Spring 2015

The effect of auditory fatigue on reaction time in normal hearing listeners

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Recommended Citation

Hulvey, Beth I., "The effect of auditory fatigue on reaction time in normal hearing listeners" (2015). *Dissertations*. 26.
https://commons.lib.jmu.edu/diss201019/26

The Effect of Auditory Fatigue on Reaction Time in Normal Hearing Listeners

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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 2015

ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisor, Dr. Ayasakanta Rout, for his constant collaboration and patience throughout data collection and the writing process. I would also like to acknowledge my committee members, Dr. Brenda Ryals and Dr. Christopher Clinard, for all their wisdom and input into this project. In addition, I would like to thank Nick Arra and Ali Bove for their help in recruiting subjects for this study. Without the help of the aforementioned individuals, this project would not have been possible.

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ABSTRACT

Hearing impaired individuals often report feeling fatigue at the end of the day. These individuals are forced to exert more cognitive effort throughout the day as they strain to understand speech in an ever-changing auditory environment through an impaired/degraded auditory system (Rabbitt, 1991). Today's digital hearing aids attempt to increase audibility and relieve cognitive strain through advanced signal processing techniques such as digital noise reduction (DNR). Recent research regarding noise and its effects on auditory fatigue in hearing impaired listeners suggests that DNR may reduce the effects of auditory fatigue (Sarampalis et al, 2009). The overarching goal of a future project is to understand the effectiveness of DNR in reducing listening effort and ways to quantify it. The present study sought to determine if reaction time alone is an accurate measure of auditory fatigue while isolating listening fatigue as a sole factor. Twenty young adults with normal hearing participated. Testing consisted of three parts: pre-test, fatigue inducing condition, and post-test. Pre- and post- tests consisted of a reaction time task using nonsense syllables and a subjective listening questionnaire. The overall reaction time in the post-fatiguing condition was higher than the pre-fatiguing condition. A one sample t test revealed no significant difference between the pre and post fatiguing condition reaction time for overall nonsense syllables and consonant final nonsense syllables. Pre- and post-fatiguing reaction time was significantly different for consonant initial nonsense syllables only. Results indicated that the 30 minute fatigue inducing condition did not affect reaction time in the post-tests for overall nonsense syllables and for consonant final nonsense syllables. This could be due to several factors. The reaction time task used in this study may not be an accurate measure of listening effort or the 30

minutes of effortful listening may not have been enough. The subjective listening effort questionnaire showed that subjects did feel more fatigued after the post-test than after the pre-test. Future studies are planned to expand upon the current study by assessing individuals with hearing loss as well as those exposed to longer duration of noise throughout the day.

Chapter I

INTRODUCTION

Many hearing impaired individuals report feeling fatigue at the end of the day. These individuals are forced to exert more cognitive effort throughout the day as they strain to understand speech in an ever-changing auditory environment through an impaired/degraded auditory system (Rabbitt, 1991). Changes in the peripheral auditory system impact higher level cortical speech processing networks as well, causing speech understanding to decline even in older adults with only mild to moderate hearing loss (Peelle, Troiani, Grossman, & Wingfield, 2011). Sensory declines in the auditory system in turn increase listening effort. With this perceptual decline in hearing, hearing impaired individuals are forced to allocate and expend more cognitive resources to understand speech. The neural activity required to re-allocate these cognitive resources to the auditory system is related to the demand of the task at hand and cognitive ability (Peelle et al, 2011). By expending more cognitive effort to maintain listening performance, hearing impaired individuals become fatigued at the end of the day (Downs, 1982). Anecdotal evidence from clinicians, teachers, and parents indicate that children with hearing loss experience fatigue due to increased listening effort as well. Increase of listening effort caused by poor signal to noise ratios in classrooms can reduce academic performance in children with hearing loss (Bess and Hornsby, 2014).

Although there has been an increase in the amount of research on listening effort and fatigue, the difference between the two terms can be confusing. It is important to understand the difference between auditory fatigue and listening effort. A couple recent articles sought to define the two terms to reduce confusion. Listening effort has been defined as “the mental exertion required to attend to, and understand, an auditory message” (McGarrigle et al, 2012). Listening fatigue has been defined as “extreme tiredness resulting from mental or physical exertion”, with auditory fatigue being “mental fatigue resulting from effortful listening” (McGarrigle et al, 2014). Additionally, fatigue has been defined as “a mood – a feeling of tiredness, exhaustion or lack of energy due to cognitive or emotional, as opposed to physical, demands” (Bess and Hornsby, 2014).

One of the most common forms of aural rehabilitation used to help hearing impaired individuals is hearing aids. There is a growing body of evidence regarding the relationship of cognitive capacity and success with hearing aids. Listening involves decoding auditory input by matching it with representations stored in long term memory and subsequent encoding into working memory. In quiet, this process is usually very fast. When auditory input is distorted by noise and/or a hearing loss, the process does not happen as smoothly – fragmented information must be stored in working memory (Rudner and Lunner, 2013). Auditory communication requires listeners to select relevant information using attention and effort, then comprehend the information before storing it into memory (Kalluri and Humes, 2012). Speech understanding in the presence of background noise is associated with working memory capacity. Unfortunately, working memory capacity declines in old age. With limited working memory capacity and declines in cognitive processing, simple increases in audibility and improved signal to noise ratios may not be enough for elderly patients (Kalluri and Humes, 2012). Advanced signal processing techniques in hearing aids are meant to help hearing impaired individuals in adverse listening environments, yet may introduce distortion as well;

therefore, it's beneficial to use measures of cognitive capacity such as reading span when determining the efficacy of signal processing techniques. Reading span tasks have been shown to correlate with speech perception in noise and can be a predictor of hearing aid benefit (Rudner & Lunner, 2013).

