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Listening Induced Changes in Heart Rate Variability for a Speech-in-Noise Task

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Communication is a functional component of everyday life. The listening process, if disrupted, can have profound consequences on communication. Contributors to the inability to listen successfully include hearing loss, noisy environments, and cognitive declines (Fraser, Gagne, Alepins, & Dubois, 2010; Picou, Ricketts, & Hornsby, 2011). As one ages, the ability to listen functionally requires more effort (Picou et al., 2011). Listening effort can be defined as the attention, perceptual resources, and cognitive resources required to recognize and understand speech (Fraser et al., 2010; Gosselin & Gagne, 2011; Hicks & Tharpe, 2002).

In general, as the cognitive and sensory demands increase, listening effort increases as well. This cause and effect relationship happens based on the proposal that there is limited cognitive space. For example, an increase in competing noise of multi-talkers allocates more resources for listening and less for recalling conversational information, monitoring the environment around the listener, or following along with the conversation (Picou et al., 2011). Divided or focused attention is an executive function helping to define one's cognitive capacity during listening effort. Staal (2004) studied effects of attention on listening effort and concluded that the perceived main task is the greatest importance to the listener. Therefore, when background noise occurs during conversation, the ability to focus attention on the conversation while ignoring the noise will improve performance. In some cases, abnormal cognition will disrupt this focus of attention making it difficult to separate the conversation from the noise especially when that noise is in speech. Individuals with greater cognitive capacity should perform better in environments where the signal is degraded reflecting less listening effort.

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Importance of Listening Effort with Older Adults

Listening effort has become a relevant topic among older adults. The older population often reports listening in nosy situations as challenging and exhausting (Gosselin & Gagne, 2011). As adults age, their ability to listen and communicate often decreases because of declining sensory (hearing and vision) and cognitive abilities. This creates less overall input, reducing overall cognitive engagements. Simple tasks are subsequently more cognitively demanding. The declining of sensory inputs and cognitive abilities explain increased listening efforts in situations such as listening in background noise (Baltes & Lindenberger, 1997; Gosselin & Gagne, 2011). As previously mentioned, attention, speed of processing, and working memory are cognitive abilities affecting effort involved with listening comprehension (Akeryod, 2008). Gosselin and Gagne (2011) report that older adults use most of their resources to recognize speech in noise, resulting in fewer resources for other cognitive functions.

Clinicians typically measure only listening performance and not listening effort. Measurements of performance include accuracy of phonemes, syllables, words, and sentences as background noise increases (Gosselin & Gagne, 2011). However, when measuring how much effort is exerted among each individual, the results can significantly vary regardless of performance. Variables affecting listening effort include hearing status, level of background noise, accompanied speech cues, cognitive ability (Fraser et al., 2010). The importance of measuring listening effort is quite simple. Older adults who perform equally do not necessarily put in the same effort. Two older adults may have scored 90% accuracy during a speech recognition task, but one older adult could be mentally exhausted after the task, while the other older adult exerted substantially less effort. Greater performance in challenging environments might be at the expense of the older adult's cognitive resources, leaving fewer resources for recall, learning, and possibly leading to mental fatigue. Mental fatigue can occur when there is less room for interpreting and integrating information during conversation due to limited cognitive resources (Picou et al., 2011). Mackersie and Cones (2011) also concluded that it is important to measure listening effort because a clinician can find out if older adults experience communication related stress and increased listening effort in certain situations, regardless if performance indicates a difference in listening abilities.

Knowing how much effort a person requires for listening may help clinicians better understand each patient's functional skills as they will learn each client's abilities and their listening experiences. Listening effort measurements may also give clinicians a tool that is sensitive to cognitive changes in older adults. Most importantly, the ability to measure listening effort efficiently may help start the rehabilitative process with better goals, plans, and prognosis. (Gosselin & Gagne, 2011).

Effects of Listening Effort on Different Older Adult Populations

Normal hearing and normal cognition. Normal older aging adults can have seemingly normal hearing and cognition. Even without known cognitive declines or hearing loss, auditory processing often declines. On average, frequency and intensity discrimination, temporal resolution, and binaural processing all become poorer as we age. Declines in these areas reflect poor auditory processing and increased listening effort. The result of these declines are responsible for the number one complaint of older adults even with normal hearing and cognition, which is understanding speech in background noise (Tun, Willimas, Small, & Hafter, 2012).

In less demanding situations, regardless of these processes, older adults with normal hearing and cognition appear to hear as well as younger adults with normal hearing. It is in environments that the signal is degraded that older adults experience increased difficulty compared to younger adults. Comprehending speech is very demanding even for a younger adult in quiet. The auditory and cognitive system is capable of receiving speech at about 120-180 words per minute. Regardless of age, the listener cannot go back and review any material that they heard. The only way to comprehend what was heard is having the ability to attend to incoming speech and recognize all the phonemes, syntactic information in real time, while holding previous sentences or ideas in the listener's short term memory. Listening is a complex process, and when you add natural declines in hearing and cognition of older adults, it is much more demanding than it was originally (Tun et al., 2012). As a result, older adults require more processing resources to understand the speech in background noise.

Normal hearing and abnormal cognition. Older adults with normal hearing and abnormal cognition will have fewer resources for listening and subsequently greater difficulty in more demanding tasks. Normal hearing is important when listening in a complex environment; therefore, normal hearing will help older adults to a certain extent. Normal hearing enables those to hear passively and code speech correctly, but cognitive abilities influence what the brain decides to do with the auditory information (Pichora-Fuller, 2008).

Reed (2013) reported that more difficult listening conditions (background noise) require more effort from older adults with normal hearing and abnormal cognition to understand the message. These older adults have difficulty ignoring unwanted stimuli such as music or voices when trying to attend to the signal of interest. These challenging environments requiring effortful listening cause older adults to utilize the majority of their cognitive resources for listening and few are left for remembering and comprehending conversation. (Pichora-Fuller, 2008). Overall, listening, comprehending, and communicating require more cognitive abilities such as attention, memory, and language representation. When these abilities decline, as a result of age, listening effort increases, especially in degraded environments.

