed regarding task difficulty and reward (high difficulty-low reward, high difficulty-high reward, low difficulty-low reward, and low difficulty-high reward). He found that during the low difficulty tasks, cardiovascular measures were low, thus the listeners had low listening effort. However, in the high difficulty tasks, the level of reward was the determinant as to how much effort was exerted. During the high difficulty-high reward task cardiovascular activity was high. The high difficulty-low reward task resulted in lower cardiovascular changes, thus the level of reward was critical as to the amount of effort exerted on the auditory discrimination tasks. These findings support the belief that researchers must consider other factors such as motivation (self-reward) as well as listening demand when researching listening effort (Richter, 2016). As with listening effort, it is important to know that there is a bidirectional relationship between listening fatigue and motivation. So, when considering listening effort or fatigue it is important to always consider motivation, because it will affect a subject's or patient's relationship with a listening task or event.

A driving belief in the research community is that listeners have a cost-benefit analysis to decide if the net benefit from the effort they will exert outweighs the costs. The cost of listening is reduced when the listener derives some benefit from listening. For example, even if the cost of listening is high and increased effort is expelled the importance of listening can make it worthwhile to exert that amount of effort. If the listener decides the costs outweigh the benefits he or she will decide not to use cognitive resources to hear, participate, or pay attention. Meaningful goals are important to understand why individuals decide to engage in effortful listening or decide to not exert the effort (Beck et al., 2012).

Stress is another factor that can affect one's listening. A listener will experience stress not only if he or she experiences a demanding situation, but stress is relative to his or her self-appraisal of their ability to meet the demands of the situation. Stress will not occur if the listener believes their resources are sufficient to meet the demands of the situation, but stress will occur if they assess their capacity to be insufficient for the demanding situation. Stress can reduce a person's performance in a given situation, but chronic stress can negatively affect one's quality of life and even auditory and cognitive functioning. Stressful situations consist of novelty, unpredictability, threat to self, and a feeling of lack of control. These characteristics are felt by many people who have hearing loss on a daily basis. Experiencing situations involving these characteristics would be stressful to almost anyone; those with hearing loss will most likely have an increase in their stress responses. Stress will increase the number of effortful listening situations one experiences. When there is an increase in stress, stress hormones are often released which can change a person's brain functioning and memory capabilities (Pichora-Fuller, 2016).

Social support can affect one's stress levels and can lower one's internal assessment of demands. Social support can be financial aid, information, emotional support, or even constructive criticism. Hearing aid patients that have support of a loved one have shown an increase in their motivation to wear and use their hearing aids and increased satisfaction. Having support could reinforce a listener to use his or her cognitive effort by internally deciding that goals are not so demanding and that the goals are being met. Social support has been proven to be a strong predictor of if a hearing loss individual will adjust to the stress of having a hearing loss (Pichora-Fuller, 2016).

Self-efficacy is thought to be one's belief in his or her "capabilities to organize and execute the courses of action required to produce given attainments" (as quoted in

Pichora-Fuller, 2016). Those who have a high degree of self-efficacy have been shown to be able to use more effort to achieve a desired behavior, and cope better with demands experienced on a daily basis (Pichora-Fuller, 2016). Whereas those who have a low degree of self-efficacy may think they are unable to live up to their own believed standards of a situation, and then determine they do not want to participate or use any effort to listen or participate in a given task.

Another factor that is important to consider regarding one's listening effort is the effect of stigma or stereotypes, especially when it comes to older adults with hearing loss. There has almost always been a negative stigma against older adults as having decreased cognitive and social abilities. These negative stigmas can hinder hearing impaired individuals from participating in social activities to best of their abilities, and can lower their self-perceptions of their cognitive and hearing abilities. Negative self-perceptions are associated with performance on hearing and memory behavioral tests. Establishing rehabilitation techniques that focus on decreasing stress and stigmas, while also increasing motivation and social support, can decrease a patient's cognitive load and listening effort. "By improving balance in the evaluation of demands on capacity, these shifts could reduce the stressfulness of listening and alleviate the experience that listening is too effortful" (Pichora-Fuller, 2016).

Another factor that could affect cognition, listening effort, and listening fatigue is the age of the listener. It is widely known that as humans age, cognition steadily declines throughout adulthood. Such cognitive declines include: decreases in attentional capacity, working memory, executive function, and temporal processing. Some theorists believe that age-related cognitive processing changes are related to the presence of hearing loss.

The cognitive dysfunction seen in adults could be a result of diminished sensory input of their auditory systems.

Bess and Hornsby (2014) reported how listening fatigue can negatively affect adults and children with hearing loss. Just as adults that work in noisy places, children experience high levels of background noise in classrooms. The background noise experienced by adults or children with hearing loss, and decreases speech audibility, increases one’s stress, decreases academic performance, increases absences, decreases speech and social relationships. Adults and children with hearing loss exert greater listening effort to try and overcome their auditory deficits (Bess & Hornsby, 2014). Children even without hearing loss do not listen as adults do. Children’s brains are still developing until fifteen years old, and thus neurologically children are not the same as adults. Children also do not have the same language vocabulary or understanding that adults have obtained throughout the course of their lives. Children therefore require more detailed auditory information so their brains can try to “fill in the gaps”. Children with hearing loss require an additional 10-15 dB SNR to develop their brains and obtain language vocabulary (Beck & Flexer, 2011).

Pichora-Fuller, Schneider, and Daneman (1995) found that older listeners with hearing loss could achieve performance on their task comparable to that of young normal hearing listeners, but the older listeners relied heavily on higher level cognitive-linguistic processing. Hearing aid technology or other rehabilitation techniques could potentially overcome the loss of audibility, and that would then allow for resources to be used for higher level processing.

In order to effectively study and treat the effect of hearing loss on cognition, researchers and audiologists must consider changing the way hearing aid patients are motivated to wear their hearing aids, and how social, cognitive, and psychological factors relate to effortful listening.

Effects of Hearing Aid Use on Listening Effort

It is known that hearing impaired listeners exert more cognitive effort to maintain listening performance, and become more fatigued at the end of the day compared to normal hearing individuals (Downs, 1982). Hearing healthcare professionals supplement a patient's hearing through the use of hearing aids, cochlear implants, FM systems, assistive listening technologies, and listening strategies. These techniques attempt to direct one's attention and cognitive resources in a productive and efficient way. Craik (as cited in Beck and Flexer, 2011) reported that even after audibility is restored through amplification, a patient's outcome is generally dependent on the allocation of cognitive processes. There is growing evidence to support the relationship with successful hearing aid users with the amount of cognitive resources they have (i.e. the greater the hearing aid success the more cognitive resources one has).

Kalluri and Humes (2012) explored the relationship between cognition and hearing aids as a treatment for hearing loss. Sensory decline in older adults, in the form of hearing loss, can have negative impact on acute auditory degradation and chronic sensory deprivation. While modern advances in hearing aid technology, DNR etc., have significantly reduced handicaps for patients with hearing loss, patients still have trouble in the ever changing auditory environment around them. It is well documented the importance of one's cognitive processing in the understanding of speech when it enters a damaged auditory system. Listeners with good cognitive function are better at processing the incoming speech signal and at understanding speech when background noise is present. One study showed hearing loss individuals with high cognitive function had approximately 20% better scores on a memory test at different signal to noise ratios compared to those who were found to have low cognitive function (Beck et al., 2012).

One study looked at the effect of background noise on response time. Houben, van Doorn-Bierman, and Dreschler (2013) developed a study that involved measuring listening effort through reaction times for three successively spoken digits in background speech shaped noise. The spoken digits were made to be highly intelligible, while the background noise was analyzed to make a -6, -1, and 4 dB SNR conditions and quiet. The study involved two tasks, an identification task where the twelve normal-hearing participants identified the final digit in the triplet, and an arithmetic task involving the participant calculating the sum of the initial and final digits in the triplet. The researchers found that reaction times for both of the tasks increased as the signal to noise ratio was decreased. The difference in reaction times across the different signal to noise ratios could be related to one's listening effort, and a test using digit triplets could be effective in measuring changes in listening effort (Houben et al., 2013).

Hornsby (2013) looked at the impact of hearing aid use on listening effort and listening fatigue. Sixteen individuals with bilateral mild to severe sensorineural hearing loss were asked to come to the audiology department at Vanderbilt University for four laboratory visits. The first visit consisted of the participants being fit with bilateral behind the ear hearing aids, with two programs (one with no digital noise reduction, and the other "advanced" program with default manufacturer settings and noise reduction on).

The dual task paradigm used had a primary task of word recognition, and the secondary tasks were a memory recall and a visual reaction time task. While participating in the dual tasks, the participants were asked to recall the five most recent words they heard as well as pressing a button as quickly as they could after a visual marker appeared. Before the dual task paradigm, participants were asked to complete a five-item questionnaire that assessed listening effort, concentration, and distractibility. The paradigm was assessed with the participants being unaided, aided with the basic settings, and aided with the advanced settings. He found that reaction times and word recall were better in the aided conditions compared to the unaided condition, suggesting that hearing aids could decrease listening effort. Subjective and some of the objective measures in this study suggest that sustained speech processing demands can lead to mental fatigue in those with hearing loss (Horsby, 2013).

Sarampalis et al. (2009) reported that noise reduction in hearing aids can reduce the cognitive load of normal hearing young adults when listening to speech in noise. Their study consisted of a dual task paradigm where the primary task was speech reception in noise, and the secondary task was either an auditory word recall task or a complex visual-reaction time task. The first experiment consisted of participants listening to Speech Perception in Noise test sentences either in quiet or four talker babble (making -2 dB SNR or 2 dB SNR), where they were asked to repeat the last word of the sentence while also remembering the word for later recall. The researchers used an offline algorithm to process the sentences, when the background noise was present to act as the signal processing algorithm of noise reduction seen in hearing aids. They found no difference in the percentage of words correctly identified right after the sentence concluded with the noise reduction algorithm applied or not applied at the different SNRs tested. Only in sentences with high context at the lowest SNR (-2 dB SNR) did they find an increase in the percentage of words recalled from memory when the noise reduction was applied. The second part of the study used Institute of Electrical and Electronics Engineers sentences, that were presented in quiet and at different signal to noise ratios (-6, -2, or 2 dB SNR) depending on the four speaker background babble. The secondary task consisted of a visual reaction time task that was given concurrently to the auditory task to measure the speed of the listener's processing. The listeners were asked to repeat the sentences back after each sentence was presented, and pay an equal amount of attention to the visual task. The percentage of words correctly identified went down as the signal to noise ratio decreased for both the unprocessed sentences and the sentences processed with the noise reduction. The listener's reaction times increased as the signal to noise ratio decreased, and performance was significantly better at the lowest signal to noise ratio with the noise reduction on than without it. They stated that this finding suggests that the use of the noise reduction algorithm could reduce listening effort and free up cognitive resources, allowing those resources to be allocated towards other processing tasks (Sarampalis et al., 2009).