Today's digital hearing aids attempt to increase audibility and relieve cognitive strain through advanced signal processing techniques such as digital noise reduction (DNR) and directional microphones. Digital noise reduction is advertised by hearing aid manufacturers to analyze input and categorize it as either signal or noise. If it is deemed to be noise, then gain will be reduced using modulation detection algorithms or filtering. This technique is used to improve the signal to noise ratio in noisy listening environments. Studies have shown variable objective evidence of the efficacy of DNR. In a systematic review of the literature by McCreery, Venediktov, Coleman, and Leech in 2012, the efficacy of DNR in children with hearing loss were studied. Overall, their findings showed no significant impact of DNR (McCreery, Venediktov, Coleman, & Leech, 2012). Although DNR wasn't proven by McCreery, Venediktov, Coleman, and Leech to benefit children with hearing loss, there was one unanswered question: do DNR techniques degrade the speech signal in child hearing aid users? Stelmachowicz et al addressed this in a 2010 study with 16 children using spectral subtraction. These researchers measured speech recognition with nonsense syllables, words, and sentences. They found performance improved as a function of SNR. There was no statistically significant difference for DNR on/off or between stimuli; there was no negative affect of DNR on perception of these stimuli (Stelmachowicz, 2010).

Literature is sparse regarding solely the efficacy of DNR – oftentimes researchers measure the efficacy of DNR in concert with directional microphones (Kerchkoff, Listenberger, & Valente, 2008). In a 2010 study, Tawfik, Danasoury, AbuMoussa, and Naguib studied the efficacy of DNR in combination with directional microphones on speech intelligibility in noisy environments adult hearing aid users. Overall, these researchers found that DNR works best when it is used alongside directional microphones (Tawfik, Danasoury, AbuMoussa, & Naguib, 2008). Another article from Oliveira, Lopes, and Alves in 2010 analyzed the speech perception of 32 individuals with hearing loss when using DNR. DNR significantly improved speech perception for the subjects in the study (Oliveira, Lopes, & Alves, 2010).

Although objective measures of the benefit of DNR have revealed variable results, a good number of studies have shown significant subjective benefit. In the review McCreery, Venediktov, Coleman, and Leech in 2012, parent questionnaires resulted in no significant differences for DNR on or off. The self-questionnaires administered to the children in the study showed that they favored DNR on when noise was coming from the back. In the study by Tawfik, Danasoury, AbuMoussa, and Naguib in 2010, subjects reported better speech quality when directional microphones were used in concert with DNR. So, although there was no statistical significance with speech recognition, subjects subjectively preferred the sound quality of hearing aids with DNR on rather than DNR off.

Directional microphones use an acoustic delay to amplify sounds at 0 degrees azimuth of the listener and to reduce sounds at 180 degrees azimuth of the listener. Hearing aids achieve directionality through the use of 2 microphone ports; sound entering the back port is acoustically delayed and is subtracted from the sound entering the front port (Kerckhoff, Listenberger, & Valente, 2008). Theoretically, DNR and directional mics should increase SNR and ultimately ease of listening; however, the efficacy of these techniques is variable. Studies such as the one published by Gwenkinov, Ricketts, Bratt, and Mutchler in 2009 suggested that although the objective measures point toward an advantage of directional microphones, the advantage is not a strong one. The researchers reached this conclusion after studying the subjective and objective preference between omni and directional microphones in 94 hearing aid users with varying degrees of hearing loss (Gwenikow, Ricketts, Bratt, & Mutchler, 2009). A study by Tawfik, Danasoury, AbuMoussa, and Naguib in 2010 found that hearing aid users performed better on the speech in noise test (SPIN) with directional microphones compared to omnidirectional microphones but only when the signal was coming from the front and noise from the back. A subjective questionnaire completed by the subjects indicated a strong preference for directional microphones in all conditions (Tawfik, Danasoury, AbuMoussa, & Naguib, 2010). Overall, directional microphones have been proven to have potential to improve speech intelligibility in noise. However, many articles show a disconnect between measures acquired in the laboratory setting and those measured in the real world. While objective laboratory tests such as the HINT or CST may indicate a directional benefit in noise, some subjects report there is no perceived benefit between directional and omnidirectional settings.

Researchers have used subjective, behavioral, and physiological measures to attempt to quantify listening effort and fatigue. Subjective measures include questionnaires, which often have a visual analog scale or descriptive/numeric anchors

(McGarrigle et al, 2012, Bess and Hornsby, 2014). These subjective, self-reported measures are a quick and easy way to gauge listening effort and fatigue. Behavioral measures of listening effort and fatigue include single-task and multi-task (or dual-task) paradigms. Subjects respond to various stimuli, which could include a speech intelligibility task, reaction time task with a response button, or word recall task. Physiologic measures researchers have used to measure listening effort and fatigue include fMRI, EEG, skin conductance, and salivary cortisol levels. Researchers often use a combination of subjective and behavioral measures to evaluate whether or not the two correlate (McGarrigle et al, 2012).

Recent research regarding noise and its effects on auditory fatigue in hearing impaired listeners suggests that DNR may reduce the effects of auditory fatigue. In a 2009 study by Sarampalis, Kalluri, Edwards, and Hafter attempted to measure listening effort by studying the effects of background noise and noise reduction techniques. These researchers hypothesized that although noise reduction does not improve speech intelligibility, its ability to lighten the cognitive load of the listener may reduce listening effort. A dual task paradigm was used to measure cognitive demands of the listener in two separate experiments. In the first experiment, normal hearing subjects were asked to listen to sentences in noise over headphones and to repeat the last word in each sentence. A visual cue prompted the subject to recall as many words as possible after every 8 sentences. The sentences in noise were either processed with a noise reduction algorithm or left unprocessed. The number of words correct was better without the noise reduction algorithm, which was expected since noise reduction does not improve speech intelligibility. However, recall performance was significantly improved with noise reduction applied. In a second experiment, normal hearing listeners listened to sentences in four talker babble at -6, -2 or 2 dB SNR. Similarly to the first experiment, some sentences were processed with a noise reduction algorithm while some were not. Randomly throughout the experiment, subjects were given a visual cue to press a button on the keyboard; accuracy and reaction time was measured for each trial. Speech intelligibility, again, showed no effect of noise reduction; however, reaction time at the -6 dB SNR condition was significantly faster (better) with noise reduction than without (Sarampalis, Kalluri, Edwards, & Hafter, 2009).