Hearing loss and normal cognition. With typical cognition, older adults with additional hearing loss, typically presbycusis, will also experience increased listening effort and listening fatigue. Difficulty hearing or even discriminating speech sounds requires extra effort. This extra effort the older adults with hearing impairment must expend to be successful during conversation or speech-in-noise tasks comes at a cost of using more cognitive resources. When more resources are allocated for hearing the message, less are available for understanding and recalling (Baltes & Lindenberger, 1997; McCoy et al., 2005). Increased listening effort due to a hearing loss will put more demands on cognitive resources needed for processing and memory. As a result, Reed (2013) concluded as older adults age, their maximum cognitive abilities will determine the success of performance and ease of listening.

It is likely that increased listening effort in the older adult population is a result of a high-frequency hearing loss and/or cognitive deficits affecting attention, working memory, processing speed, or the ability for one to use temporal fine structure cues (Akeroyd, 2008; Schneider, 2011). The consensus is that older adults and those with hearing loss often expend greater effort to maintain equivalent listening performance compared to younger adults and those with normal hearing.

Measurements of Listening Effort

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Listening effort can be measured either subjectively through estimated measures or objectively using dual-task paradigms or physiological measurements (Gosselin & Gagne, 2010; Hicks & Tharpe, 2002; Mackersie & Cones, 2011; Zekveld, Kramer, & Festen, 2010;).

Subjective measures. Currently, subjective measurements are clinically the only tool used to measure listening effort (Mackersie & Cones, 2011). They are also used to evaluate the relationship between perception and objective psychophysiological measures of listening effort. The use of questionnaires or self-reports measure the perception of ease of listening or the effort involved in listening (Gosselin & Gagne, 2011; Hicks & Tharpe, 2002). Often subjective measures are given immediately after a completed task and may include perceived accuracy of performance and the amount of effort expended during a task (mental demand). This allows the clinician to know how much the listener feels he or she is struggling compared to performance. Common forms of evaluations include simple rating scales of 1-100 or 1-10 to quantify effort. In addition, a scale such as the NASA Task Load Index can be used (Mackersie & Cones, 2011;Picou et al, 2011). There is often a poor correlation between performance and subjective scales as older adults often overestimate performance and underestimate effort, while younger adults tend to underestimate their performance and overestimate effort. As a result, research has moved toward an objective way to measure listening effort looking at dual-task paradigms and electrophysiological measures.

Objective measures.

Dual-task paradigm. Dual task measures quantify listening effort objectively. A dual-task paradigm involves a primary auditory task and a secondary task comprising of another sensory modality. Both tasks are performed separately and then concurrently (Gosselin & Gagne, 2011; Hicks & Tharpe, 2002). During the primary or secondary task performed separately, the listener can devote all attention to complete the task to their full potential. However, performing both tasks together causes divided attention resulting in increased listening effort. The dual task paradigm assumes that the cognitive system has a limited capacity of resources (Gosselin & Gagne, 2011). The primary task uses the mental capacity needed to complete the task. The secondary task uses the spare mental capacity. Adding background noise to a work recognition task will decrease performance of the secondary task. The amount by which the secondary task decreases is a measure of listening effort (Hicks & Tharpe, 2002). Mackersie and Cones (2011) report there is often little or no change in the primary task when observing decrements on the secondary task.

Commonly, the primary task is a word recognition test that will be simultaneously presented with a visual task as the secondary task. For example, as the listener is repeating sentences in varying signal-to-noise ratios (SNR), they are also pushing a button every time the letter “C” is presented on the screen in front of them. As the SNR is increased, the response time of pushing the button for the letter may increase. The difference in response time for the isolated and combined condition defines listening effort. Even if the listener succeeds on both tasks, response times may get slower with increasing noise (Gosselin & Gagne, 2011). Clinically, this type of objective measurement is not practical as it is time-consuming and can be difficult for some adults and children to complete due to trouble multi-tasking rather than listening effort. .

Psychophysiological measures. A second type of objective measure of listening effort is electrophysiological measurements such as skin conductance, heart rate variability (HRV), electromyography (EMG), and pupil dilation. Stress may be the cause of increased listening effort. The human stress response includes the autonomic nervous system (ANS) and the endocrine system. This activation of the ANS from exposure to mental stress can result in an increase in activity of the sympathetic branch accompanied by decreased activity of the parasympathetic branch (Staal, 2004). The arousal of the sympathetic nervous system could result in these physiological changes. These changes are measured through pupil dilation, (EMG), skin conductance, breathing rate, heart rate, and HRV (Andreassi, 2007). These measures of ANS activity in response to an auditory task may be a good tool for quantifying listening effort (Makersie & Cones, 2011).

Pupil dilation. Recent studies conclude pupil dilation is a sensitive tool for measuring listening effort (Staal, 2004; Zekveld et al., 2010). Increased pupil dilation has been associated with increased mental effort and poor speech intelligibility. For example, increased pupil dilation has been observed with increased noise levels during a word recognition task and decreased performance. As the cognitive load increases, pupil dilation increases (Kahneman, 1973; Picou et al., 2011; Zekveld et al., 2010). Typically, measurements of pupil dilation are taken with a pupillometer, an infrared video system before and after the speech task is heard by the listener (Zekveld et al., 2010). Unfortunately, this measurement is not practical as equipment is expensive for clinical use.

Electromyograpic measures (EMG). EMG measurements are currently another form of physiological measurements of listening effort. Measuring muscle activity involves the frontalis muscle located on the forehead. Electrodes are placed on the listener's forehead so that the positive and negative electrodes are above the right and left eyes. The clinician will place the ground electrode in the middle of the forehead in line with the others. Often there is an increase in EMG activity associated with an increase in task demand. However, EMG activity may be less sensitivity than skin conductance (Mackersie & Cones, 2011).

Skin conductance. Skin conductance is a common physiological measurement used when evaluating listening effort. These measurements are recorded from two surface electrodes placed two inches apart on the palm of the listener's hand. Skin conductance measures the moisture level of the skin reflecting activation of sweat glands during a demanding task. Often, there is an increase in skin conductance associated with an increase in task demand. Research has used skin conductance in response to a dichotic listening task and results do show skin conductance can be a sensitive measure of listening effort (Mackersie & Cones, 2011). However, as skin conductance can be a sensitive measure, it can also be unreliable as skin conductance is sensitive to subject and recording conditions and not measureable in up to 25% of individuals (Braithwaite, Watson, Jones, and & Rowe, 2015).

