

**Aging, Hearing Acuity and Physiological Stress**

Master's Thesis

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## Abstract

### Hearing Acuity, Aging and Physiological Stress

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Chronic stress can contribute to an increase in disease frequency which can debilitate the body. Increasingly prevalent in young adults, hearing loss remains endemic to an aged population. Though effortful listening has been shown to decrease memory performance, presently it is unclear if the cognitive demand implicit in effortful listening takes a physiological toll on the body. To understand if and how effortful listening affects relevant physiological functions, we tracked changes in cardiovascular and endocrine stress systems. Participants were 12 young adults with normal hearing and 18 older adults with a range of hearing acuity. Stimuli consisted of recorded six-word lists for free recall presented in either a silent background or in an effortful condition in which the words were partially masked by 20-Talker babble. All participants were exposed to both conditions in randomized order. Heart rate variability and salivary alpha amylase were

monitored. A decrease in high frequency spectrum power during effortful listening as compared to silent listening was found in young adults, reflecting decreased vagal activation ( $p < .01$ ). Higher alpha amylase secretion relative to baseline was found during effortful listening in both young and older adults, evidencing greater sympathetic nervous system (SNS) activation ( $p < .05$ ). Also, a significant interaction between age group and listening difficulty was found ( $p < .05$ ). In older adults, poor hearing was associated with higher alpha amylase levels during difficult listening ( $p < .05$ ). While decreasing memory performance, this study shows that effortful listening causes an activation of stress systems. As auditory difficulties remain common in an aging population, attendant physiological stress presents negative health outcomes.

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Although many older adults maintain good hearing well into their 70s and older the incidence of hearing loss tends to increase with age. Many older adults experience age-related biological changes including significant hearing loss, particularly in the higher frequency ranges that are important for perception of speech (Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996). This may begin with the very high frequencies and then progress to include the frequencies in the speech range. The primary speech range is from 500 to 2,000 Hz, although some of the low energy, high frequency consonants are in the 2,000 to 4,000 Hz range (Turner & Cummings, 1999). Few issues are as important to the quality of life of older adults as the ability to comprehend and recall heard information whether it is instructions from medical care providers, verbal instructions on how to complete forms, or the latest news of family and friends. It has been found that older adults in good health with good hearing are nevertheless at a significant disadvantage in attempting to deal with rapid speech relative to their younger adult counterparts (Wingfield, McCoy, Peelle, Tun, & Cox, 2006). It has also been found that this difficulty with rapid speech is exaggerated when the speech materials have syntactic forms likely to strain working memory and when the speech must be heard in a background of other speakers talking at the same time (Peelle, Troiani, Wingfield, & Grossman, 2010). Natural speech is very often accompanied by background sounds such as the sound of a radio, TV, or other voices. Background noise further challenges the auditory and cognitive systems of older adults who tend to show changes with age that include reductions in the capacity of working memory, generalized slowing of perceptual operations, and an increased difficulty in dividing attention (Tun & Wingfield, 1999;

Wingfield, Tun, & McCoy, 2005). Increased perceptual effort in speech comprehension associated with hearing loss comes at a cost for downstream encoding of memory for speech. A well-supported *effortfulness hypothesis* explains the notion that the extra perceptual effort required to accurately comprehend speech takes up processing resources that may otherwise be used for memory encoding of the heard speech (McCoy, et al., 2005). Hearing loss has been shown to detrimentally impact cognitive function (Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989) but the impact on physiological stress systems is yet to be addressed.

Despite progress in engineering of hearing aid devices, including technology that selectively amplifies specific frequency ranges matching the user's audiometric profile, it is estimated that two-thirds of older adults with hearing loss do not use hearing aids (Society, 1999). Given the prevalence of hearing loss in older adults, little research thus far has examined if and how increases in perceptual effort and cognitive load required in effortful listening affect health relevant stress systems.

It has been shown that chronic psychosocial stress can increase susceptibility to illness and disease and accelerate the aging process (Yancura, et al., 2007). Additionally, chronic elevation of stress levels is associated with a broad range of cognitive and neurological consequences including effects on learning and memory, plasticity, and neuronal atrophy (Goosens, Sapolsky, & Riddle, 2007). Acute stress activates the sympathetic nervous system (SNS) and the hypothalamic-pituitary axis (HPA) and repeated activation of these systems can lead to long-term dysregulations. Dysregulation of the SNS and HPA can have downstream effects on physiological systems including

increased risk of disease (McEwen, 2000). As hearing loss and impairments in cognitive function remain prevalent in an aging population, possible physiological stress effects pose serious health consequences.