Listening effort and fatigue was studied in children with mild to moderate hearing loss compared to age-matched peers in a series of two experiments. Although the first experiment using salivary cortisol levels as a physiologic measure of stress/fatigue yielded no significant results, the researchers did reach significant findings in a second experiment using a dual task paradigm. The dual task paradigm required the children to repeat words in noise at various signal to noise ratios (quiet, +10, +15, and +20 dB SNR) (primary task) while responding to a visual reaction time task using an LED light and a response pad (secondary task). Children with hearing loss had significantly longer reaction times than children with normal hearing. Despite the objective differences between the groups, subjective self-ratings of fatigue were not significantly different (Hicks & Tharpe, 2002).

Listening effort and mental fatigue in hearing aid users was studied in 16 middle age adults with mild to severe sloping sensorineural hearing loss. Subjects underwent a dual-task paradigm designed to evaluate word recognition, word recall, and visual reaction times. Subjects were tested in three different conditions – with omnidirectional microphones, with directional microphones + digital noise reduction, and without hearing aids. Subjects also completed subjective questionnaires. Out of all the tasks, word recall was greater and reaction times were faster in the aided conditions. Subjective ratings and word recognition were not significantly different in the aided/unaided conditions. The results of this study indicate that sustained speech processing demands lead to fatigue in individuals with hearing loss. Hornsby suggests that noise reduction algorithms and directional microphones lighten the cognitive load of hearing aid wearers, decreasing auditory fatigue; in addition, the author mentions more work is needed in this area (Hornsby, 2013).

Studies evaluating the effects of digital noise reduction and other signal processing techniques of hearing aids on listening fatigue seem to heavily rely on dual task paradigms as a means to measure auditory fatigue. These dual task paradigms often use speech in noise measures (a primary task) in conjunction with visual reaction time (a secondary task). Dual task paradigms can be influenced by the complexity of the secondary task, making it difficult to determine whether these tasks are actually measuring auditory fatigue and whether the results are contaminated by poor audibility. Researchers using the dual task mention that the paradigm will yield inaccurate results if the subject stops allocating cognitive resources to the primary task (Hicks and Tharpe, 2002). Is there an easier way to measure auditory fatigue without the need to parse out the effects of poor audibility at very low signal to noise ratios?

The over-arching goal of a future project is to understand the effectiveness of digital noise reduction in reducing listening effort and ways to quantify it. First, we need to decide if reaction time alone is an accurate measure of auditory fatigue and design a study that isolates listening fatigue as a sole factor. In order to study this, it is necessary to apply the same principles on normal hearing listeners and understand if listening fatigue manifests itself in reaction time tasks and subjective ratings. This study will serve as the first in a series of experiments to understand the role of noise reduction in reducing listening effort. The study aims to test the effect of listening fatigue on reaction time and perceived listening effort in normal hearing individuals. We hypothesize that reaction time is an accurate measure of auditory fatigue; specifically, that reaction time will be slower after inducing auditory fatigue. In addition, we hypothesize subjects will report greater fatigue on a subjective questionnaire after inducing auditory fatigue. Future studies will look at the effects of auditory fatigue on the reaction time of hearing impaired subjects. Future studies will also utilize poorer signal to noise ratios to see if the effect of fatigue is greater than at favorable signal to noise ratios.

Chapter II

METHODS

Twenty normal hearing participants above the age of 18 (range: 18-31 years) participated in the study. The majority of the participants were audiology doctoral students and undergraduate students at James Madison University. Participants were recruited by word of mouth and through mass email to audiology students. Inclusion criteria for the study consisted of normal hearing as defined by pure tone air conduction audiometric screening at 20 dB HL, no diagnosis of ADHD spectrum, no current consumption of strong medication or excessive alcohol, and no diagnosis of middle ear pathology. Participants gave verbal acknowledgement that they do not fall in the aforementioned categories of exclusion criteria. Prior to testing, participants underwent an audiologic screening to ensure normal hearing and middle ear function. The screening consisted of otoscopy, tympanometry, and a pure tone screening of 250-8000 Hz at 20 dB HL. All participants had thresholds less than or equal to 20 dB HL and most participants had type A tympanograms; two subjects had negative middle ear pressure in one ear only (160 daPa), but since thresholds were less than or equal to 20 dB HL, the researchers did not feel they were at a disadvantage for testing. The entire session (including hearing screening and test procedure) lasted approximately sixty to ninety minutes. All sessions were scheduled in the morning to begin between the times of 8:00 AM to noon to reduce the amount of fatigue subjects might have experienced after a full day of listening. The testing was conducted in the double walled sound booths located in the Hearing Aid Research Laboratory at James Madison University.