Heart rate variability (HRV). There is recent interest in using HRV as an objective measure of listening effort, specifically for speech-in-noise tasks for routine audiology clinic. (Mackersie, MacPhee, & Heldt, 2015). HRV has previously been used in the field of cardiology and psychology as a stress response indicator and an assessment for cognitive load. HRV is defined as the variation in time between heartbeats and has been used as a physiological measure of listening effort. HRV is thought to be related to physical and mental demands as well as an autonomic nervous system function (Aasman, Mulder, & Mulder, 1987; Garde, Lauresen, Jorgensen, & Jensen, 2002; Hansen, Johnsen, & Thayer, 2003; Hjortskov et al., 2004).

In addition to HRV, breathing rate and heart rate are often measured and closely related to each other. Typically, respiration movements are accompanied by fluctuations of pulse. As a result, heart rate increases with inhalation and decreases with exhalation. Normal rhythm of heart rate is controlled by processes modulated by innervations from the sympathetic and parasympathetic divisions of the autonomic nervous system (ANS). The parasympathetic system slows the heart rate and the sympathetic system speeds up the heart rate. As a result, stress caused by an increase in task demands increases heart rate and decreases HRV, which reflects a response from the sympathetic system. On the contrary, when stress is low, HRV increases reflecting the parasympathetic nervous system. During low stress vagal inputs from stretch receptors in the lungs and vascular system cause heart rate to vary widely as heart rate is in synch with breathing. (Bernston et al., 1997; Task Force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). It is assumed that when any given listener is performing a demanding auditory task, HRV will decrease as a result of increasing listening effort (Kahneman, 1973).

Seeman and Sims (2015) used HRV to measure listening effort using diotic-dichotic listening tasks and Speech-in-Noise Test in varying fixed SNR conditions for young adults with normal hearing. The study concluded HRV is sensitive to task complexity as HRV was reduced for the most challenging test conditions compared to more favorable listening conditions. Since talking can increase breathing rate and heart rate, while decreasing HRV (Bernardi et al., 2000), it is possible verbal responses to the speech-in-noise tasks obtained in Seeman and Sims (2015) study may have influenced HRV measures obtained. Use of HRV as an objective measure of listening effort during a speech-in-noise task not involving a verbal response would eliminate possible artifact in HRV caused by talking. In addition, a fixed performance level instead of a fixed SNR would control for differences in HRV related to any individual differences in performance.

Mackersie, PacPhee, & Heldt (2015) also support the use of HRV as an objective measure of listening effort. The study included adults with and without hearing loss. The speech-in-noise task was performed at equal performance levels and results concluded stress was greater for those with hearing loss compared to those with normal hearing. Specifically, decreased HRV was observed for only the adults with hearing loss during the lowest SNR conditions. The results are consistent with the proposal that greater stress reflects the autonomic nervous system activation and the use of more cognitive resources to maintain the speech recognition performance. The study used a 5-talker babble with two of the five talkers reversed to reduce intelligibility. The reduced intelligibility of the masker may have resulted in less listening effort from the normal hearing listeners. Maskers closer to speech-like sounds make understanding more difficult because more cognitive resources are required as explained by the concept of informational masking. It is of interest to further research effects of different noise types to observe if masker type results in any changes in HRV sensitivity.

HRV can be quantified by various temporal and spectral analyses of heart-rate recordings (Boonnithi & Phongsuhap, 2011; Task Force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). Temporal estimates of HRV include variance analyses of heart rate. Two examples include Standard Deviation of the R-to-R (SDRR) and the Root Mean Sum of Squared Differences (RMSSD), and SDNN (normalized SDRR) (Boonnithi & Phongsuhap, 2011; Dorman et al., 2012). SDNN as a temporal measure tends to be more sensitive to low frequency changes and requires a longer sample for an accurate estimate, where spectral measures are not as sensitive to duration (Bernston et al., 1999). Spectral analyses quantify oscillations in heart rate using a fast Fourier transform of two specific frequency bands, low frequency (LF) and high frequency (HF), responding to the sympathetic and parasympathetic autonomic responses. The LF band is thought to reflect both parasympathetic and sympathetic inputs, which measures stress directly. The HF band is thought to reflect parasympathetic inputs only, which become higher in times of rest, which indirectly measures stress (Task Force of the Eureopean Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). Mackersie et al, (2015) analyzed the HRV data using HF component and found significant differences across SNR for their hearing impaired participants, which may be indirectly measuring stress. The normal hearing participants had similar HF measures regardless of SNR. The LF component, HF component, and SDNN is of further interest when looking at effectiveness of HRV as an objective measure for listening effort during speech-perception tasks.

Rationale for the Current Study

The primary purpose of the current study is to further refine HRV as an objective measure of listening effort. Currently, it is unclear if changes in breathing as a result of vocalizing responses affect HRV patterns for sentence-in-noise conditions. Another purpose is to investigate the sensitivity of the different temporal and spectral measures of HRV. A third purpose of the current study is to compare different masker types to determine the most sensitive measure to use with HRV objective measures of listening effort. Lastly, the study will look to find a relationship between individual differences in listening effort and differences in measures of cognition, specifically working memory capacity with a linguistic component.

Method

Participants

Sixteen participants (5 men and 11 women) with normal hearing, 18- 38 years of age (mean age: 20.9 years), were recruited. Subjects were not excluded for any other reason aside from age and degree of hearing loss. A power analyses on pilot data has determined that a sample size of 13 to14 participants provided adequate power ($1-\beta > .80$) for HRV.

Normal hearing was assessed via air conduction pure-tone threshold search. Hearing was considered to be normal if air conduction pure-tone thresholds from 500 Hz through 8000 Hz were less than 25 dB HL. Each participant completed a hearing screening, two cognitive tasks, and the primary listening task combined with psychophysiological measures of listening effort.

Participants were recruited through flyers posted in the Illinois State University Communication Sciences and Disorders department building in Fairchild Hall. All participants were compensated for their time and the entirety of study was completed at Illinois State University Hearing Research Lab. This project was approved by the Institutional Review Board at Illinois State University. The screenings, listening tasks, and psychophysiological measures were completed in a single 2 hour session. Data from one participant was excluded due to excessive movement artifacts in the heart rate recordings.

Materials and Procedure

Cognitive tasks.