Desjardins' (2016) study investigated both the independent and combined effects of a hearing aid directional microphone and a DNR algorithm on decreasing listening effort in participants with hearing loss. Listening effort was assessed using a dual task paradigm. The primary task involved patients repeating sentences in quiet and in four talker babble. The secondary task asked participants to use a computer mouse to track a moving target on a computer screen. Each of the tasks were presented with an overall speech recognition performance level of 50% correct with and without the microphone and/or DNR algorithm activated. Participants were also asked to report how effortful it was to listen to the speech signal in each of the listening conditions. Her findings showed no significant change in listening effort with the DNR on versus with it off, but did show that listening effort was reduced with the use of directional microphones (Desjardins, 2016). Picou, Moore, and Ricketts (2017) also found directional microphone technology to improve listeners' subjective and objective listening effort

It is widely accepted in the fields of audiology and acoustics that noise reduction algorithms do not increase speech intelligibility. Noise reduction comes into play when a hearing aid's channel does not detect background noise in the presence of a speech signal. Because background noise and speech look alike acoustically to a hearing aid, the hearing aid's noise reduction will do nothing to the gain of the channel where both speech and noise are present. While we know noise reduction algorithms do nothing to increase speech intelligibility, hearing aid users show a distinct preference for noise reduction algorithms, and often times opt for the higher level hearing aid technology to obtain these algorithms (Sarampalis et al., 2009).

Could it be that the studies found a change in listening effort or is it because of a change in audibility (less audible cues at most difficult SNRs)? Could the participants be straining to hear the primary signal over the background noise, which caused them to have longer reaction times? Another limitation is the noise reduction algorithm used to shape the noise in some of the studies, because this is not the type of DNR that could currently be allocated in today's hearing aids.

Chapter III

METHODS

Twelve adult males, 23 to 58 years of age (mean age =39) with a hearing sensitivity of 25 dB HL or better participated in this study. All of the participants were employees of James Madison University's Facilities East Campus Power Plant who were a part of a hearing conservation program. The employees at the power plant work 8-hour shifts in a noisy environment that requires frequent verbal communication. The reported noise level at this work environment often exceeds 85 dB SPL and the employees were required to wear standard foam ear plugs during their work shift. Communication in a noisy environment was reported to be fatiguing at the end of the work shift.

As part of the hearing conservation program, all subjects underwent otoscopy, tympanometry using an Interactoustics A222 tympanometer, and a pure-tone hearing screening using a Madsen Astera audiometer. Subjects were included in this study if they passed a hearing screening at 25 dB HL at octave frequencies between 500 – 2000 Hz, no reported diagnosis of ADHD spectrum, no reported consumption of strong medication or alcohol, and no existing middle ear pathology.

The subjects were scheduled before and after their work shift at the campus power plant for their pre and post work testing respectively. Eight of the subjects were in group 1, completed the pre-testing before their work day, went to the JMU power plant for their work shift, and then returned to the hearing aid lab following their work day. Group 2 (n=4) completed post testing immediately following their work shift at the JMU power plant, and then returned to the hearing aid lab for their pre testing just prior to the start of a work shift. A chart of the test procedure for both groups can be seen in figure 2. Participants were advised to refrain from consuming caffeine prior to testing as caffeine is considered to be a stimulant which could affect reaction times. The pre and post work testing sessions each lasted approximately thirty minutes in length. All testing took place in a 2 m x 2 m x 1.8 m double-walled sound booth (Industrial Acoustic Corporation, Bronx, NY) in the James Madison University Hearing Aid Research Laboratory. The test protocol for this study was approved by the James Madison University Institutional Review Board on Human Subjects (IRB approval number 15-0295).

The reaction time task was custom designed using commercially available software (Super Lab 4.5, Cedrus Corporation, San Pedro, CA) on a dedicated personal computer. The reaction time was measured with a dedicated 7-button Cedrus RB-730 response pad. The reaction time test entailed a series of eight sets of seven nonsense syllables (a total of 56 unique stimuli) presented in the sound field through Tannoy Systems6 Loud Speaker located 1 meter at ear level directly in front of the subject. The nonsense syllables were presented in isolation without a carrier phrase. A visual prompt was displayed on the computer screen to alert the participants that the next stimulus was ready to be presented. The latency of stimulus presentation was randomly varied by the computer to prevent anticipation bias by the participants. In order to present three different SNRs, background noise of eight talker babble was synthesized offline in a commercial sound editing software (Sony SoundForge 9.0) and streamed through a Denon AVR 3806 amplifier and presented in sound field through a Polk audio FXi5 loud speaker. Both speech and noise loud speakers were located directly in front of the subject, equipment set up can be seen in figure 3. The quiet condition was achieved by presenting nonsense syllables alone. The +5 and +10 SNRs were achieved by calibrating the sustained root mean square (RMS) level of the noise to be 5 and 10 dB below the reference of the nonsense syllables. The nonsense syllables were presented at 70 dB SPL and the RMS of the 8 talker babble was adjusted to be 65 dB SPL for the +5 SNR condition and 60 dB SPL for the +10 dB SNR condition. A Quest SoundPro sound level meter was used to verify the sound level during daily calibration. The order of presentation of the three signal to noise ratios was counterbalanced across the participants.

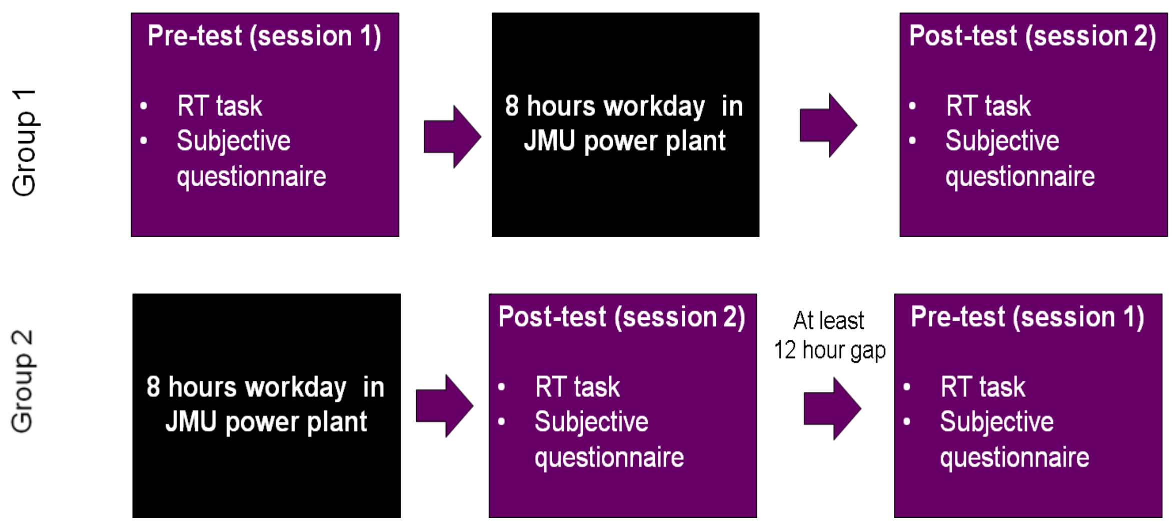

Figure 2. A flow-chart of the test procedure for the eight subjects in group 1 and the four subjects in group 2.

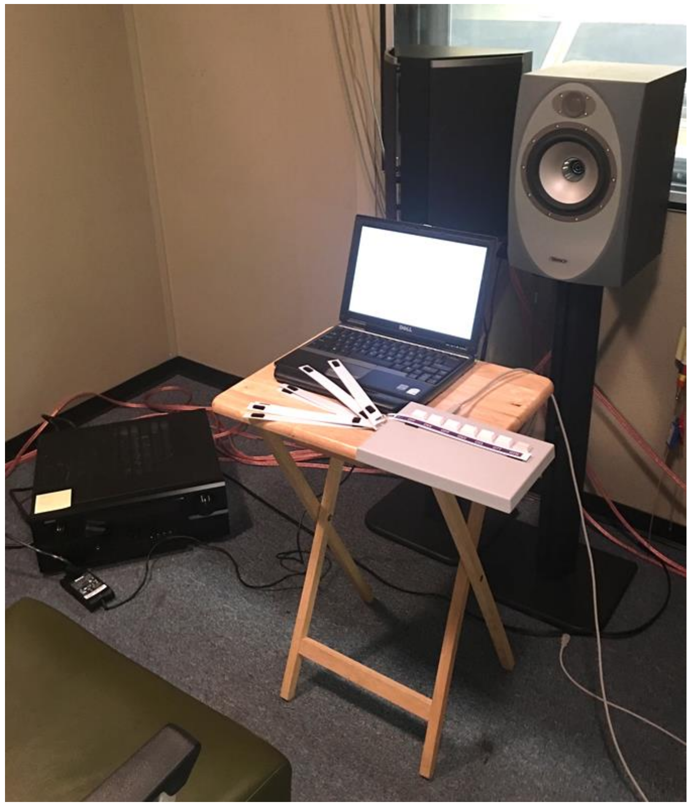

Figure 3. Equipment set up of the reaction time task with the laptop and Cedrus response pad

Participants were asked to complete the subjective rating questionnaire after completion of the reaction time test during both sessions. The subjective rating questionnaire was taken from the International Telecommunications Union (ITU, 1996) and Hornsby (2013). The questions were modified slightly to be more representative of our study. Participants were asked to rate each question on a scale of 1-5, (1=not fatigued, 5=extreme fatigued). The questions are presented below:

1. Did you have to concentrate very much while listening to the syllables in noise?
2. Did you have to put in a lot of effort to hear what was being said in the syllable task?
3. Could you easily ignore other sounds when trying to listen to the noisy speech?
4. How well can you maintain your focus and attention right now?
5. How mentally/physically drained are you right now?

Chapter IV

RESULTS

Reaction Time

The reaction time task yielded 672 unique data points per subject. The reaction times were inspected for quality and outliers. It was discovered that due to a problem in the data acquisition system, if a subject responded before the completion stimulus presentation, the system did not register that response. This prompted the subject to press the button after some time to ensure the response was appropriately recorded resulting in unusually prolonged reaction times. Any reaction time falling beyond ± 2 standard deviations of the mean was considered an outlier and excluded from further statistical analysis. Since the participants completed each task twice, the two data sets were averaged to yield one set of data per each signal to noise ratio for the pre and post test sessions. A repeated measures ANOVA was performed on the pre and post work shift reaction times with signal to noise ratio (three levels: quiet, +5, and +10) as a within-subjects factor. Statistical analysis was also performed comparing each participant's objective reaction time scores and their subjective rating scales.