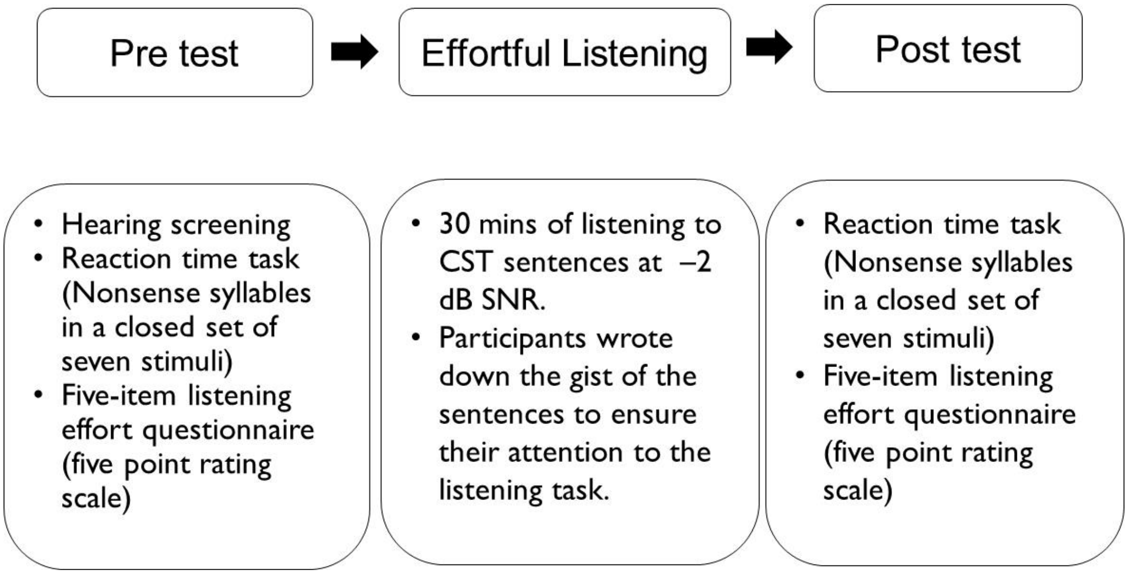

Figure 1. Flow-chart of the test conditions

There were three parts to the testing: a pre-test, a fatigue-inducing condition, and a post-test. The pre-test and post-tests consisted of two measures. The first measure was a reaction time task and the second was a self- reported listening effort rating scale questionnaire. The reaction time task used a 7-button Cedrus RB-730 response pad connected to Superlab 4.5 software and was situated within a double-walled sound booth. The response pad sat on the participant's lap during testing. Participants listened to eight different sets of seven nonsense syllables (Levitt and Resnick, 1978) at 70 dB SPL in quiet (for complete list of nonsense syllables used, please see Appendix B). The nonsense syllables either began with a consonant and ended with a vowel (ex: ba, ga, da) or a vowel and ended with a consonant (ak, ahm, ag). As each nonsense syllable was played, the participant identified the nonsense syllable he/she heard by pressing the corresponding button labeled with the various nonsense syllables on the response pad. The SuperLab software allowed for breaks in between the different sets of nonsense syllables so the completed syllable set on the response pad could be changed to the next set by the researcher. The stimuli were streamed from a personal computer (SuperLab 4.5 software) and presented via supra aural headphones (Sennheiser EH-1430) connected to the computer. The Superlab 4.5 software tracked both the amount of time it took the participant to press the button (reaction time in ms) and whether or not the participant correctly identified the nonsense syllable. Prior to completing the reaction time task in the pre-test, participants performed a practice run with all eight sets of nonsense syllables to become familiar with the task and equipment. None of the data from the practice run was saved. The actual pre-test began directly after the practice run.

After the reaction time task was completed, participants listened to a 30 second sample of the fatigue inducing condition, which is described in the paragraph below. Participants then completed a listening effort questionnaire which was based on the listening effort questionnaire recommended by the International Telecommunications Union (ITU, 1996) and questions from Hornsby (2013). Subjects rated their listening effort during the reaction time task and fatigue inducing condition as well as their global feeling of fatigue on a five point scale (1 = extreme fatigue, 5 = no fatigue) (ITU, 1996; Hornsby, 2013). The questions are presented below.

1. Did you have to concentrate very much while listening to the syllables in quiet?

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?

Figure 2. Equipment set up; left panel- real ear measurements were taken with the iPod headphones; right – the reaction time task with the laptop and Cedrus response pad.

Immediately following the pre-test measures, participants underwent an effortful listening task which was meant to induce auditory fatigue. Participants spent 30 minutes listening to sentences in noise presented at 70 dB SPL and -2 dB SNR from the Connected Speech Test (CST). The CST sentences are grammatically correct, meaningful, connected sentences on a particular topic spoken by female talker presented in a background of eight-talker babble. The -2 dB SNR criteria was chosen through a pilot study during which four subjects were asked to listen to CST sentences at -5, -3, -2, -1, and 0 dB SNR. The pilot subjects were asked to rate each sample SNR on audibility and fatigue on a scale from 1 to 10 (1 = no difficulty or fatigue, 10 = extreme difficulty or fatigue). Through this pilot study, -2 dB SNR was determined to provide enough audibility for subjects to understand the content yet still feel fatigued. Real ear measures on the Audio Scan were used to verify each subject is hearing the sentences at 70 dB SPL by placing the probe microphone in the ear canal along with the iPod headphones while a 1000 Hz calibration tone was played. The volume on the iPod was adjusted until the volume was at 70 dB SPL. In order to ensure that participants were truly engaged in listening to the sentences in noise, subjects were given a pad of paper to take notes on the various topics of the CST sentences.

After listening to the CST sentences in noise, participants completed the post-test, which included the same reaction time task and subjective questionnaire as the pre-test, which was previously described in detail. Throughout the testing session, the participant was seated in a comfortable chair with the ability to take breaks at any time they desired.

Chapter III

RESULTS

Reaction times recorded pre and post the fatiguing condition were analyzed for all twenty subjects. The overall mean reaction time before the fatiguing condition was 639.5 ms, with a standard deviation of 187 ms. The overall reaction time for post-fatiguing condition was higher than the pre-fatiguing condition, with a mean reaction time of 661.8 ms and a standard deviation of 189.3 ms across all subjects. Please refer to Table 1 below for a summary of mean reaction time.