RSPAN. The Reading Span Test (RSPAN) was used to assess working memory using a linguistic component. Previously working memory tasks using digit span testing was studied to determine if cognitive differences account for any individual differences in listening effort. Results were not significant, however, it was suggested to try assessing working memory using a linguistic component as it is more closely related to auditory experiences. Ronnberg et al., 2013 reported that working memory capacity is a crucial ability when it comes to understanding language as it is important to be able to store and processing auditory and visual information simultaneously. The study reported that digit span as an assessment for working memory capacity taps into short term memory and is not as good of a predictor of language comprehension, which is important to assess when researching adults with hearing loss and listening effort. For the current study, RSPAN was administered using PowerPoint on a desktop computer situated approximately two feet in front of the participant at eye level. The sentences originated from the Revised Speech Perception in Noise (RSPIN) test sentences. The participant was given two sets of 21 low context sentences presented in blocks varying from one to six sentences in length. Each sentence was visually presented for five seconds before the next sentence of the block was presented. Participants were asked to read aloud each sentence individually and recall the final word of each sentence. The same procedure was repeated with two sets of 21 high context sentences. Each participant completed four lists total including two high context lists and two low context lists. The order of list presentation was randomized for each participant and a practice list was included before starting the task. Overall accuracy and the maximum successful set size of each list were recorded. However, Ronnberg et al., 2013 suggest that accuracy or total correct is a more sensitive predictor than maximum set size.

Stroop. The Stoop test was administered to assess selective attention. The task was performed on a laptop computer using SuperLab software. The text on the computer screen consisted of 100 random presentations of color words (red, yellow, blue, and green). The participants were placed approximately one foot in front of the computer screen and were asked to press the button on the response pad that matches the color of the word seen on the computer screen. The response pad was designed to have a yellow, blue, red, and green button. For example, if the word blue in green font was presented, the participant would have pressed the green button on the response pad. If the participant responded incorrectly, the word wrong would appear before the next presentation. A brief practice list consisting of 15 random presentations were completed prior to the task. Accuracy and decision speed comparing congruent and non-congruent presentations were recorded.

Listening task.

California Consonant Test. The CCT is a closed set speech perception test consisting of 100 single Consonant-Vowel-Consonant words, and was chosen as it allows for non-verbal or written responses. In addition, the test is considered to be relatively easy to score for adaptive signal-to-noise ratio (SNR) procedures. Adaptive SNR procedures ensure equal performance across participants. Mackersie and Cones (2015) suggest without equal performance, a condition that is too difficult can result in lower task engagement and lower psychophysiological reactivity.

Three word lists in three different noise conditions were completed with test and condition order determined by a Latin-square design. These three word lists were created from the original 100 CCT stimuli presentations. List one and two were comprised of the first and last 50 stimuli, respectfully. The third list was created by a randomization of the last 50 stimuli of the original CCT list. Each list was paired with a 4-talker babble and speech shaped noise (SSN) and saved as a wave file that was routed through a two channel audiometer (Madsen Orbiter 922, GN Otometrics, Taastrup, Denmark) presented binaurally at 60 dB HL through insert earphones to participants seated in a sound-attenuating booth. The level of the word stimuli was selected to ensure adequate audibility of the word lists. Each condition was approximately 6 minutes long, which was equal length to rest periods.

The noise level paired with each of the three word list was determined by a fixed performance level. Each participant completed two lists with the 4-talker babble at an individually customized SNR equaling a performance level of 71.9% and 50%. The third list was completed with the SSN at 71.9%. This customized level used an adaptive threshold search procedure. This procedure fixed the speech level at 60 dB HL while the noise level was adjusted from a starting level of 60 dB HL. For the 71.9% performance level, the noise was increased by

2 dB for every two consecutive correct responses and decreased by 1 dB for every incorrect response (a 2 up-1 down procedure). The third condition used four-talker babble and the stimuli were presented at an individually customized SNR equaling a performance level of approximately 50%. The noise was increased by 1 dB for every single correct response and decreased by 1 dB for every incorrect response (a 1 up-1 down procedure). The customized SNR provided an opportunity to examine the listening effort for the different noise types at the same level of intelligibility and it controlled for differences in effort attributed to by differences in performance.

The participant was instructed to sit in a chair in front of a desktop computer, which was set up as dual monitors where the second monitor was placed outside of the sound booth to be monitored by the examiner. All three conditions (babble 71.9%, babble 50%, and SSN 71.9%) were completed. The closed set of choices from the CCT word lists for each presentation was displayed in a word document on the computer monitor directly in front of the patient. The participant was instructed to check the box using the mouse next to the choice that matched the word they heard through the insert earphones. The participant's answers were viewed by the examiner on the secondary monitor and manually graded as correct or incorrect. To assess performance, percent correct scores were calculated and individual SNR were recorded.

General procedure

Subjective measures of listening effort. Subjective ratings of effort and perceived performance were obtained after each of the three listening conditions. These measures were recorded to compare to objective measures of listening effort and performance obtained in the study. The participants were asked to rate the task difficulty and performance level on a 100 point scale. The first question was phrased, "Please rate the level of difficulty you had with this task on a scale of

0-100. Zero being very, very easy, 100 being very, very difficult." The participants were asked a second question regarding performance. The question was phrased "Please rate your level of performance on a scale of 0-100. Zero being you got 0% correct, 100 being you got 100% correct." The participants were asks to say aloud the rating and the score was recorded.

Psychophysiological recordings and analyses. Psychophysiological responses, including heart rate, breathing rate, and HRV were acquired using the I-330 C2+ six-channel biofeedback system by J & J Engineering (Spokane, WA). HR measures used a three-electrode configuration, with placement on both sides of the abdomen between the ribs and the hip for the negative (left) and positive (right) leads and just below the right clavicle for the ground electrode. The skin of each particpant was cleaned with alcohol wipes and gauze pads prior to each electrode placement and impedance was check beforing beginning the session. Breathing rate was measured with a magnetic elastic belt sensor placed around the abdomen over the participant's clothing at the level of the diaphragm.

Psychophysiological data were obtained across the three 6 minute listening conditions and for six minutes following the task as a post-test baseline. This resulted in equal sample length for both the baseline and task intervals. Samples of unequal length may bias temporal estimates of HRV and it is known that longer samples can have greater variance than shorter samples (Berntson et al., 1997; Task Force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). Analyses of pilot data established that SDNN had greater sensitivity to task complexity and SNR compared with root-mean-square successive difference, which is a commonly use temporal measure of HRV. As a result, SDNN will be used to analyze temporal measurements of HRV. Raw heart rate data were checked and corrected for skipped or double beats and movement artifacts prior to any temporal analyses.