The mean reaction time for the quiet condition was 867.6 ms (SD = 203.3) before and 775.6 ms (SD=196.3) after the fatigue inducing condition. The shorter group mean reaction time after the fatigue inducing work days was opposite of what was expected. Similarly, the reaction time at +10 dB SNR was 868.4 ms (SD=199.5) for the before, and 781.1 ms (SD= 186.1) for the after conditions. Mean reaction time for +5 dB SNR was also longer for the before condition 897.3 ms (SD = 227.2) and 825.2 ms (SD = 204.8).

The data was analyzed with a repeated measures ANOVA design using SPSS 23. While looking at the data reaction times for the most difficult listening condition (+5 SNR) the mean reaction time was longer than the other two conditions, however, the results did not reach significance ($F(2, 11) = 4.32$, $p = 0.06$). Mean reaction time across all subjects before and after exposure to the fatigue inducing condition at the different SNRs for the six conditions are displayed in figure 4.

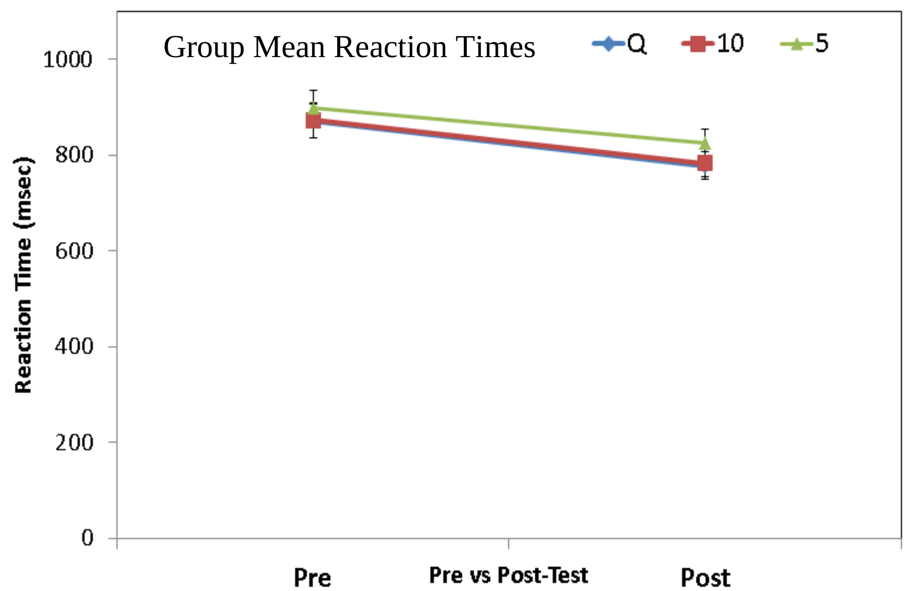

Figure 4. Group mean reaction time before and after the fatigue inducing condition at the three different SNRs. Error bars represent ±1 standard error.

Results showed that reaction time for the second session was significantly shorter than the first session ($F(1, 11) = 5.71$, $p = 0.04$). It was also discovered that there was a strong practice effect; the second time a subject did the experiment his reaction time got shorter. Mean reaction time before and after exposure to the fatigue inducing condition for the eight participants who completed the pre-work condition first are displayed in figure 5. The mean reaction time for the four participants who completed the post-work condition first is displayed in figure 6. Both graphs show a shorter reaction time the second time the participant underwent testing.

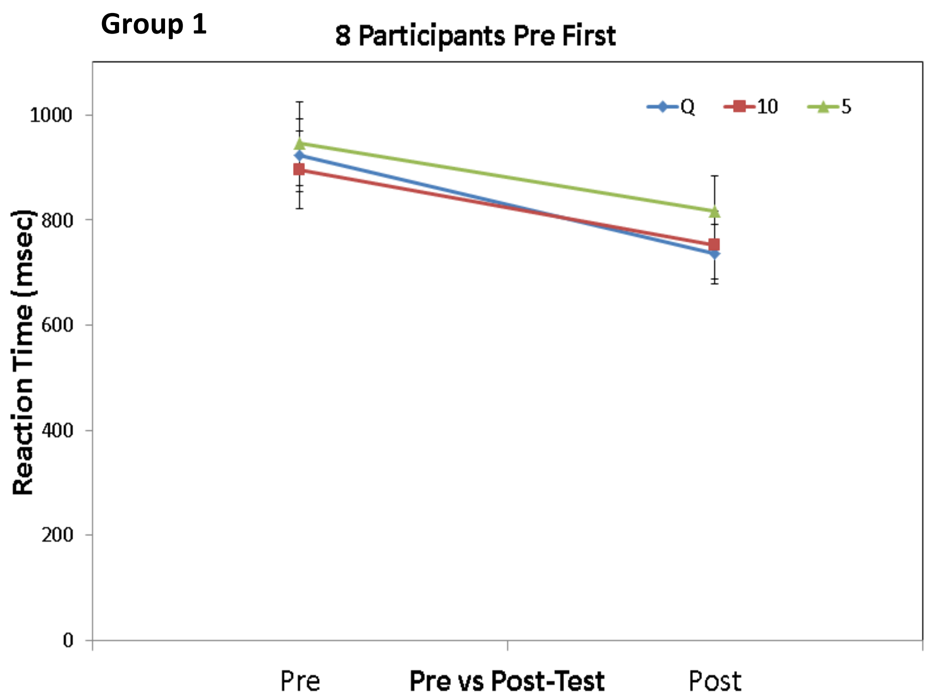

Figure 5. Group mean reaction time before and after the fatigue inducing condition at the three different SNRs for the eight group one participants. Error bars represent ±1 standard error.

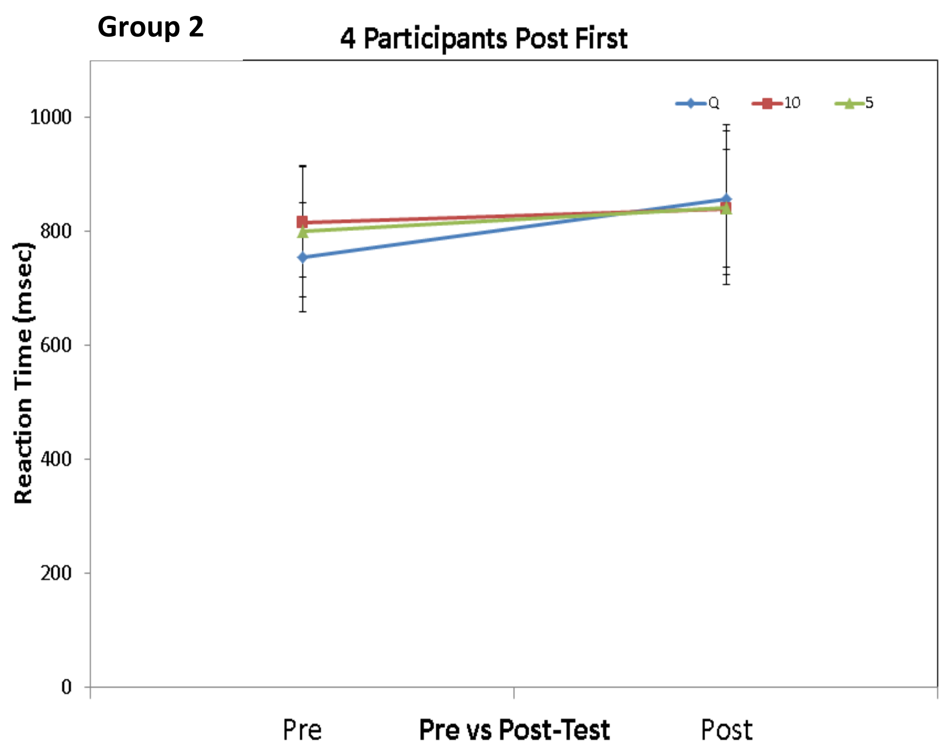

Figure 6. Group mean reaction time before and after the fatigue inducing condition at the three different SNRs for the four group two participants. Error bars represent ±1 standard error.

Subjective rating

After exposure to the reaction time task, the subjects were given a short questionnaire to rate their level of fatigue and amount of listening effort used on the reaction time task. The questionnaire was administered before and after the subject was exposed to his fatiguing work day. Like the previous studies, the difference between the reported fatigue was most noticeable for question 4 (How well can you maintain your focus and attention right now?) and question 5 (How mentally/physically drained are you right now?). These two questions were isolated because these questions addressed listening fatigue. However, compared to Hulvey (2015) and Athey (2016) this study saw a greater difference between reported fatigue for question 3 (Could you easily ignore other sounds when trying to listen to the noisy speech?). This finding showed that subjects who work in noisy places might have a harder time attending to speech in the presence of noise after working in a noisy environment. The ratings from the subjective questionnaire were compared through a nonparametric Wilcoxon Signed-Rank test, which revealed significantly higher reported fatigue after effortful listening ($Z = -3.92$, $p < .005$), which is displayed in figure 7.

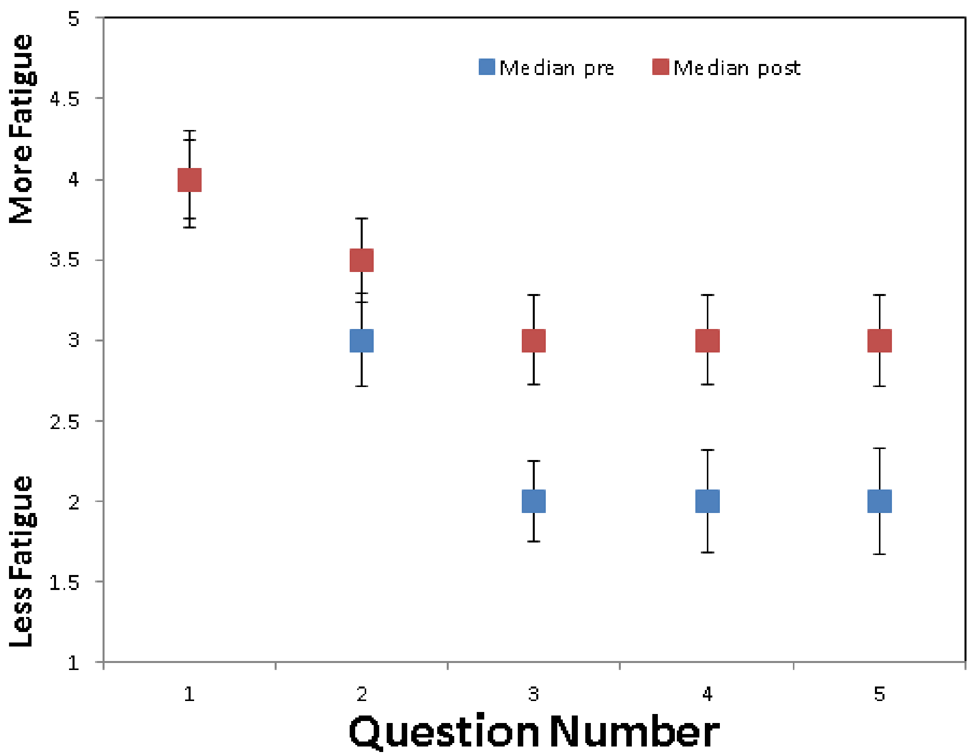

Figure 7. Comparison between mean pre and post test listening fatigue; the y- axis depicts the subjective rating of listening fatigue and the x-axis represents individual items on the questionnaire. Error bars represent 1 SE.