Further analysis was performed by separating consonant initial nonsense syllables (CINS; ex: /da/ and /ga/) and consonant final nonsense syllables (CFNS; ex: /ak/ and /at/). A summary of this analysis can be found in Table 1 below. The pre-fatiguing mean reaction time across all the subjects for the CINS was 444 ms, with a standard deviation of 83.5 ms while the post-fatiguing condition mean reaction time was 490.2 ms, with a standard deviation of 99.7 ms. The pre-fatiguing mean reaction time across all the subjects for the CFNS was 756.8 ms, with a standard deviation of 121.2 ms while the post-fatiguing mean reaction time was 764.8 ms, with a standard deviation of 151.7 ms.

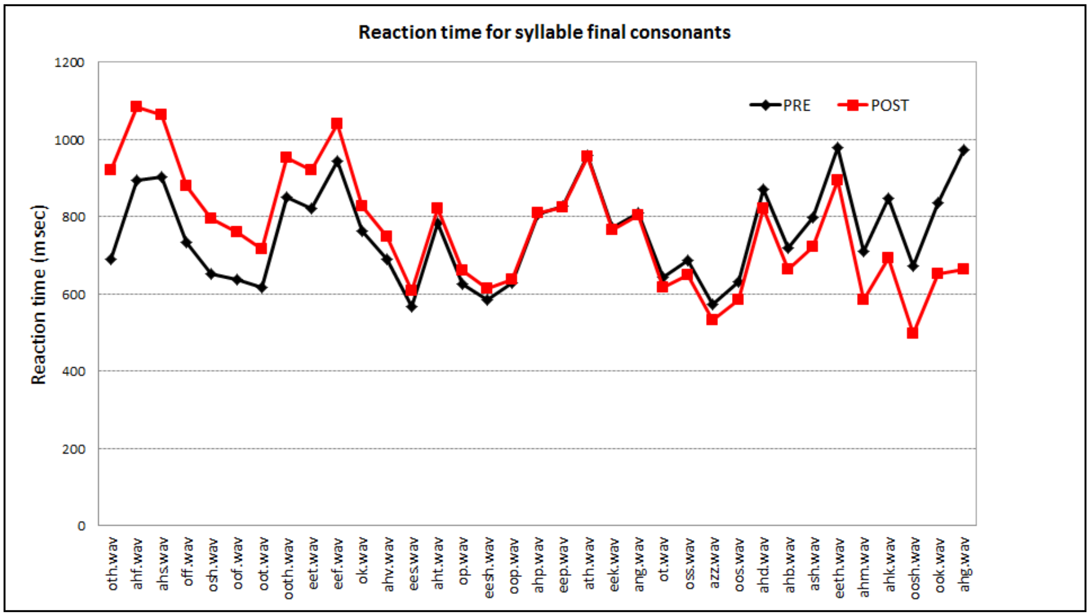

Fig. 3: Consonant Initial (CINS) average reaction time, pre-fatiguing condition (in black) and post-fatiguing condition (in red). Data was sorted in increasing order of pre-fatiguing condition reaction time.

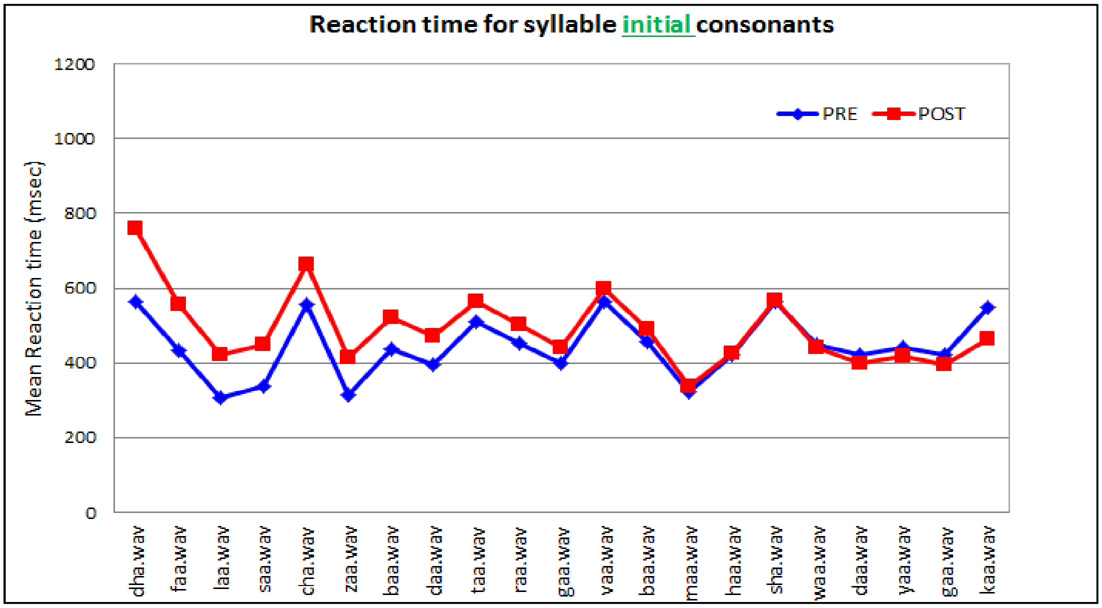

Fig. 4: Consonant Final (CFNS) average reaction time, pre-fatiguing condition (in black) and post-fatiguing condition (in red). Data was sorted in increasing order of pre-fatiguing condition reaction time.

Table 1. Summary table of mean scores and t-test.