Double and skipped beats were visually identified in the raw data as being different from surrounding adjacent beats by a factor of 2. These were multiplied or divided by 2 to correct or normalize prior to data analyses. Movement artifacts presented themselves as data points with an interburst interval of 300 ms or shorter (≥200 beats/min; Mulder, 1992). These identified data points were removed prior to analysis. Movement artifacts were only a significant problem in one participant, who was excluded from the study.

Data analyses.

Statistical analyses, including a repeated measures analysis of variance (RMANOVA) and Spearman rho correlations were conducted with the SPSS statistical package (Version 20;IBM Corp., Armonk, NY). Comparison were made for heart rate, breathing rate, and heart rate variability across SNR and noise type. For analyses, difference scores for HRV (LF and HF bands) and SDNN were calculated by subtracting the average for the task from the baseline (ΔLF, ΔHF, and ΔSDNN). For convenience, this kept all positive psychophysiological responses positive. Pairwise analyses with a Bonferroni correction for multiple comparisons were made for significant RMANOVA main effects for HRV (LF, ΔLF, HF, ΔHF, SDNN, ΔSDNN) across SNR and noise type (Babble 71.9%, Babble 50%, SSN 71.9%). Spearman rho correlations were made with the subjective estimates of listening effort, cognitive data, and psychophysiological estimates. Results for the correlations were considered with $\alpha = .05/3 = .02$ as a correction for multiple comparisons.

Results

CCT Performance

Average percent correct scores were all near projected fixed performance levels of 71.9% and 50% for each of the three listening condition. The average SNR for babble at 50% fixed performance level was -6 dB HL, 1.2 dB HL for babble 71%, and 4.5 dB HL for SSN 71.%.

Heart Rate and Breathing Rate.

As shown in Figure 1 and Figure 2, no differences were observed for both heart rate and breathing rate among the different noise types.

Figure 1. Average heart rate (HR) for three listening condition and baseline

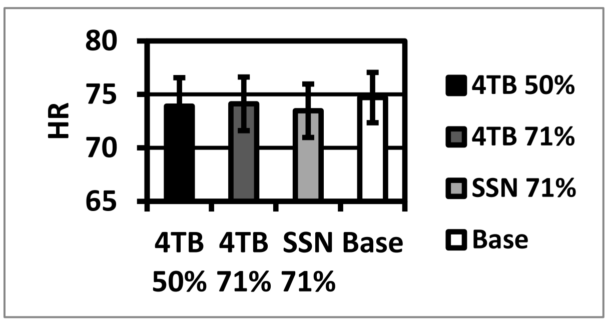
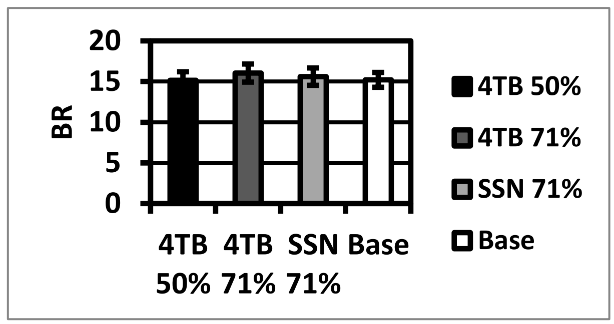


Figure 2. Average breathing rate (BR) for three listening condition and baseline.



ΔLF, ΔHF, and ΔSDNN Measures Across Noise Type

As shown in Figure 3, SDNN, LF band and HF band components of HRV are presenting with smaller differences from baseline for SSN conditions and larger differences from baseline with babble conditions. This large difference from baseline seen with babble conditions for LF, HF, and SDNN are considered statistically significant differences, $F(3, 45) = 2.897$, $p < .05$; $F(3, 45) = 8.231$, $p < .001$; $F(3, 45) = 6.524$, $p < .01$ (see Table 2). Figure 4 represents a common trend of ΔLF, ΔHF, and ΔSDNN, which shows that when these measures are subtracted from the baseline, the largest difference is seen with babble conditions, not SSN. However, these larger differences are not statistically significant ($p>.05$, see Table 2). Post hoc Bonferroni-corrected pairwise comparisons indicated there was a significant difference between the babble condition and baseline measures. Results also indicated the babble conditions were not significantly different from each other and SSN was not significantly different from baseline or from babble conditions.

Figure 3. Average HRV measurements for all three listening conditions and baseline measurements. Results reveal statistical significant differences between measures for babble conditions compared to baseline.

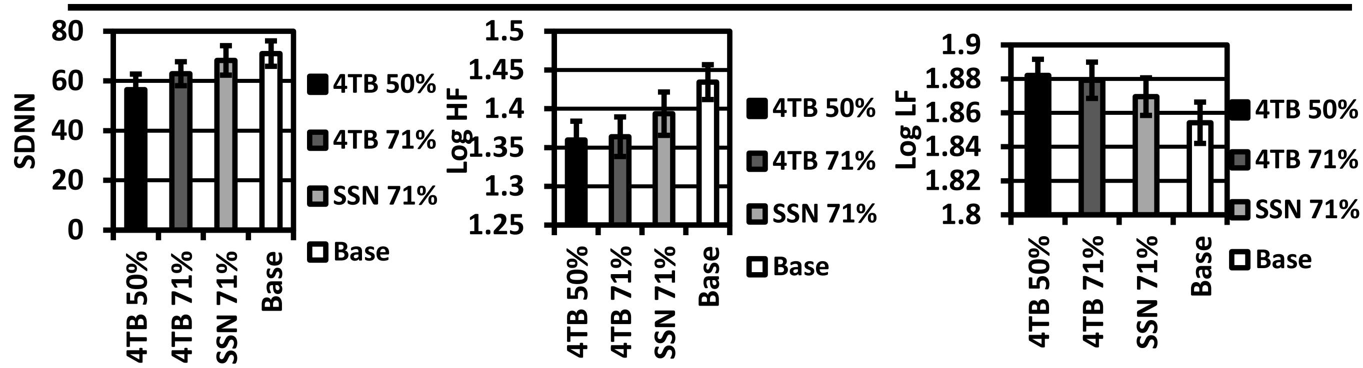
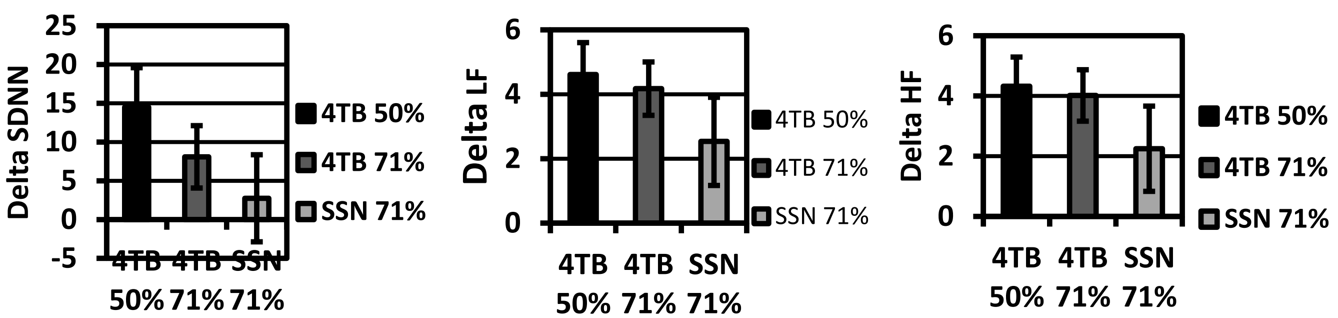