The goal of this study is to determine how a sustained increase in perceptual effort in comprehending speech affects relevant physiological stress systems. To investigate this question, we tracked both sympathetic (SNS) and parasympathetic (PNS) nervous system activity by analyzing cardiovascular reactivity, as well as biochemical markers of SNS activation during conditions of easy and difficult listening in young and old adults. Effortful listening is induced by presenting spoken words at an equal volume with multi-talker babble followed by free recall of the words. Masking language in this way emulates acoustical backgrounds often associated with effortful listening and results in significant decreases in memory for the speech. Masking words has been shown to disrupt a hypothesized short-term memory buffer and affect later recall of the masked words (Piquado, Cousins, Wingfield, & Miller, 2010).

Salivary alpha-amylase, as secreted in saliva, is utilized to assess changes in SNS activation. Salivary alpha-amylase, secreted in response to adrenergic activity, is increasingly used as a marker for the SNS and is shown to be a robust indicator of experimentally induced stress across the lifespan, complimenting the use of cortisol (Strahler, Mueller, Rosenloecher, Kirschbaum, & Rohleder, 2010). The combination of alpha-amylase and heart rate variability measures provide insight into changes in both SNS and PNS activity during listening and recall of spoken language. Accordingly, we predict that effortful listening will affect heart rate variability as well as alpha-amylase



output, reflecting small changes in both SNS and PNS activation. However we do not predict a large enough stress perception to increase cortisol levels in either young or old adults and therefore excluded this measure from analysis.

The present study consisted of two experiments measuring physiological activation during listening conditions of varying difficulty levels. Both experiments contained identical stimuli and similar protocol and both salivary alpha-amylase and cardiovascular activity were measured in young and old adults in experiment 1. In experiment 2, cardiovascular activity was the single measure of physiological stress in a sample of older adults.

## **Experiment 1**

### **Methods**

#### **Participants**

Participants were twenty healthy volunteers (12 young  $M=20.7$  years,  $SD=1.8$ ; 8 old  $M=75.2$  years,  $SD=5.4$ ). Eligibility, demographics, current health status and health behaviors (e.g. smoking status, medication) were assessed via in-person screening. Participants were age-matched on memory functioning and education as assessed by the WAIS-III (Wechsler, 1997), Shipley Vocabulary Test (Zachary, 1991), and self-reported years of formal schooling. Hearing acuity was measured by pure tone average (PTA 500, 1000, 2000 Hz) and speech reception threshold (SRT). Hearing acuity of young adults was within the normal range (PTA  $M=2.2$  dB HL,  $SD=3.0$ ; SRT  $M=-.83$ ,  $SD=1.9$ )

(Hall, 1997). Four older adults had age-normal hearing (PTA  $M = 18.4$  dB HL,  $SD = 6.5$ ; SRT  $M = 13.7$ ,  $SD = 4.7$ ) and four older adults had mild to moderate hearing loss (PTA  $M = 29.5$  dB HL,  $SD = 4.2$ ; SRT  $M = 30$ ,  $SD = 7.0$ ). Exclusion criteria were hearing aid use, acute or chronic medical or psychiatric diseases, pregnancy, and corticosteroid, adrenergic, or psychotropic medication, and chronic tobacco or alcohol consumption. The study protocol was approved by the local institutional review board, and written informed consent was provided by all participants. All eligible participants were asked for self-reports of chronic stress, depressive symptoms, and subjective communication beliefs using the perceived stress scale (PSS; (Cohen, 1988 24, 385-96)), the Center for Epidemiologic Studies Depression Scale (CES-D; (Radloff, 1977 1, 385-401) and the self assessment of communication questionnaire (Schow, 1982).

## **Stimuli**

Stimuli consisted of 70 six-word lists and were delivered binaurally by a female voice via a Grason-Stadler audiometer. Each listening condition consisted of consecutive presentation of 35 word lists either in a background of multi-talker babble or in a silent background. In the difficult condition, multi-talker babble and word lists were presented at an equal volume. All participants were exposed to both easy and difficult listening conditions in randomized order. Words were drawn from the Toronto Word Pool (Friendly, 1982) and six-word orderings were randomly constructed using MATLAB computer software (Mathworks Co).

## **Experimental procedure**

Volunteers were informed about the study over telephone and arrived in the laboratory for testing during the afternoon. After giving written informed consent, participants were screened for eligibility and completed cognitive and hearing tests. Participants were exposed to two experimental conditions (difficult or easy listening) of approximately 15 minutes in length each separated by a 20 minute rest period wherein they viewed a soothing nature video (BBC, 2006). Word lists were heard through insert earphones at a volume of 30 dB above the participants SRT. Presentation rate was two seconds per word and following each word list participants had 13 seconds to perform free recall of the prior list. Saliva samples were collected upon entrance to the laboratory and start, end, and 5 minutes post each listening condition. Self report questionnaires were completed upon conclusion of the experiment.

## **Physiological Measures**

To minimize any confounding effects of time of day, all trials were completed in the afternoon. Saliva samples were collected using salivettes; a plastic tube containing a sterile cotton roll (Sarstedt, NC, U.S). Participants removed the cotton roll from the tube and were instructed to place the cotton in their mouth. To protect against saliva collection from only one gland and ensure consistency in collection, participants were instructed to move the cotton around in a circular pattern for 2 minutes (Rohleder & Nater, 2009).