	Pre Mean (SD)	Post Mean (SD)	t-test	p value (2-tailed)
All stimuli	639.5 (186.9)	661.8 (189.3)	t(55) = -1.67	0.10
Final consonants (e.g. /aad/, /oot/)	756.8 (121.2)	764.8 (151.7)	t(34) = -0.41	0.68
Initial consonants (e.g. /da/, /tha/)	443.9 (83.5)	490.2 (99.7)	t(20)= -3.25	**0.004***

Mean reaction times for pre and post listening fatigue task were calculated and paired comparison t-tests were performed to evaluate statistical differences. The results are summarized in table 1. There was no significant difference between the before and after reaction times using combined reaction times from consonant initial and consonant final nonsense syllables (t(55) = -1.67, p = 0.10). The overall data was then divided into two groups for further analysis – stimuli with consonants in the syllable initial (e.g. /da/, /tha/) and final positions (e.g. /aav/, /oot/). Predictably, the reaction times for identification of nonsense syllables with initial consonants were shorter than the final consonant syllables. The fatigue inducing task also resulted in significantly longer reaction times for those syllables with initial consonants (t(20) = -3.25, p = 0.004).

In addition to the reaction time task the subjects were given a short questionnaire to rate their level of fatigue before and after the thirty minute fatigue inducing task. The subjects reported significantly higher level of fatigue in the post test compared to the baseline (see figure 5). A Wilcoxon signed-rank test confirmed that subjects reported more fatigue after the effortful listening task than the pretest (Z = - 6.78, $p < 0.05$).

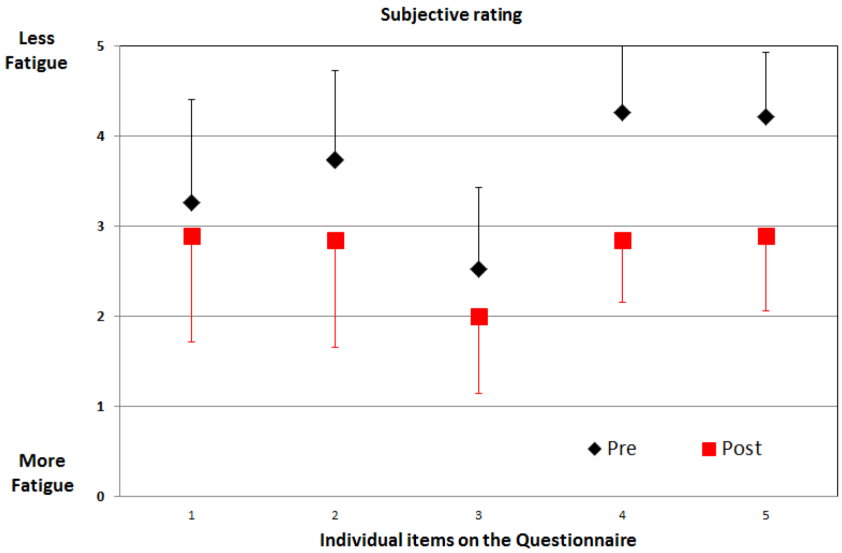

Figure 5. Comparison between pre- and post-test listening fatigue; the y- axis depicts the subjective rating of listening effort (1=more fatigue, 5 least amount of fatigue) and the x axis represents individual items on the questionnaire. Error bars represent 1 SD.

Chapter IV

DISCUSSION

The primary objective of this study was to assess the effect of listening fatigue on reaction time in a simple nonsense syllable identification task. Listening fatigue was induced by presenting thirty minutes of connected speech at -2 dB signal to noise ratio, and requiring the subjects to write down the main idea of what they heard for the entire duration. Reaction time for randomly presented nonsense syllables was measured before and after the fatigue inducing task. Results revealed that reaction time was significantly longer for consonant- initial nonsense syllables. However, no difference was observed for all stimuli combined, or for the subset of consonant- final nonsense syllables.

It should be noted that this study assessed the effect of listening fatigue through reaction time and did not evaluate listening effort. Several authors have measured listening effort through use of a single task (Gatehouse and Gordon, 1990; Houben et al., 2013) or a dual-task paradigm (Fraser et al., 2010; Gosselin and Gagné, 2011; Hicks and Tharpe, 2002; Hornsby, 2013; Sarampalis et al., 2009; Stelmachowicz et al., 2007). In the dual-task paradigm, the listening effort expended on the primary task could possibly be measured by the performance (e.g. reaction time) on the secondary task. Any decrease in the performance on the secondary task (e.g. longer reaction time) can be interpreted as an increase in listening effort. It has also been postulated (Kalluri and Humes, 2011; Sarampalis et al., 2009) that an increase in listening effort could be a result of listening fatigue. Many different types of secondary tasks have been employed to measure listening effort with mixed results which have led to a lack of clarity about the validity of dual task paradigms. Measures of listening effort using reaction time for speech identification tasks have been shown to be a useful method (Gatehouse and Gordon, 1990; Houben et al., 2013).

The basic argument and the end goal of these studies was to evaluate if digital noise reduction resulted in reduced listening effort because hearing aid users report fatigue at the end of the day. To the knowledge of this author there is no reported study which controlled for the nature and duration of listening fatigue in their subjects for the pre and post measure of reaction time. Hornsby (2013) measured reaction time in a dual task paradigm at the end of the work day but the listening environment (hence level of fatigue) was not controlled or monitored. The current study addressed this limitation by presenting the same fatigue inducing condition to all subjects. Reaction time for nonsense syllable identification in quiet was used as a direct measure of listening fatigue in lieu of the dual task paradigm.

Reaction time in quiet:

The result of this study was disappointing as there was no significant difference between the overall mean reaction time before and after the thirty minute fatigue inducing task. This raises two questions: 1) were the nonsense syllables in quiet too easy to identify and hence did not task the cognitive system enough? 2) Was the thirty minute listening task long enough to introduce fatigue?