Correlation between reaction time and subjective rating of fatigue

Differences between pre and post reaction times were calculated for each subject. The differences for the subjective fatigue ratings for each subject were also calculated for the three SNR conditions. Figure 8 shows a scatter plot of the differences in post minus pre subjective rating and reaction time for the three SNR conditions. The difference for the subjective ratings was calculated by subtracting each subject's average subjective rating post fatigue minus pre for questions four and five. Each subject's change is reaction time pre vs post was calculated by subtracting their mean reaction time before the work day from their mean reaction time after the work day. Each of the twelve subjects has a data point for quiet in the blue, +10 SNR in the red, and +5 SNR in the green. A negative difference in reaction time indicates that the mean reaction time before the work day was longer than the mean reaction time after the work day. A Pearson correlation test was performed to examine the correlation between the subjective and objective measures. A strong correlation was found in the subjects that subjectively said they were more fatigued because they had a greater change with their pre vs post reaction times, however, the data are confounded by the learning effect.

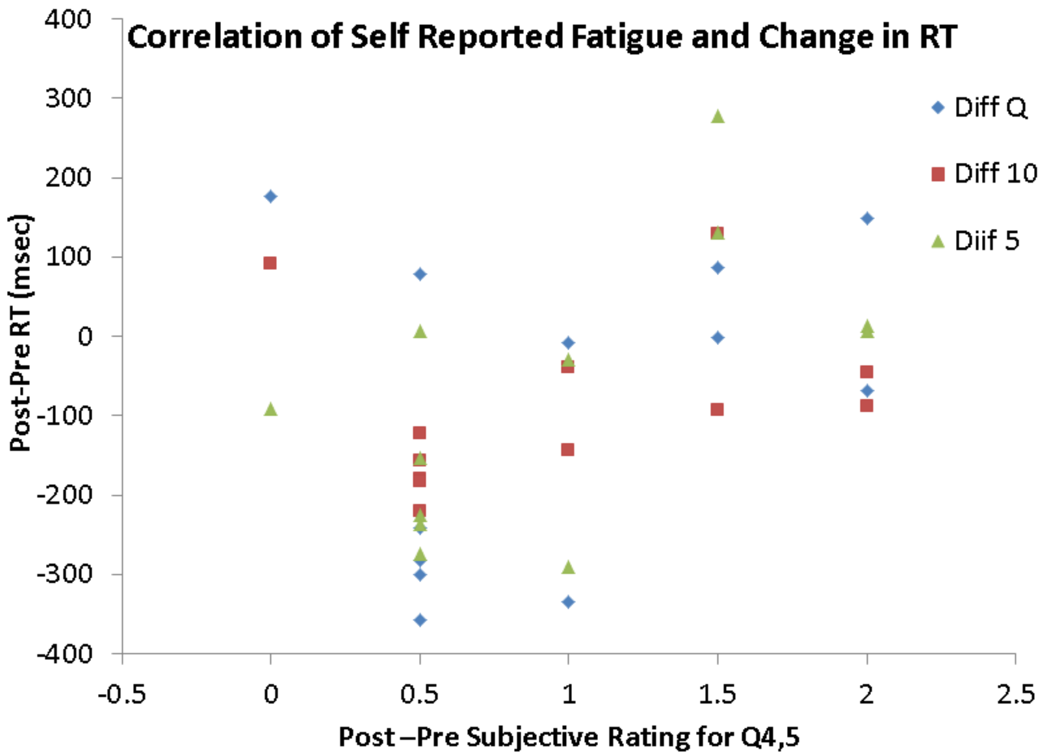

Figure 8. Scatter plot of subjective versus objective measures of listening fatigue for each of the three SNRs.

Chapter V

DISCUSSION

The effectiveness of listening fatigue on reaction time

The objective of this study was to continue to assess the effect of listening fatigue on reaction time using a simple single-task paradigm that could possibly be used in a clinical setting. As a continuation of the dissertations by Hulvey (2015) and Athey (2016), this study was the final piece of the puzzle to see if a reaction time task is a good measure of one's listening effort or listening fatigue. The nonsense syllables in this study were presented to the subjects in quiet, +5 dB SNR, and +10 dB SNR. Hulvey (2015), found that there was no change in reaction time to the nonsense syllables when presented in quiet before and after an effortful listening task of the thirty minutes. Following Hulvey, Athey (2016) found that the same effortful listening task was not enough to elicit listening fatigue because there was no change in reaction time after the effortful listening task both at +5 and +10 dB SNR.

Listening effort versus listening fatigue

Previous research on listening effort demonstrates that the effect of increased listening effort can only be seen at the most challenging listening situations (Hornsby, 2013; Houben et al, 2013, Sarampalis et al., 2009). This study also found an increase in reaction time to the stimuli in the hardest +5 dB SNR condition compared to the easier +10 dB SNR and quiet, however, the +5 dB SNR grand mean reaction time was not found to be significantly longer. This is different than the findings from Athey (2016) who found that the mean reaction time at the +5 dB SNR was significantly longer than the mean reaction time at +10 dB SNR, see figure 9. Her finding could possibly be due to her stimuli being in the presence of a burst of noise that encompassed the nonsense syllable stimuli. To combat that effect to try and replicate more real world conditions this study had continuous eight talker babble going on in the background the entire time. Athey found that the reaction time task had an effect on listening effort, which we consider to be a change in SNR, which has been found in other studies. Because Athey (2016) found significance in listening effort using two SNRs, this study used the same SNRs to assess listening fatigue by controlling for listening fatigue. This study controlled for listening fatiguing by extending Huvley and Athey's fatigue inducing condition to be the entire work day (8 hours) in a noisy environment. While the participants were experiencing and listening in a noisy environment for the day, they were also physically working throughout the power plant. The work environment exceeding 85 dBA was thought to auditorily fatigue the subjects, just like hearing aid users experience while wearing hearing aids throughout the day. Because the participants were physically working it was thought that the participants had some degree of physical fatigue. This study saw no effect of listening effort and could have possibly seen a statistical effect of listening fatigue if results were not confounded by a learning effect, see figure 10.

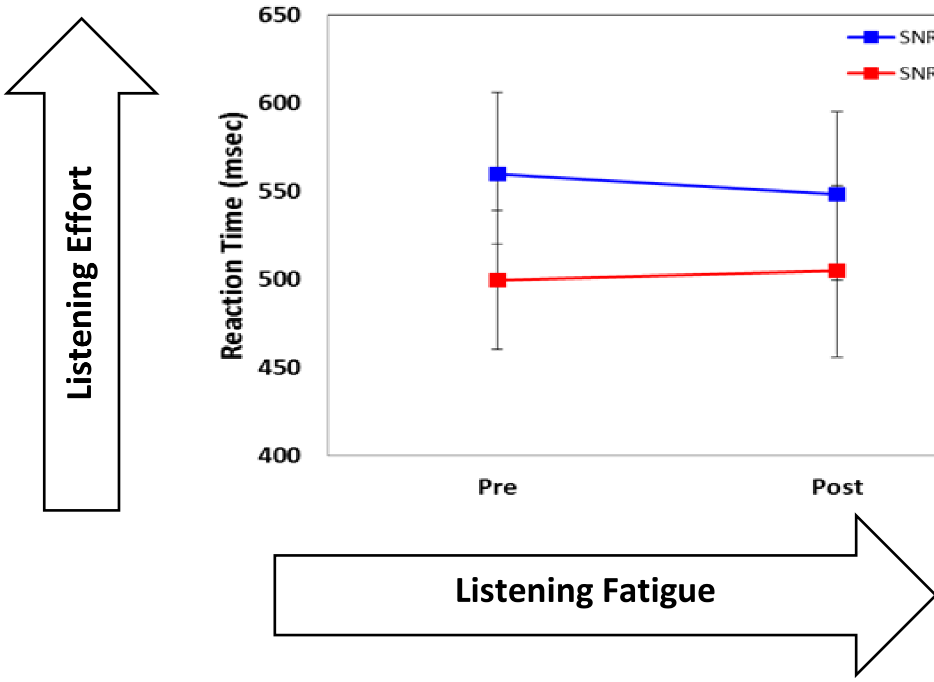

Figure 9. Athey (2016) results for mean reaction time (msec) before and after exposure to the fatigue-inducing listening task. Error bars indicate ±1 SEM.

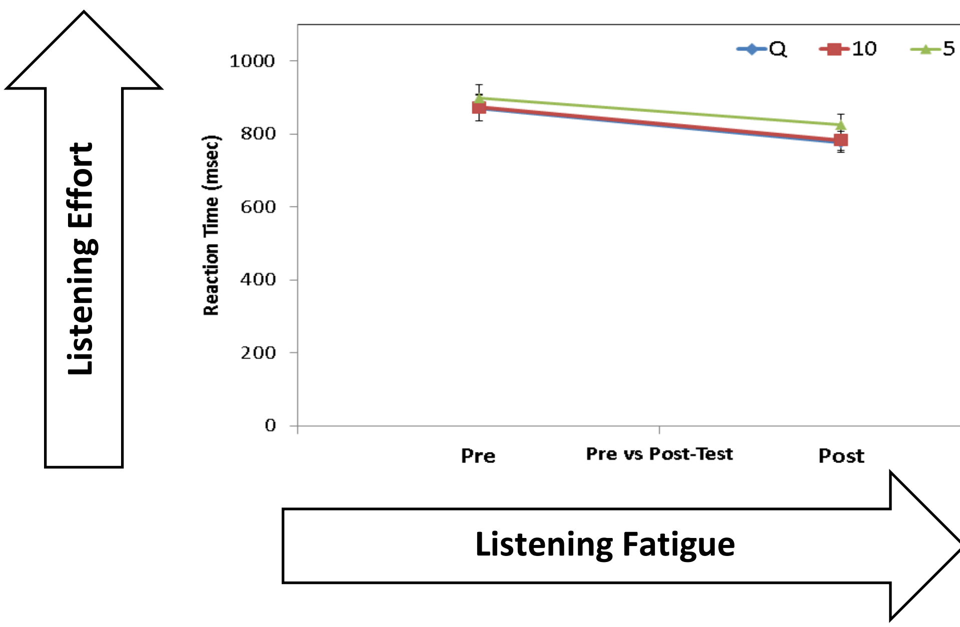

Figure 10. Group mean reaction time before and after the fatigue inducing condition at the three different SNRs. Error bars represent ±1 standard error.