Figure 4. Average differences in HRV measures from baseline across three listening conditions. All three measurements display a larger difference for the babble condition compared with SSN condition.



Subjective Measures.

Table 1 shows the average subjective listening effort measure increased with the babble 50% condition compared to SSN and babble 71.9% condition. This is expected as a fixed performance SNR level of 50% is a harder task than a 71.9% fixed performance SNR level. RMANOVA results for subjective effort presented with ___________________ (see Table 2).

Table 1. Descriptive statistics for HRV and subjective listening effort measures across conditions.

	Task Complexity					
	SSN 71.9%		**Babble 71.9%**		**Babble 50%**	
Measure	**M**	**SD**	**M**	**SD**	**M**	**SD**
SDNN	68.25	23.71	62.91	19.27	56.49	25.07
ΔSDNN	2.74	22.45	8.08	16.08	14.50	20.33
HF	1.39	.111	1.36	0.10	1.35	0.09
ΔHF	2.24	5.66	4.01	3.41	4.32	3.87
LF	1.86	0.04	1.87	0.04	1.88	0.03
ΔLF	2.53	5.47	4.17	3.31	4.61	3.96
Sub Effort	57.5	12.11	54.06	20.91	68.25	18.00
Sub Performance	62.5	14.71	68.12	14.81	54.68	16.47

Table 2. Repeated measures analysis of variance (RMANOVA) statistics for subjective effort and performance measures and measures of HRV including the differences in baseline for HRV

Measure	**df**	**F**	**P**	**Partial η^2**
LF	(3, 45)	8.23	**<.001**	.35
ΔLF	(2, 30)	2.43	> .05	.14
HF	(3, 45)	6.52	< **.01**	.30
ΔHF	(2, 30)	2.61	> .05	.14
SDNN	(3, 45)	2.89	< **.05**	.16
ΔSDNN	(2, 30)	2.16	> .05	.12
Subjective Effort				
Subjective Performance				

Cognitive measures.

Table 3 shows the average accuracy for the stoop test was 99%. On average, reaction times to the congruent presentations were faster than noncongruent presentations as would be expected since the color word and the font color matched. Also shown in Table 3, the average RSPAN accuracy determined by number of words correct in a 21 item list was approximately 15 (71%).

Table 3. Descriptive statistics for cognitive tasks (Stroop and RSPAN) including Stroop accuracy and reaction times for congruent and noncongruent presentations and RSPAN accuracy.

Cognitive Measures		
Measure	**M**	**SD**
Stroop		
Accuracy (%)	99.00	0.01
Congruent (ms)	1097.31	56.08
Noncongruent (ms)	1316.05	74.05
RSPAN		
Accuracy	15.64	1.66

Correlation Analysis: Psychophysiological, SNR Conditions, Subjective Measures, and Cognitive Tasks

No significant Spearman rho correlations were found for the either cognitive measures or Δ SDNN. However, correlations were significant between both SNR conditions and subjective measures with spectral HRV measures, ΔHF and ΔLF (see Table 4).

Table 4. Spearman rho correlations for cognitive tasks, subjective listening effort ratings, SNR, and psychophysiological measures.

Spearman's Rho		RSPAN	STROOP	SNR	SUB	∆SDNN	∆HF	∆LF
RSPAN	Correlation Coefficient	1.000	-.189	-.075	.046	-.265	.047	.053
	Sig. (2-tailed)	.	.484	.781	.865	.320	.862	.845
	N	16	16	16	16	16	16	16
STROOP	Correlation Coefficient	-.189	1.000	.016	.209	.241	-.315	-.238
	Sig. (2-tailed)	.484	.	.952	.437	.368	.235	.374
	N	16	16	16	16	16	16	16
SNR	Correlation Coefficient	-.075	.016	1.000	-.309	-.012	**.654****	**.610***
	Sig. (2-tailed)	.781	.952	.	.244	.965	.006	.012
	N	16	16	16	16	16	16	16
SUB	Correlation Coefficient	.046	.209	-.309	1.000	.046	**-.612***	**-.573***
	Sig. (2-tailed)	.865	.437	.244	.	.866	.012	.020
	N	16	16	16	16	16	16	16
DELTA SDNN	Correlation Coefficient	-.265	.241	-.012	.046	1.000	-.044	-.015
	Sig. (2-tailed)	.320	.368	.965	.866	.	.871	.957
	N	16	16	16	16	16	16	16
DELTA HF	Correlation Coefficient	.047	-.315	**.654****	**-.612***	-.044	1.000	**.956****
	Sig. (2-tailed)	.862	.235	.006	.012	.871	.	.000
	N	16	16	16	16	16	16	16
DELTA LF	Correlation Coefficient	.053	-.238	**.610***	**-.573***	-.015	**.956****	1.000
	Sig. (2-tailed)	.845	.374	.012	.020	.957	.000	.
	N	16	16	16	16	16	16	16

Discussion

The intent of the study was to further refine HRV as a sensitive and objective measure of listening effort. The study eliminated verbal responses to prevent the influence breathing can have on heart rate. The study also used two different noise types to assess the most sensitive masker when assessing listening effort with HRV measures. Temporal and spectral HRV measures were used to evaluate the most sensitive measures when assessing listening effort.

Lastly, cognitive tasks were performed to see if differences in cognition influence individual differences in listening effort.