Houben et al. (2013) argue that it is important to measure reaction time with stimuli consisting of high intelligibility. This ensures an accurate measurement of speech recognition score (percent correct) as well as reaction time. In fact, their data showed a significant increase in reaction time and a sharp decrease in speech recognition score at -6 dB signal to noise ratio compared to -1 dB. Similar result was also reported by Sarampalis et al. (2009). It is unclear whether the changes in reaction time at -6 dB signal to noise ratio is due to actual changes in listening effort or due to the difficulty in audibility which in turn results in longer reaction time. In the present study the nonsense syllables in quiet were highly intelligible with at least 80% correct response for all subjects.

The mean difference (post – pre fatigue) in reaction time for the entire set of nonsense syllables was 23 ms, and the difference for a subset of stimuli consisting of consonants in the initial position (e.g. /ba/, /ka/) was 47 ms. The latter is comparable to the difference in reaction time at -6 dB reported by Sarampalis et al. (2009). Though the overall difference of 23 ms was not found to be statistically significant, the p-value was 0.1. The non-significance is due to identical pre and post reaction time scores for the other set of nonsense syllables (those starting with a vowel, e.g. /ob/, /ot/, /oz/). Because the stimuli were presented without a carrier phrase or an alerting signal, the syllables starting with a vowel gave the listener a chance to 'listen in' before the critical target consonant. It can be argued that these stimuli are easier than the nonsense syllables with a consonant at the initial position. Based on the findings of this study it is recommended that a larger set of stimuli with consonant initial syllables be used in future research.

Another way to increase the difficulty of the task is by presenting the stimuli in noise without making the stimuli too difficult to understand (e.g. -6 dB signal to noise ratio). Houben et al. (2013) and Sarampalis et al. (2009) reported that reaction time did not change at signal to noise ratios above (better than) 0 dB even for conditions that potentially required greater listening effort. We can therefore extend this study to include nonsense syllables in noise (e.g. 0, +3, and +6 dB signal to noise ratios) that would make the identification task more challenging without making it extremely difficult to understand. In such an experiment, the different signal to noise ratios can be indicators of listening effort. For example, one would expect a listener to expend more effort while listening at 0 dB SNR compared to +6 dB SNR. The fatigue inducing task can be used as an effector of listening fatigue.

Was the thirty minute listening enough to introduce fatigue?

As pointed out above, the thirty minute listening task might not have been long enough duration to introduce listening fatigue. At least, we were not able to measure the effect through reaction time for all types of nonsense stimuli. The thirty minute duration was arrived after a pilot study asking young normal hearing listeners to rate their level of fatigue listening to connected speech at -5, -3, -2, -1, and 0 dB SNRs. When the subjects in this study were asked to rate their level of listening fatigue before and after thirty minutes of listening (and writing down what they heard), they reported significantly higher level of fatigue in the post test. It is reported anecdotally that many hearing impaired listeners complain about listening fatigue at the end of the work day but their speech recognition of auditory performance does not show any changes. The questionnaire in this study was adapted from Hornsby (2013). Even though he did not use a before and after comparison following a fatigue inducing task, the magnitude of self-reported change in fatigue level in the present study is comparable to that of Hornsby (2013).

The use of subjective rating scales to assess listening fatigue is fairly quick and clinically feasible. However, there is inherent listener bias in these types of measures. It is also difficult to know which percept a listener is judging as these measures are extremely sensitive to subtle changes in instruction. Hence, it is necessary to complement a subjective questionnaire with an objective measure of listening fatigue. Based on the results of this study, it is inconclusive if reaction time measured in a simple task can be that complementing objective measure. The significant differences for one subset of the stimuli appears promising to extend this study to include more signal to noise ratios and varying lengths of listening fatigue inducing situations.

Limitations of the current study

One of the major limitations of this study is that we only included young normal hearing college students who are presumably adept at multitasking. It has been reported that older adults expend more listening effort than young normal adults while listening to speech in noise (Gosselin and Gagné, 2011). Since older people constitute a large proportion of hearing aid users, it is necessary to conduct this same study using older subjects. Hence, the findings of this study cannot be generalized to older listeners.

As discussed above, the tasks used for measuring reaction time might have been too easy for the subjects.

Even though the subjective rating scale showed significantly higher rating of fatigue, it is unclear if an exposure to a longer duration fatigue inducing listening situation could have resulted in a more robust change is reaction time. From personal experience of this researcher, any longer than 30 minutes of listening and monitoring at -2 dB SNR is very fatiguing. Any further increase might deter subjects from completing the study. Instead, the current study can be extended to a subject population that works in a noisy environment requiring frequent oral communication (e.g. noisy call center workers, cafeteria workers, and on-duty police officers). It is difficult to control for the noise level at different realistic noisy environments. To circumvent this issue the subjects in such a study could be provided a noise dosimeter or hearing aid users' data logging feature to record what type of acoustic environment the subject is exposed.

Conclusions

1. The participants in this study reported a higher level of listening fatigue after exposure to only thirty minutes of listening at -2 dB signal to noise ratio.

2. Reaction time was prolonged for a subset of nonsense syllables. However, no such difference was observed for the entire set of stimuli suggesting that reaction time was not a sensitive measure of fatigue at least under these test conditions.