Effectiveness of the fatigue inducing condition

We believe the fatigue inducing condition of the eight hour work day was effective in fatiguing the subjects. We increased the fatiguing condition to be much longer and louder than the condition used by Hulvey (2015) and Athey (2016). Hulvey and Athey's fatiguing condition involved participants listening to thirty minutes of Connected Speech Test sentences (at -2 dB SNR) in the presence of eight talker babble, which were presented to the subjects at 70 dB SPL. Subjectively participants stated they were fatigued after listening to the task, and Athey showed a significant difference in reaction time for the +5 dB SNR condition. For this reason we considered the reaction time task she used to be fatiguing. However, to control for fatigue this study increased the fatiguing condition to be eight hours in length and in background noise exceeding 85 dBA, much louder than the 70 dB SPL experienced by prior participants. This study was able to find that while the eight hour work day in a noisy place was long enough to fatigue the subjects, as seen on their subjective questionnaires.

Subjective rating of listening fatigue

Subjective rating scales can be used as a direct measure of a subject's self-reported level of fatigue. Johnson et al. (2015) evaluated the clinical applicability of subjective rating versus word recall task as a measure of listening effort. They concluded that a subjective rating method was more sensitive in measuring listening effort. We evaluated the effect of the fatigue inducing condition by analyzing the subjective questionnaire administered before and after the work day. Specifically, questions 4 (how well can you maintain your focus and attention right now) and 5 (how mentally/physically drained are you right now) because they addressed the issue of listening fatigue. All participants indicated a significantly higher level of fatigue rating on both questions after a work day in noise at the James Madison University Power Plant. This finding is consistent with the fact hearing impaired listeners complain about listening fatigue at the end of the work day, and comparable to the results found by Hornsby (2013) and others.

The use of subjective rating scales has been used clinically for years to assess what a patient is feeling compared to what objective measures are telling the audiologist. Subjective rating scales are useful because they are easy and quick for a patient to complete and are very easily incorporated into a clinical practice. Some problems using subjective rating scales include the sensitivity of their instruction to a subject or each subject's interpretation of the words used in the instruction; in our case "effort" they could think of it relative to auditory or physical effort. However, it is necessary to use a subjective measure in combination with an objective measure to have another means of result verification. Our results show the importance of considering multiple factors when looking at listening effort and listening fatigue. Based on the results of this study, and the results of Hulvey (2015) and Athey (2016), caution should be used while interpreting reaction time data as a measure of listening fatigue or listening effort. While changes between the SNR conditions likely indicate changes in listening effort, while changes in reaction time pre vs post is negligible.

Limitations of the current study

One of the limitations of this study could be that the task was too difficult for the participants to complete and thus not able to put the cognitive resources towards the task because they felt like they could not complete it. As noted by Richter (2016), task effort increases with increasing task difficulty but drops drastically when a task is found to be too difficult. We believe we addressed this by allowing the participants a familiarization task prior to the start of any testing.

As previously noted, the familiarization task was too short that learning was still occurring in the post testing. There was a learning effect shown because we found a significant difference in the reaction time of the session a subject did second, be it post test for group 1 and pre test for group 2. The second time the participant experienced the study they had faster reaction times, and thus they possibly were still learning the task the second time they saw the experiment. To control for this issue, subjects should be given more than a familiarization task in order for them to become more comfortable with the task to the point they are no longer learning. In future research learning could potentially be avoided by having a longer familiarization task.

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APENDIX A

List of nonsense syllables used as stimuli in this study

1. oth
2. ahf
3. ahs
4. off
5. osh
6. oof
7. oot
8. ooth
9. eet
10. eef
11. ok
12. ahv
13. ees
14. aht
15. op
16. eesh
17. oop
18. ahp
19. eep
20. ath
21. eek
22. ang
23. ot
24. oss
25. azz
26. oos
27. ahd
28. ahb
29. ash
30. eeth
31. ahm
32. ahk
33. oosh
34. ook
35. ahg
36. dha
37. faa
38. laa
39. saa
40. cha
41. zaa
42. baa
43. daa
44. taa
45. raa
46. gaa
47. vaa
48. baa
49. maa
50. haa
51. sha
52. waa
53. daa
54. yaa
55. gaa
56. kaa

APENDIX B- Raw Data for All Subjects in Quiet Pre Fatigue

	Pre Q											
	S1	s2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13
ahb	983	1109	695	1460	1214	863	1165.5	551.5	280	949	1350	1887.5
ahd	1411	1343	503	2006	1710	1142.5	754.5	375	925.5	901	1263	1416
ahf	1220.5	1700	1052.5	1565.5	465	1016	1381	671	1086	518	1022	1431
ahg	1837	2174	609	1665	1105	1362	1005	527	607	1385.5	833	1529.5
ahk	1561.5	1551	619		1206.5	990	1231.5	565		959	1389.5	1463
ahm	1452	1006.5	478	1695	630.5	976	1634.5	400	1229.5	909.5	1453	919.5
ahp	1947	1358.5	687	742	1528	1590.5	1412	742	1606	1117.5	1893	1614.5
ahs	2301	1001	600.5	1504	1529.5	1370	1377	1392	721	801	1311.5	849.5
aht	2073	1542.5	727	1220		1301.5	1308.5	434		1303.5	1149.5	1463
ahv	2051	1318	590	1104	1173.5	1615	553	406	615	1126.5	1054.5	583.5
ang	1742	1112.5	436	762	1264.5	1130	1215	104	993.5	1559.5	770.5	1099
ash	946	1554	596.5	1443	1810	1284	1691	365	1444	1330	1123	1652
ath		1305.5	984	962	1169	1377	1585	465		257	800	1170
azz	520.5	1232	792	1448	570.5	841	960.5	155.5	266.5	736	1049.5	1091
baa	1087	504.5	575	678.5	543	195.5	257.5	337	401.5	375.5	817.5	433.5
baa	238	513.5	641	313	305.5	282	346.5	283.5	338	306	649.5	298
cha	170	1072.5	337.5	1392	162.5	698	801	199	459	616.5	1026	1000.5
daa	512	154.5	258.5	289	698	727.5	656.5		218.5	449	817	465
daa	498.5	485.5	197	523	323	605	279	197.5	349	531.5	1284	237
dha	2097	1051	463.5	1960	2012	1444		620	1206.5		1107	
eef	1216		622.5	1493	2007.5	1102	1507.5	1198	814	926		1105
eek	1267.5	1058	838	1454.5	584.5	974.5	779.5	1269	822.5	871	1206.5	1167
eep	908	1023	774.5	1342.5	823	1317	381	750.5	495	661.5	1045.5	704
ees	948.5	1144.5	262	604.5	1109	278	443.5	510.5	1052.5	700	965.5	1086
eesh	1796.5	1387.5	474	856.5	889	690	384.5	641.5	649.5	797.5	953	537
eet	1472	1020	172.5	1545	1707	517	1132.5	388.5	1357	900	851.5	844
eeth	1055	1094.5	843	960	1976	339	1269.5	712.5	849.5	1001	778	1122
faa	541	853.5	329.5	768.5	1008.5	418	328.5	616.5	457	1073	720.5	704.5
gaa	518.5	288	551.5	512.5	680	520.5	232.5	554	225	416	999	1151
gaa	401	317.5	270	429	366	654	159.5	119	198	508.5	1084.5	548
haa	351	400	594	1071	617.5	905	760	205.5	177	360	575.5	505.5
kaa	1377.5	1030.5	383		1564.5	1125.5	133.5	565	1396	324	1260.5	1173
laa	316.5	220	390	333.5	439	415	428.5	661.5	206	508.5	701.5	565.5
maa	734	425.5	199.5	720	777	546	349	537	265	599.5	809	538
off	621	1200	845	1077.5	614	1117	1285	286	604.5	980	1124.5	614
ok	1478	1077	814	883.5	814	1533.5	979	718.5	1038.5	1527.5	1359.5	1207
oof	1305	1066	898	1237	892	672	933.5	633	522.5	577.5	866	647.5
ook	1521	1554.5	989.5	1868	820.5	1430	1303	277.5	1038	990	1038	1506.5
oop	919.5	1320	897	639.5	709	1798.5	472.5	742	859	687	809	1354.5
oos	1602.5	1375	473	1043.5	1866	441	477.5	468.5	1815.5	713	1303	708
oosh	1589	1166	285.5	683.5	1481.5	873	1086	338.5	508.5	846	771.5	684.5
oot	1548.5	982.5	348	1074.5	1486	875	663	388.5	399	965	1318.5	454.5
ooth	1337	1405	879.5		1262	1307.5	1509	703.5	854	430	1588	848
op	1376.5	844	677	1090.5	1094	1156.5	581	430	1091.5	605	1146.5	1389.5
osh	633	1271	386	1430.5	778.5	1131	1293	524	885.5	950.5	920	1220
oss	1134.5	852	481.5	783.5	1560.5	1393	798	506.5	625.5	888	1251.5	1609
ot	1170.5	911	582.5	760.5	1237	1053.5	722.5	606	475	736	1524.5	1035.5
oth	594.5	1593.5	251	875.5	810.5	1090	1140.5	307.5	768.5	1188	765	1198.5
raa	238.5	1881	185	360	1158.5	441	679	280	352.5	528.5	744.5	768
saa	339.5	1002.5	283	1779	1079	1804	70	264	1690	613	1094	779
sha	1112	946.5	83.5	1490.5	907	732.5	650.5	251	569	481.5	498.5	683.5
taa	1063	940.5	239.5	400	353	928	479.5	512.5	409.5	879.5	608	760
vaa	143.5	400.5	279	1102	310	1065	143	760	1205.5	890	1263.5	
waa	1315	524.5	101.5	572	860.5	477	412	93.5	622	388	652.5	893.5
yaa	723.5	189	550	603	365.5	422.5	476	181	349.5	764.5	1109	884
zaa	449	761.5	73.5	361	583	577	521	119.5	313	241	752.5	116
Mean	**1086.645**	**1029.364**	**520.51**	**1036.557**	**1000.191**	**945.1875**	**810.5182**	**489.2818**	**730.3208**	**775.4091**	**1029.482**	**957.6759**
SD	563.0189	441.9524	254.56	471.5032	493.3637	410.4221	452.7934	271.7305	420.9976	317.6097	284.6656	406.4118