HRV

In previous work by Seeman and Sims (2015), HRV appeared to be sensitive to both task complexity for diotic-dichotic listening tasks and SNR for a speech-in-noise task. As studied by Bernardi, et al., (2000), talking during a speech-in-noise task can increase breathing rate and heart rate, resulting in a decrease in HRV. Due to the influence talking can have on breathing, heart rate, and HRV, the CCT was used in the current study to assess if HRV remains a sensitive measure of listening effort without the participant verbally responding to the auditory task. Results of the current study support the use HRV as the measure was sensitive to speech-in-noise testing with a 4-talker babble masker. The pattern for each HRV measure used in the study reflected greater stress in the babble 50% condition compared to baseline, however, it should be noted that there was no statistical difference between fixed performance levels of 50% and 71.9% for babble (see Figure 3 and 4). It was expected that increased effort would have been observed in the babble 50% compared to both babble and SSN at 71.9% fixed performance level. This lack of statistical significant differences between the two fixed performance levels may have been contributed by a younger adult population with normal hearing. With this population, a wider range of fixed performance levels may have been warranted to expect significant differences in stress and HRV. Future studies may see statistical differences when assessing an older adult or hearing impaired population with the same fixed performance levels.

Noise Type

The stimulus presentation may effect HRV estimates of listening effort. The current study used both an energetic (SSN) and informational masker (4-talker babble) to compare effects of maskers on HRV estimates of listening effort. Results suggest that the traditional 4-talker babble elicits the most stress during the speech-in-noise task as differences between babble conditions and baseline were statistically significant. The difference between SSN and baseline was not statistically significant, neither was SSN from babble conditions (see Figure 4). This statistical significance of babble conditions is expected as informational maskers are closer to speech like sounds, therefore requiring more cognitive resources when attempting a speech-in-noise task, resulting in increased stress and decrease HRV. Previously stated, Mackersie et al. (2015) used a 5-talker babble with two reversed talkers to reduce intelligibility. This reduced intelligibility creates a masker that is less speech like, therefore may have contributed to the study's results showing no difference for HRV across SNR conditions for normal hearing participants. To the contrary, Dorman et al. (2013) used a multi-talker presentation, which is a more intelligible masker. This type of masker in a speech-in-noise task may have increased stress and decreased HRV resulting in statistically significant results. The current study and Dorman et al. (2013) suggest an informational masker that will increase intelligibility such as a 4-talker babble or multi-talker will have positive effects on HRV sensitivity to listening effort in future studies.

Temporal and Spectral Components of HRV

The current study evaluated temporal and spectral components of HRV to understand which measures are most sensitive to listening effort. The study suggests both temporal and spectral components are sensitive to listening effort, specifically SDNN and the LF and HF band measures. All three of these measures reflected statistically significant differences in HRV as expected with speech-in-noise tasks with a babble masker. The HF band measure was studied by Mackersie et al. (2015) and results are consistent as she reported the measure can indirectly reflect stress as seen in participants with hearing loss, but she did not find this to be true for participants with normal hearing. The difference between the two studies may have been the type of masker Mackerise used as mentioned earlier or the monaural presentation of speech stimuli compared to the current study, which used a binaural presentation. As mentioned earlier, the HF band results in a decrease in power under stress conditions because it is associated with parasympathetic inputs, which results in the HF band increasing with rest. The current study found that normal hearing listeners had significantly more power in the HF band at baseline compared to babble conditions. However, LF band measures are of interest because they directly reflect stress. The LF band is greater under stress because it is associated primarily with the sympathetic system (fight or flight response). Again, the limitation of the measure is that it requires a longer sample for accurate estimation, which may be why some studies have not sued the measure as part of their design. The current study was able to support the use of the LF band as significantly greater power in the LF band under babble conditions compared to baseline. The current study also used SDNN as a temporal measure of HRV, which is sensitive to the duration of the recording. As a result, both the rest periods and listening tasks were 6 mintues each. Dorman et al. (2013) used a temporal measure, SDRR to examine HRV as an objective measure of listening effort. The current study and Dorman et al. (2013) report consistent results in that both temporal measures, SDRR and SDNN, found to have significant statistical changes from baseline for babble conditions.

Another interesting finding with the spectral analyses, LF and HF bands, was the significant correlation found between ΔHF and ΔLF and SNR. On average, the hardest listening condition, babble 50%, had an SNR of -6 dB HL, the second hardest listening condition, babble 71.9% had an SNR of 1.2 dB HL, and the easiest listening condition, SSN 71.9%, had an SNR of 4.5 dB HL. So, the spectral analyses were sensitive to these changes in SNR as a reflection of listening effort. Increased listening effort as expected by poor SNR conditions, resulted in changes in the ΔHF and ΔLF bands.

Cognitive Measures and Listening Effort

Cognitive measures assessing selective attention (Stroop) and working memory capacity (RSPAN) were completed to evaluate if differences in cognition account for induvial differences in listening effort. Typically individual perform better on speech perception testing with better working memory and selective attention. Spearman rho correlations determined no significant correlation between the subjective measures and differences in HRV measures or SNR. Perhaps there was not enough variance in cognitive abilities of the young adult population to adequately assess the relationship between cognitive ability and listening effort in the current study.

Subjective Measures

Subjective measures are often criticized as being too variable. Results from the current study showed that on average, perceived effort displayed greater scores for the hardest listening condition of a 50% fixed performance level speech-in-noise task. The other two listening conditions were set at a 71.9% fixed performance level and the perceived effort scores were similar with less effort perceived compared to the 50% fixed performance level. (see Table 1). Zekveld et al., 2010 report individuals tend to estimate perceived effort based on performance or task complexity and not actual listening effort. As a result, the current study also evaluated perceived performance scores and on average, the participants perceived their performance level near the actual fixed level of the listening condition. For example, for the 50% babble fixed performance listening condition, participants on average perceived their performance to be 54%. Results of the current study do not show much variability in subjective listening effort and participants seemed to differentiate between perceived effort and performance level.

Another interesting result of the study was that the subjective measures correlated with the objective measures of listening effort, which is not a common expectation (Gosselin & Gagne, 2010). Specifically, the study found a significant correlation between subjective measures and ΔHF and ΔLF bands. This significant correlation may indicate the potential for consistency between subjective and objective measures of listening effort.