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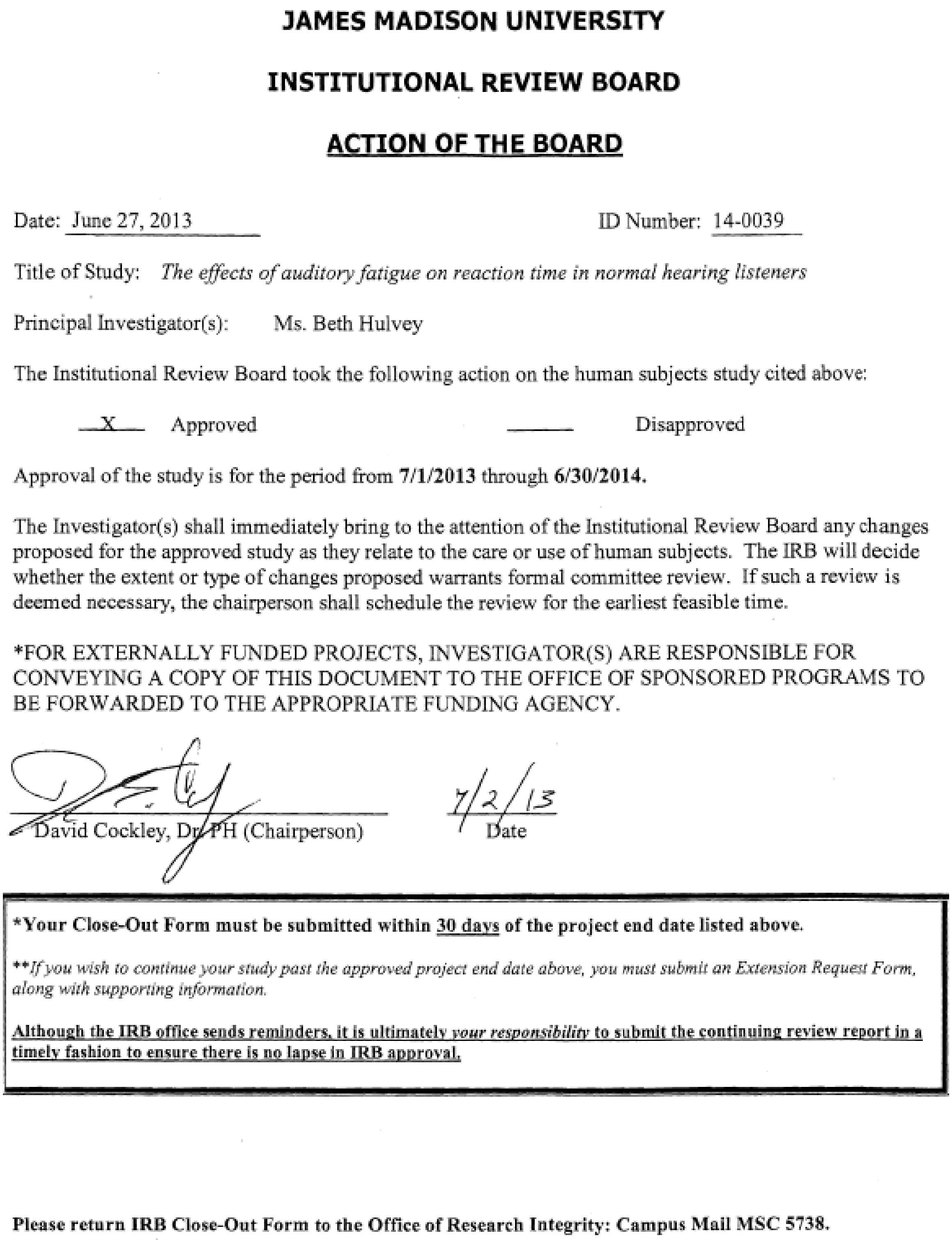
Appendix A

James Madison University Institutional Review Board Approval and Consent Form



JAMES MADISON UNIVERSITY

INSTITUTIONAL REVIEW BOARD

ACTION OF THE BOARD

Date: June 27, 2013 ID Number: 14-0039

Title of Study: *The effects of auditory fatigue on reaction time in normal hearing listeners*

Principal Investigator(s): Ms. Beth Hulvey

The Institutional Review Board took the following action on the human subjects study cited above:

_X_ Approved ______ Disapproved

Approval of the study is for the period from **7/1/2013** through **6/30/2014.**

The Investigator(s) shall immediately bring to the attention of the Institutional Review Board any changes proposed for the approved study as they relate to the care or use of human subjects. The IRB will decide whether the extent or type of changes proposed warrants formal committee review. If such a review is deemed necessary, the chairperson shall schedule the review for the earliest feasible time.

*FOR EXTERNALLY FUNDED PROJECTS, INVESTIGATOR(S) ARE RESPONSIBLE FOR CONVEYING A COPY OF THIS DOCUMENT TO THE OFFICE OF SPONSORED PROGRAMS TO BE FORWARDED TO THE APPROPRIATE FUNDING AGENCY.

David Cockley, Dr.PH (Chairperson) 7/2/13 Date

***Your Close-Out Form must be submitted within 30 days of the project end date listed above.**

***If you wish to continue your study past the approved project end date above, you must submit an Extension Request Form, along with supporting information.*

Although the IRB office sends reminders, it is ultimately *your responsibility* to submit the continuing review report in a timely fashion to ensure there is no lapse in IRB approval.

Please return IRB Close-Out Form to the Office of Research Integrity: Campus Mail MSC 5738.

Consent to Participate in Research

Identification of Investigators & Purpose of Study

You are being asked to participate in a research study conducted by Beth Hulvey 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 student's completion of her dissertation in order to fulfill the graduation requirement of the Au.D. 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 to does not exceed OSHA limits.

Benefits

Potential benefit from participation in this study is a free hearing screening.

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: Beth Hulvey
Communication Sciences and Disorders
James Madison University
Email: hulveybi@dukes.jmu.edu

Advisor: Dr. Ayasakanta Rout
Communication Sciences and Disorders
Telephone: 540-568-3874; Email: routax@jmu.edu

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

Appendix B

List of nonsense syllables used as stimuli in this study

Consonant final

oth
ahf
ahs
off
osh
oof
oot
ooth
eet
eef
ok
ahv
ees
aht
op
eesh
oop
ahp
eep
ath
eek
ang
ot
oss
azz
oos
ahd
ahb
ash
eeth
ahm
ahk
oosh
ook
ahg

Consonant initial

dha
faa
laa
saa
cha
zaa
baa
daa
taa
raa
gaa
vaa
baa
maa
haa
sha
waa
daa
yaa
gaa
kaa