APENDIX C- Raw Data for All Subjects in Quiet Post Fatigue

	Post Q											
	S1	s2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13
ahb	844.5	879.5	566	714.5	912.5	1415	1238	758	726	1415.5	974	431.5
ahd	1143.5	622.5	655.5		839	1463	1253	624	799	1045.5	1158.5	566.5
ahf	1085.5	670.5	1006	1043.5	815	1494	1215	775	912	1455	750.5	1119
ahg	943.5	234	520	1149.5	1504	993.5	1183	607.5	1224	2079	1168.5	745
ahk	1093.5	854.5	702.5	898	1062.5	1415.5	1446	496		1725	911	805.5
ahm		824	407		1382.5	1455	1103	246.5	1933	1174.5	926	519.5
ahp	1332.5	1214	439	845	1380.5	1223	1246	621	1062	1367	1413	613.5
ahs	1342	859	297.5	919	1696	1056	1871	386	1895.5		1009	755
aht	765	1343	791	1318	1931.5	1111		759		1304	903	631
ahv	845	1206	255	679	1005		1239	799.5	919	1175	941	975.5
ang	935.5	913	218	703	1418	1042	778	328.5	1882.5	1137.5	673.5	507
ash	258	84.5	515	585.5	948	1396	1397	724	1036.5	1476.5	803	157
ath	1229.5	1432.5	306	1558	1176.5	1505	1465	634		1551.5		530
azz	728	561	688.5	790.5	808.5	713.5	866	177.5	601.5	993.5	553.5	455.5
baa	399	769	407.5	558.5	481.5	649.5	489	202.5	1161	625.5	665	578
baa	376	329.5	289.5	462.5	442.5	392.5	562.5	190	225.5	576	809.5	274
cha	535	252	351.5	551.5	1098	482	187.5	593.5	705.5	986.5	409.5	218
daa	894.5	235.5	313	965	658	1265.5	266.5	219.5	162.5	274	650	458
daa	299	197	299	482.5	461	463	270	142.5	189	414.5	556.5	125
dha	1250.5	949	428.5	1122	1350	1612	1372	388	1595.5		972.5	813
eef	747.5	1166	367	1581	1980	1406	1087	1110.5	1468	959.5		495
eek	674.5	910.5	422.5	1171.5	782.5	576	813	543.5	535	751	758.5	566
eep	1446	833	664.5	628	678.5	1630.5	678	495	704	958	902	447.5
ees	1051.5	110.5	166	1353.5	1372.5	582	789	263.5	797.5	903	686	1381.5
eesh	439.5	433.5	393	542	1129.5	689.5	1294.5	586	809.5	729	825.5	810
eet	731.5	812	108	561.5	988	1861	724	347.5	643.5	1684	869	232.5
eeth	688.5	626	433	1760	1505.5	2112	1648	1081	711.5	1049	841.5	753.5
faa	464	594	303	493	873	1057	1073	107	1177	681.5	1265	457.5
gaa	182.5	329.5	120	470.5	656	1960	393	90	519.5	426	585	681
gaa	236		206	275	422	798	693.5	133	255	515.5	470.5	478
haa	489	185	336	478	377	1735	249.5	471	520.5	1030.5	584.5	496.5
kaa	611.5	965	341.5	452	718	1253.5	373.5	469	56	446	494	655
laa	277.5	207	286	284	405.5	909.5	653.5	198	238	637.5	542	415.5
maa	543	129.5	434	543.5	1185	401	115	162	467	1090	424.5	226
off	1092.5	545.5	813.5	669	731	1131.5	1097	518.5	838	1454	973	522.5
ok		920	718	517	603		757.5	716	1069	1022.5	1354	1526
oof	1158.5	1005	679	782	1149	1034	920	456.5	1279	1119.5	834	455
ook	823	702.5	613.5	1002	1318	1526	1466.5	618	732	1046	670	1121
oop	588.5	613.5	800	584.5	620	842.5	913	412.5	574.5	978	845	1128.5
oos	1248.5	715	164.5	684.5	1457	1391.5	930	395	913.5	718	936.5	539.5
oosh	937	1098.5	270.5	588	617.5	749	774	528.5	1556.5	441.5	634.5	887.5
oot	708	703.5	210.5	1007.5	1259		911	451.5	733.5	805	896	741.5
ooth	1685	1108.5	954	538.5	709	639.5	1205	571	1150.5	913.5	1306	813.5
op	830	968.5	637	517	786.5	1347.5	667.5	733	2192	629	1015.5	997.5
osh		1544	346	706	1499	1334.5	762	688.5	478	1097	977.5	
oss	957	654.5	690	819	1564.5	871.5	1136.5	429.5	705	897.5	1169	871
ot	906	493	980.5	986	592	1821	580	795	634	909.5	814	1253
oth	847	838.5	466.5	725	626	446.5	1817	822.5	666	1538	715	538
raa	519.5	368.5	335.5	374.5	1375	792.5	656.5	512	512.5	519	353	448
saa	629.5	381	270.5	515.5	735	1110	183	202	430	1134	638	311
sha	1288.5	674	611.5	968	477	571.5	1106.5		485	1051	300	492
taa	384	416.5	416.5	206.5	690	1302.5	952.5	401.5	200.5	273	544.5	761
vaa	796	25	616	1017	1874	841	975.5	969	880	393	703.5	394
waa	435.5	573	274	321.5	773	286.5	477	54.5	358	469	637	445
yaa	547.5	365.5	230.5	674.5	1356		645.5	389.5	300.5	1283.5	333.5	254
zaa	374	554.5	194	589	664	746	384.5	66	232.5	58	408.5	368
Mean	**785.6226**	**672.7273**	**452.2946**	**754.287**	**998.5536**	**1094.288**	**897.2727**	**481.0909**	**808.5377**	**951.5926**	**788.0278**	**622.5545**
SD	350.5641	362.0944	225.0281	339.4643	420.8035	450.614	421.2483	257.0673	493.465	417.071	264.7647	304.0686

APENDIX D- Raw Data for All Subjects in +5 SNR Pre Fatigue

	Pre 5											
	S1	s2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13
ahb	694	1229.5	902	749.5	575.5	488	1111.5	414.5	1006.5	1659	1557.5	1094
ahd	1228.5	881	629.5	1566.5	911	805.5	739	239	1158.5	875	1868.5	1280
ahf	1869.5	856	709		703	1613.5	1261.5	686	1750.5	1267	1382	1008
ahg	1904	981	694.5	1793		1217	969.5	745	1249	1301.5		898
ahk	1420	654	805.5	1422.5	1278	1339	1438	895.5	1925.5	1022	1629	1049
ahm	2060	574.5	741	671	1471	1476	1047.5	397.5	1278.5	1542	1741.5	721
ahp	1867.5	1007	575	1463	567.5	829	1039.5	527.5	1366.5	1187.5	1766	993
ahs	1497	1552	598	1008	1137	888	658	465.5	1153	1048	1169.5	1394
aht	974	1159	1180.5	1643	1118	1029.5		830	1382	1125	1125	521
ahv	1872	1616.5	613.5	1235	1597	1845	1104.5	647	1509	1828	1288	553
ang	2313	992.5	712	1993	1426	1528	1114	452.5	681	1000	1170	907.5
ash	1667	1342	315	741.5	835.5	1250	886	420	1395	659	1410	876
ath	2144	1067	623	1170	841.5	530	1027	858.5	1505	1095.5	1761	915
azz	1233.5		471.5	984	1709.5	675	490	465	610	1005	1105.5	619
baa	1040	523	1136	649	320	365.5	498	385	457	943		51
baa	371	542.5	479	816.5	472.5	631.5	394.5	275	465.5	751	1001	730
cha	186.5	739.5	505.5	1609.5	211	752	595	138	506	608	745	315.5
daa	323	266	94.5	659	11	457	164	26	841	360	1129.5	525.5
daa	443.5	396	372	318	405	571.5	237.5	326	269.5	339	820.5	254
dha	1172.5	1363.5	819	1715	1372	1139	917.5	1035.5	1555		1515	
eef	871	855.5	1115.5	1473	512	1173.5		679	623	1387	1566	976.5
eek	399	609.5	443	1662.5	615	967.5	846.5	760	599.5	573	1278	346
eep	686	596	525	1453	823	755.5	752	477.5	872	621	1126	673
ees	773	900	348	1556	382	1347	527	191	1586.5	1044.5	1317.5	1143
eesh	1344	436.5	399.5	1353	740	806.5	1161.5	601	481.5	751	1105	386.5
eet	1284	555.5	586	1020	780.5	377.5	1252.5	537.5	739.5	1394	1354.5	1349
eeth	905	1558	520	2162	1297		1002	875	778	1765	1009	1620
faa	289	1176	383		1121	1247		833	417		1313.5	1617
gaa	726.5	650	159.5	414.5	481	1620	505.5	225.5	361	1084.5	943.5	1002
gaa	417	232.5	220	494	261.5	402.5	334.5	78	646.5	427.5	1236	494.5
haa	1465.5	1090	144.5	785	232.5	1054.5	457.5	424	1079.5	422.5	1287	650
kaa	1126	439	316.5	693.5	414.5	947	870	661	910	1073	1124.5	1397
laa	1372	885	252.5	454	510	460	447.5	215	414	661.5	821	440.5
maa	513	260	153.5	257.5	1097.5	280	145.5	217	249	1023	825.5	147
off	632	1522	1275	2083.5	641.5	1702.5	1103	782	638	1810.5	1547	1262.5
ok	1302	958.5	990	1290	932	1629	915	223	1940	1972.5	1636	759
oof	1004	982	945	555	1355	901	1160	839	1178	443.5	1497.5	1571.5
ook	471	613.5	971.5	1605	1007	1255	970.5	523.5		565.5	1357	1210
oop		1028	657.5	1046	602.5	1937	772	575	831	780	1528.5	667
oos	497.5	991	250.5	2195	1497	1207.5	748.5	249.5	1856	911	983.5	707
oosh	1442.5	809	315	930	876.5	1576.5	780	388.5	1104.5	319.5	1028	638.5
oot	783	827	462	2100.5	1804	1583	511	436.5	829	553.5	1253.5	1103.5
ooth	1924	1204	516	1441	1333	903	1491	511	1667.5	684	1691.5	879.5
op	1827.5	689	779	1220.5	700	1373.5	798	884.5	1054.5	1221.5	1564	966
osh	866	1022	628.5	2170	1484.5	1027.5	876	866	1801.5	578	1149	604
oss	1563.5	924.5	607.5	1209	1444	1099	969.5	384.5	1416	632.5	1242	1178.5
ot	709	1439	817.5	1512	1087.5	1376.5	878.5	526	938.5	1109.5	1384.5	1318
oth	1793.5	1227	555.5	870.5	796.5	1130	987	826.5	1194	1132	1896	621
raa	480.5	819	214.5	865	889	809	511.5	305.5	440.5	517.5	831.5	481
saa	685.5	956.5		1501.5	950	1571.5	428		1085	901	949.5	463.5
sha	847.5	619	540		371.5	634	410.5	426	475	929	1066	477.5
taa	537	569	240	1001.5	954	432.5	177.5	167	459.5	590.5	913	963
vaa	289.5	418.5	341	824	393.5	472	856.5		737.5	1246	1591	1401
waa	1346.5	841	101	493	940.5	633	461.5	245	260.5	993.5	1238	799
yaa	843.5	303	555	676.5	436.5	1115	606.5	221.5	709	482.5	899.5	398
zaa	290	265.5	175	825.5	704.5	265	362	88	191.5	274	624.5	82.5
Mean	**1065.218**	**854.8**	**554.1727**	**1177.358**	**862.3636**	**1009.118**	**769.217**	**490.2222**	**956.8727**	**935.0093**	**1265.972**	**827.2364**
SD	570.0735	360.9309	289.7806	525.4048	427.9766	440.9251	329.9867	255.8782	483.8235	417.9686	308.2669	395.2976