Study Limitations and Future Directions

It is possible that the fixed performance levels of the listening conditions were too similar and not accurately reflecting the sensitivity of HRV as the conditions were not reflecting large differences in listening effort from the young adult, normal hearing population. Also, a young adult, normal hearing population may have not had differences in cognition to assess its influence on individual differences in listening effort. Future studies should include an older adult population to assess the impact of cognitive differences on listening effort. Further studies may also include populations of interest including children and those with hearing loss.

Conclusion

HRV remains a sensitive objective measure of listening effort despite using a nonverbal listening task. Spectral and temporal measures of HRV including SDNN, HF band, and LF band measures are most sensitive to listening effort as the measures reflect changes in power as a result of stress. Specifically, ΔHF and ΔLF were found to be sensitive to SNR changes. Results suggests that HRV objective measures of listening effort are most sensitive to speech-in-noise tasks using an informational maskers such as a 4-talker babble. Maskers closer to speech-like sounds increase intelligibility, which increases task difficulty and is likely to be sensitive to HRV measure as a result of stress. Further research will need to be completed to determine if HRV measures can adequately assess individual differences in listening effort across the older adult population.

References

Aasman, J., Mulder, G., & Mulder, L. (1987). Operator effort and the measurement of heart-rate variability. *Human Factor*: *The Journal of the Human Factors and Ergonomics Society*, *29(2)*, 161-170.

Akeroyd, M. A. (2008). Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults. *International Journal of Audiology*, *47*(Suppl. 2), S53–S71.

Andreassi, J.L. (2007). Psychophysiology: Human behavior and physiological response (5th ed.) Mahwah, NJ: Lawrence Erlbaum Associates.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life.. *Psychology & Aging*, *12*(1), 12.

Bernardi, L., Wdowczyk-Szulc, J., Valenti, C., Castoldi, S., Passino, C., Spadacini, G., & Sleight, P. (2000). Effects of controlled breathing, mental activity and mental stress with or without verbalization on heart rate variability. Journal of the American College of Cardiology, 35, 1462–1469.

Berntson, G. G., Bigger, J. T.Jr., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., … Van der Molen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. Psychophysiology, 34, 623–648.

Boonnithi, S., & Phongsuhap, S. (2011). Comparison of heart rate variability measures for mental stress detection. Computing in Cardiology, 38, 85–88.

Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2015). A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments via the Biopac MP36R & AcqKnowledge software (Technical Report; Revised

Version 2.0). Birmingham, United Kingdom: Selective Attention & Awareness Laboratory, Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham.

Dorman, M. F., Spahr, A., Gifford, R. H., Cook, S., Zhang, T., Loiselle, L., … Schramm, D. (2012). Current research with cochlear implants at Arizona State University. Journal of the American Academy of Audiology, 23, 385–395.

Fraser, S., Gagné, J.-P., Alepins, M., & Dubois, P. (2010). Evaluating the effort expended to understand speech in noise using a dual-task paradigm: The effects of providing visual speech cues. Journal of Speech, Language, and Hearing Research, 53, 18–33. [Article]

Garde, A. H., Laursen, B., Jørgensen, A. H., & Jensen, B. R. (2002). Effects of mental and physical demands on heart rate variability during computer work. European Journal of Applied Physiology, 87, 456–461.

Gosselin, P. A., & Gagné, J.-P. (2011). Older adults expend more listening effort than young adults recognizing speech in noise. Journal of Speech, Language, and Hearing Research, 54, 944–958.

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. International Journal of Psychophysiology, 48, 263–274.

Hicks, C. B., & Tharpe, A. M. (2002). Listening effort and fatigue in school-age children with and without hearing loss. Journal of Speech, Language, and Hearing Research, 45, 573–584.

Hjortskov, N., Rissén, D., Blangsted, A. K., Fallentin, N., Lundberg, U., & Søgaard, K. (2004). The effect of mental stress on heart rate variability and blood pressure during computer work. European Journal of Applied Physiology, 92, 84–89.

Kahneman, D. (1973). Attention and Effort. Englewood Cliffs, N.J.:Prentice-Hall.

Mackersie, C. L., & Cones, H. (2011). Subjective and psychophysiological indices of listening effort in a competing-talker task. Journal of the American Academy of Audiology, 22, 113–122.

Mackersie, C. L., MacPhee, I. X., & Heldt, E. W. (2015). Effects of hearing loss on heart rate variability and skin conductance measured during sentence recognition in noise. Ear and Hearing, 36, 145–154.

McCoy, S. L., Tun, P. A., Cox, L. C., Colangelo, M., Stewart, R. A., & Wingfield, A. (2005). Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech. The Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 58(A), 22–33.

Mulder, L. J. M. (1992). Measurement and analysis methods of heart rate and respiration for use in applied environments. Biological Psychology, 34, 205–236.

Pichora-Fuller, M. (2008). Audition and cognition: Where lab meets clinic. *ASHA Leader, 13*(10), 14-17.

Picou, E. M., Ricketts, T. A., & Hornsby, B. W. Y. (2011). Visual cues and listening effort: Individual variability. Journal of Speech, Language, and Hearing Research, 54, 1416–1430.

Reed, M. (2013). When the brain gets hard of hearing: Paying attention to cognition in hearing rehabilitation. *Canadian Hearing Report, 8*(3), 42

Rönnberg, J. A., Lunner, T. A., Zekveld, A. A., Sörqvist, P. A., Danielsson, H. A., Lyxell, B. A., & ... Linköpings universitet, I. O. (2013). The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances. *Frontiers In Systems Neuroscience*,

Schneider, B. A. (2011). How age affects auditory-cognitive interactions in speech comprehension. Audiology Research, 1(1), 34–39.

Seeman, S., & Sims, R. (2015). Comparison of psychophysiological and dual-task measures of listening effort. Journal of Speech, Language, and Hearing Research.

Staal, M.A. (2004). *Stress, cognition, and human performance: A literature review and conceptual framework* (Report No. 2004-212824). Moffett Field, CA, United States : NASA Ames Research Center.

Task Force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. European Heart Journal, 17, 354–381.

Tun, P., A., Williams, V., A., Small, B., J., & Hafter, E., R. (2012). The effects of aging on auditory processing and cognition. *American Journal of Audiology, 21*(2), 344-350.

Zekveld, A. A., Kramer, S. E., & Festen, J. (2010). Pupil response as an indication of effortful listening: The influence of sentence intelligibility. Ear and Hearing, 31, 480–490.