APENDIX E- Raw Data for All Subjects in +5 SNR Post Fatigue

	Post 5											
	S1	s2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13
ahb	648.5	1086.5	654	805.5	1446	1341	1813.5	591	871	1023	1046	565
ahd	647	877.5	550	453.5	1415	1270	1670	489	662.5	1398	1022	568
ahf	1516.5	1469	1063	1126	991	1131	1797.5	591	1039.5	1484	1837	751
ahg	1472.5	1409	832	864.5	1089	1505	945.5	586.5	1425.5	1473		722
ahk	1382.5	1565	877.5	1349.5	759.5	899.5	1658	767	1182	1304	1550.5	446.5
ahm	806.5	791	719	1647		1183	1701.5	511	1406	920	1101.5	768
ahp	1207	711	463	1173	1526	892.5	1334.5	286.5	871.5	711.5	1461	647
ahs	1183	1000.5	529	1424	1305	1121	1089	257	1232		1075	434
aht	672.5	1397	631.5	1380.5	774.5	1660		744	1541	847	1814	488.5
ahv	462	965	416	711	1118.5			535	888	1684.5	1295	695
ang	178.5	434	360.5		1642	1222	961	291	513.5	769	1153	193
ash	1059.5	1139	707	525	1172	577	891.5	564	995.5	1160	2051	133
ath	1730.5	1217.5	857.5	1996	883	848.5	962	862	1241	1634	1202	866
azz	314	848	265.5	505	881.5	1001.5	1057	617.5	426	1161	833	514
baa	322	303	1359	992	872.5	289.5	1017	257	435	450.5		257
baa	393	266	609.5	776.5	649.5	272	498	657	194.5	627	656.5	433
cha	426	233	418.5	858	873.5		897	282.5	267	720	458	194.5
daa	321.5	417.5	394	362	602	586	906	315	282.5	474.5	1360.5	129.5
daa	381.5	421.5	174.5	483.5	468.5	746	453	205	149	198	764	620
dha	1131.5		803.5	1260	1773	1306	316	391	509		788	573.5
eef	639.5	999	893.5	1118	1230	1083	1502	528.5	1085	1039.5	854.5	695.5
eek	662.5	910.5	703.5	815	646.5	1182	943	367	623	791.5	960	471
eep	830.5	944	790	821	959	518	1183.5	623	647	815.5	1382.5	224
ees	924	900.5	150	1036	1357	682.5	1013	285.5	1325.5	485.5	733	470
eesh	1329	1352.5	418	569.5	1225	1488	985.5	611	1185	777.5	904	801.5
eet	1271.5	979	277	731.5	588.5	1018.5	1260	668	500	928.5	692	324.5
eeth	618.5	1936.5	489	1432.5	1161	1568	2017	530	674	882.5		978
faa	442.5	825	458	1129	1824	1016.5	1695	115	610		785	
gaa	913.5	344.5	79	496	777.5	1709	473	489	1120.5	555	826	313
gaa	429.5	613	877	773	438	747.5	613.5	268.5	342.5	590.5	716	412.5
haa	561	312	161.5	296	856	1508	497	377	656.5	400.5	585	73
kaa		845	566	1285	1019	821	1813	479	280	422.5	1228	
laa	949	821.5	262	797	591.5	748	247	222	253.5	915	637.5	487
maa	1080.5	298	226	585.5	654.5	623	329.5	225	105.5	679	672.5	354
off	1629.5	532	980.5	1097.5	953	726	2311	606	781	716	873	697.5
ok	1764	733.5	694	916	1191	1126	978.5	359	1214	1311.5	1778	1122
oof	523	780	747.5	847.5	1642	649	283	660	1194	1017	1018	432
ook	1050	1078	1111	1430.5	1032.5	1437.5	1104	400		700	1001	644.5
oop	1144.5	914	538.5	878.5	722	904.5	1280.5	703	660	918	1290.5	437.5
oos	1120.5	889	303.5	1006.5	1105	1061.5	923.5	513	1087	689.5	1040.5	432.5
oosh	767	1179	564	653.5	1579	1571	588	647.5	473.5	893.5	772	806
oot	1010	1407	287	1354.5	1717.5	1095.5	1251.5	453.5	692	446.5	1033	951.5
ooth		1063	796.5	1012.5	887	898	1487	828		633.5	1490.5	627
op	1745	996.5	622	1367	1076.5	1316.5	1261	451.5	989	957	1191	719.5
osh	1585	383.5	826	871.5	701	794.5	1291.5	435	523	807.5	1098	750.5
oss	1205	1112	425.5	975	1413	786	908.5	331	609.5	856	930.5	710
ot	1498.5	611	789	702	924.5	1851	1743	486	1077	782.5	1132.5	521
oth	702.5	1247	890	994	1122	770.5	1515	722	962.5	938	1130	1097.5
raa	1103	1191.5	416.5	903.5	569	576	809	274.5	865	943.5	575.5	872
saa	1259.5	1366	271	762	671.5	1507.5	343	182.5	734	582.5	773	63
sha	691.5	540	1115	507	499.5	754	729	173	76.5	409.5	763	371
taa	537	9	176	432.5	479	1519.5	864.5	241	297.5	815.5	672	912.5
vaa	806	314	449.5	584	1186	966.5	329.5	984	873	1750	1181	239
waa	814	763.5	204	396	725	1042.5	556.5	238	269	479	644.5	317.5
yaa	1132	1117	460.5	667.5	286.5	515.5	700.5	470	364.5	580.5	917.5	574
zaa	288.5	562.5	49	736	561	463	696.5	64	225	178	776.5	122
Mean	**912.6574**	**862.2**	**566.9911**	**903.1364**	**992.9636**	**1016.602**	**1046.194**	**460.9107**	**731.6111**	**843.9057**	**1028.783**	**537.4537**
SD	427.6821	398.8223	293.6261	355.4189	378.9235	378.3515	497.7973	203.0425	387.8863	359.1142	351.9752	261.5583

APENDIX F- Raw Data for All Subjects in +10 SNR Pre Fatigue

	Pre 10											
	S1	s2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13
ahb	878.5	1701.5	781.5	2055	1421.5	839	959	383	606.5	1627	1558.5	456.5
ahd	692	1158	624	1438.5	1658.5	2101.5	872	471	614.5	1451.5	1308	616.5
ahf	1400	1790	990	1718	774	1701.5	1439.5	894	1357	1460	1318	337
ahg	802	1641	737	1712	1677	946	1537	449	944.5	909.5	833	529.5
ahk	1447		958.5	1325.5	1428.5	1886	879.5	964.5	1056	1452.5	1405.5	761
ahm	1519	1150.5	607	1454.5	1109	1280	743	1028.5	750.5	917	1741	1024
ahp	1352	1109	525.5	1381.5	1589	1454	847	645.5	1429	971.5		720
ahs	624.5	1362.5	481.5	1497.5	1550	1663	1347	1312	1735.5	1088	1161	1348
aht	782	1055		2133.5	1557	975	1614.5	979	1894		822	1064
ahv	1532.5	1350	396	1124.5	1788	968	1464	693.5	951	822	1110	968.5
ang	1389.5	634	282	1130	1144	665	169	395	1050	549	882	388.5
ash	1585.5		306.5	678	977.5	1420.5	1347.5	499.5	1115	451		741
ath	841	1217	689	1417	1071.5	977	1137	743.5	1329.5	888	1761	602
azz	898	889	528	1345	1463	634	687.5	529	840.5	1476.5	1009.5	851
baa	1088	1112.5	639	562	648.5	450.5	117	240	393	1451	802	211
baa	338	404	729	538	184	508.5	897	526.5	281	781	905.5	762.5
cha	1089.5	594	618	1419	442	1146	74	314	283.5	536	1258	76
daa	951	937.5	426.5	427	665	617.5	186.5	473	298	447	1369	172.5
daa	285.5	180.5	197.5	549	291.5	540	174	355.5	174	451	1212	247
dha	1962	1627	853	964.5	1962.5	1514	1625	397	853.5		1195	
eef	695	481	936	1223	2109	1653.5	1446.5	1053.5	814.5	1156	1566	895
eek	655	1302	919	1046.5	518	903.5	671.5	595	600.5	749	1174.5	425
eep	677.5	998.5	597.5	1031	1044.5	1598	519.5	510.5	798	909.5	1110	922
ees	630	1126	293	1139.5	452.5	980.5	477.5	508	462	756.5	1093.5	695
eesh	1479	1368.5	137	1073	873	1249.5	841.5	447.5	617	838	1088	571
eet	1236	763.5	276.5	1051.5	1561.5	805.5	611.5	472.5	756	851	1227	518.5
eeth	1249	1289	553.5	2031			1147	1344	1203	1502	770	985
faa	914	1383.5	633	1185	674	1232.5	409.5	503.5	609	640	905	499
gaa	361	513	248	288.5	615	129.5	231	256	352.5	1173	943.5	522
gaa	205.5	246	742	398	547	262	3	131.5	230.5	387.5	988.5	254.5
haa	872	912.5	608	399.5	526.5	424	801.5	225	408	517	927	426
kaa	1380	589	520	963	780	398.5	124.5	918	566	1114.5	820.5	302.5
laa	621	573.5	302.5	487	477.5	614.5	597	308	301.5	771.5	717	751
maa	266.5	520	2	394	1207	346	145.5	221.5	209.5	279.5	721.5	244
off	923.5	1012.5	997	1145	734	1301	1187	533.5		1621	1155.5	1118
ok	1462		877.5	918	1358.5	1639.5	1193.5	271.5	708.5	1526	1460	631
oof	618	691.5	956.5	1588.5	945	1591	1388	580.5	810	850	1090	1032
ook	1347	846	1157	1415	781	1482	486	497	1075.5	692.5	1157.5	1161
oop	1336	610	897	713	807	1122	1623.5	561.5	612.5	1039	1120.5	978.5
oos	1177	960.5	593.5	2029	2047	771.5	697.5	617	730	919.5	1238.5	1008
oosh	1604	1370	387.5	1000	1108	742	784	469.5	517	409.5	931	473.5
oot	878	670.5	365.5	1189	2200	1610.5	702	674.5	1003.5	638	1494	646.5
ooth	1403.5	1261.5	668.5	1693.5	1398	639.5	1448.5	781.5	1084.5	612	1717	1128
op	756.5	1277	868	784	1420.5	1481.5	941.5	787.5	1196	608.5	1277	535
osh	923.5	771.5	468	1546.5	1169	929.5	1207.5	1242	817	645.5	933.5	1820
oss	1443.5	482	284.5	1366	1241	945.5	684.5	769.5	1387	976.5	875	1107
ot	1291.5	1227.5	466.5	1220	1981	1791	1237.5	885	803	890	1097	1542
oth	538	762	220	1067	796	1808	1068.5	410	808	1626.5	1441.5	987
raa	520.5	760	272.5	1128.5	1094	560	520.5	376.5	545.5	390	744	881.5
saa	542	845	55	894.5	844	1438	143.5	37.5	794	748	918	576
sha	267	730	261	859	487.5	1012.5	472.5	292	364.5	649	650.5	671
taa	584.5	808.5	383	464.5	879.5	1256	475	574	200	606	808.5	650
vaa	103.5	1606.5	537	1431	646.5	1249	619	322	552	503	840	634.5
waa	709.5	606	453	446	707	300	206	636	181.5	738	1149	535
yaa	1436	1099.5	342.5	747.5	1042	101.5	694	539.5	446	443	1228.5	438.5
zaa	0	288	154.5	297.5	655	433.5	367.5	193	233.5	257	536.5	274.5
Mean	**938.6429**	**955.9434**	**541.8727**	**1098.634**	**1075.073**	**1037.991**	**790.9196**	**568.5446**	**740.9818**	**865.9815**	**1103.074**	**703.9182**
SD	451.9783	393.5048	271.6151	476.2592	500.2892	503.029	469.3953	289.9376	399.4031	381.6167	285.2887	352.1888

APENDIX G- Raw Data for All Subjects in +10 SNR Post Fatigue

	Post 10											
	S1	s2	S3	S4	S5	S6	S7	S8	S10	S11	S12	S13
ahb	726.5	925	815	1102.5	589.5	855	1158	637.5	518.5	1253	830.5	407.5
ahd	966.5	1006	582.5	1502	1158	1127	854.5	847	622.5	1045	998	224
ahf	668.5	1077	926	1478	975	447	1279	902	896		655	654
ahg	1472	241	578.5		1809	1488.5	1576.5		825.5	1592.5	881	697.5
ahk	1055	1615.5	751	1062	629	1326.5		558.5	687	974	1647	534
ahm	863	919	574		733	1262	862	861.5	598	876.5	966	127.5
ahp	830.5	821	509	1398	1668	2006	1007.5	733.5	687.5	909		863.5
ahs	1330	604	441.5	728	1898	655	1848	1440	1153	1885	930	872.5
aht	718	1660	582.5	1752	901	1647	1814		1142.5		1358.5	519
ahv	1247	1558	455.5		1301.5	857	1110	727.5	767	958.5	1118	1160
ang	1312.5	762	192.5	1128	888	1425.5	746	434	242.5	751.5	769.5	308
ash	948	403	164.5	916	1411	660.5	675	260	716	1476		660
ath	1185.5	1321.5	1008	1358	1025	850		456.5	961	1176.5		721.5
azz	569	552.5	328.5	992.5	1360.5	993	881.5	258	433.5	1370	642	321.5
baa	344	577	464	465	369.5	682	1233	442	401	625	888	759.5
baa	249.5	615.5	577	360.5	760	626	570	313	394.5	672	697.5	218.5
cha	425	151	618.5	929.5	209	906	1385	209	698.5	920	417.5	519
daa	466	568	513		288.5	378	521.5	281	170.5	656	714	283
daa	101.5	244	300.5	709	292	565.5	429	122	173	371.5	636	141.5
dha	1196.5		749	949	1043	1300	381	1147	1194		957	1052.5
eef	1238	520	671.5	870.5	1406	280.5	1454	718	685.5		783	599.5
eek	862.5	295	800	661	1277.5	647.5	630.5	854	472.5	1093	895	400
eep	999.5	958.5	814	790	1501	926	576	622	535	749	1278	663
ees	997.5	631	365	788.5	861	1310	837.5	164.5	390.5	1155.5	853	613.5
eesh	1087.5	737	352.5	912.5	1060.5	1120.5	822.5	504	528.5	1041	1009	969.5
eet	899.5	1464.5	372	994.5	1482	292.5	516	874	891.5	1090	820	1196.5
eeth	738	624.5	706.5	562.5	928	1176.5		1401	1203	1632	738	625.5
faa	586.5	1022.5	746	1513.5	494	1377.5	1187	432	417	1076	1696	190
gaa	440	353.5	272	392	1104.5	1016	226.5	111	266.5	990	633	561
gaa	333.5	436.5	326.5	501	715.5	750	358.5	164.5	495	540	526	254.5
haa	280.5	256.5	759	1117.5	825	832.5	960	742	264.5	1046	640.5	482
kaa	853.5	500	237.5	1093.5	1787.5	990.5		251.5	262	554.5	709.5	367
laa	772	324.5	300.5	390	566.5	486	573.5	52	198.5	1020	605.5	302
maa	314.5	481.5	49	402.5	998.5	264.5	337		130	375.5	504.5	258.5
off	1127	900	612.5	898	635.5	1651	1134	541.5	907	835.5	873	572
ok	1083	1255	437	931.5	856	1425		599	557	1323.5	1445.5	1241
oof	483	1576	794	1364.5	1268	1114	1375	498	1240.5	1170.5	876	955.5
ook	820	495	761.5	736	1205.5	1187.5	514	959.5	482	1230.5	823.5	615
oop	533	570.5	502.5	747	729.5	1928.5	1002.5	560	690	691.5	949.5	531.5
oos	801	1606	369.5	1265.5		957.5	1270	522.5	597	674.5	778	530.5
oosh	1062	844.5	883.5	813	1364.5	663	639	527	342.5	725.5	704	299
oot	1300	999	333	1336	1376	1028	886	568	839	1290	1112.5	735
ooth	1516	949.5	540.5	1229.5	2053	957.5	1238	776	920	1006.5	1320	750
op	1404	531.5	542.5	790	797	1334	1053	380.5	685	949.5	819	798.5
osh	917	1113	410	1091	1257	898	1481	956	1131.5	524.5	1153.5	526
oss	1063.5	649	333.5	1141	1066.5	1130	1105	623.5	439.5	972.5	775	322.5
ot	1524	893.5	446.5	838	957.5	1305.5		721.5	549.5	961.5	1061	350
oth	1528	1474	586	1254	762	710.5	1402	220	1013.5	398.5	1269	1020
raa	832	407.5	248	455.5	1150	88	615	208.5	592.5	1047	560	433.5
saa	239	230.5	142	676	492	14	127	204.5	144.5	1164.5	892	519
sha	308	989	362.5	619	392	1003	1555	252	179.5	790.5	763	92.5
taa	89	624	360	613.5	520	1303.5	808	93.5	464.5	1068.5	615.5	449
vaa	544.5	426	552	920	520	1073.5	1143.5	793	560.5	392.5	1308.5	984
waa	442	749	236	517	1201	700	796.5	159	109	939.5	565	365
yaa	804.5	943	292	932.5	683.5	653	292.5	291.5	140.5	1427	605.5	647
zaa	257.5	279.5	122.5	624.5	446	577	792.5	95	146	320.5	696.5	121.5
Mean	**817.0625**	**776.9364**	**495.9018**	**915.625**	**982.7**	**950.5357**	**920.8**	**529.6321**	**584.875**	**957.2885**	**882.3019**	**560.4464**
SD	392.0705	410.0832	222.8512	334.67	434.3798	426.2325	416.0827	326.8923	315.72	341.0209	283.9418	287.847

APENDIX H- Subjective Rating Raw Data

	Pre					Post				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
S1	3	3	2	2	2	3	3	2	2	3
S2	4	4	2	4	3	5	5	4	4	4
S3	5	1	1	1	1	4	4	3	3	3
S4	4	3	3	1	4	2	3	3	3	3
S5	4	4	4	3	4	5	5	5	5	5
S6	2	2	1	1	1	4	4	3	2	4
S7	5	4	3	2	3	4	4	3	4	4
S8	2	2	2	3	2	3	2	2	3	4
S10	5	3	3	2	3	4	3	3	2	3
S11	4	4	2	1	1	4	3	2	2	1
S12	4	3	2	2	2	4	3	2	3	3
S13	4	4	2	4	1	4	4	4	3	3

APENDIX I – Consent to Participate in Research

Consent to Participate in Research

Identification of Investigators & Purpose of Study

You are being asked to participate in a research study conducted by Hollis Leidy from James Madison University. The purpose of this study is to evaluate how listening fatigue affects reaction time as well as perceived listening effort. This study will contribute to the researcher's completion of her dissertation in order to fulfill the graduation requirement of the Doctorate in Audiology degree.

Research Procedures

Should you decide to participate in this research study, you will be asked to sign this consent form once all your questions have been answered to your satisfaction. This study consists of several listening tasks and a hearing screening that will be administered to individual participants at James Madison University. You will be seated in an acoustic booth and listening to different messages from sound field speakers around you.

Time Required

Participation in this study will require a maximum of 2 hours of your time.

Risks

The investigator perceives a likelihood of very minimal risks arising from your involvement with this study: listener fatigue. The participant will be free to take as many breaks as needed. The noise you will be exposed is significantly below permitted OSHA limits.

Benefits

Potential benefit from participation in this study is a free hearing screening. Additionally, you will be paid $10 per hour for two hours of listening.

Confidentiality

The results of this research will be presented at dissertation defense meeting with JMU Communication Sciences and Disorders faculty. The results of this project will be coded in such a way that the respondent's identity will not be attached to the final form of this study. The researcher retains the right to use and publish non-identifiable data. While individual responses are confidential, aggregate data will be presented representing averages or generalizations about the responses as a whole. All data will be stored in a secure location accessible only to the researcher. Upon completion of the study, all information that matches up individual respondents with their answers will be destroyed.

Participation & Withdrawal

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind.

Questions about the Study

If you have questions or concerns during the time of your participation in this study, or after its completion or you would like to receive a copy of the final aggregate results of this study, please contact:

Researcher: Hollis Leidy
Communication Sciences and Disorders
James Madison University
Email Address: leidyht@dukes.jmu.edu
Telephone: 540-568-3874

Advisor: Dr. Ayasakanta Rout

James Madison University
Email Address: routax@jmu.edu
Telephone: 540-568-3874

Questions about Your Rights as a Research Subject

Dr. David Cockley
Chair, Institutional Review Board
James Madison University
(540) 568-2834
cocklede@jmu.edu

Giving of Consent

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigators provided me with a copy of this form. I certify that I am at least 18 years of age.

____
Name of Participant (Printed)

______________________________ ____________
Name of Participant (Signed) Date

______________________________ ____________
Name of Researcher (Signed) Date