A Polar Heart Rate Monitor (Polar Electro Oy, Kempele, Finland) was fitted at the start of the experiment and continuous heart rate measurement lasted for the duration of the study. Heart rate variability was analyzed based on interbeat intervals (R-R) by the software tool Kubios (Biosignal Analysis and Medical Imaging Group, UEF, Finland). Continuous data were Fast Fourier transformed and high and low frequency bands (HF; 0.15 to 0.4Hz, LF; 0.04 to 0.15 Hz) as well as a time domain measure (*SD* R-R) were used in our analysis. The HF and LF bands are primarily influenced by the PNS and SNS respectively, while *SD* R-R is influenced by both systems (Electrophysiology, 1996). Heart rate variability was binned into one minute intervals for each period of analysis (two experimental conditions and baseline rest period).

## **Results**

The following sections present evidence of physiological stress caused by challenging listening conditions as well as word recall performance and relevant self-report assessments. Specifically, results of heart rate variability and salivary amylase analysis will be presented.

### **Behavioral and Self-Report**

Listening to and recalling speech in a noisy background resulted in diminished memory performance. A paired t-test revealed significantly lower recall performance in

the difficult listening condition in both young and older adults  $t(19) = 7.53, p < .01$ . On average, young and older adults' scores on the self-reported depression index (CES-D;  $M = 12.15, SD = 9.17$ ) were within the normal range and no significant difficulties in communication were reported. Scores on the perceived stress scale were marginally above the normal range ((Cohen, 1988) PSS;  $M = 21.15, SD = 8.87$ ).

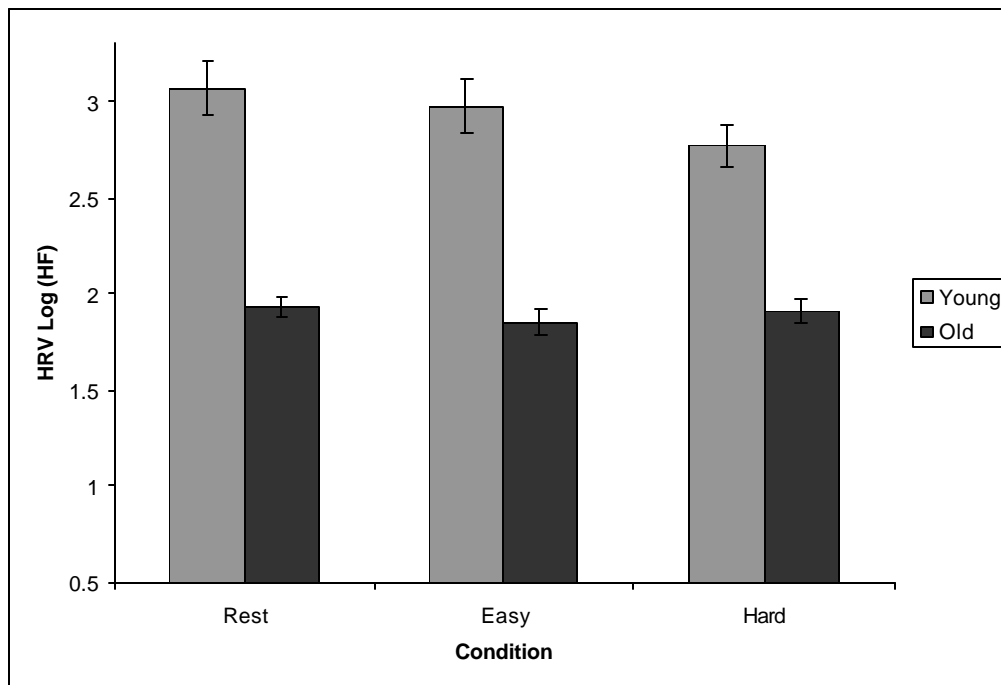
Young adults did not report different levels of experienced stress during listening conditions  $p > .05$ . However, older adults report significantly higher levels of experienced stress and fatigue in the difficult listening condition compared to normal listening  $t(7) = 2.80, p < .05$ .

### **Heart Rate Variability**

Heart rate variability was calculated based on both time-domain and frequency domain data. HRV over time,  $SD$  R-R, did not differ significantly between difficult and normal listening conditions. A repeated measures ANOVA comparing effects of condition and time did not detect differences in mean heart rate for either age group  $p > .05$ . Frequency spectrum analysis, derived from Fast Fourier Transformation, showed decreased high frequency spectrum power during difficult listening in young adults as shown in Figure 1. A general linear model comparing effects of condition and time revealed a significant main effect of listening condition on high frequency HRV in young adults  $F(1,66) = 11.49, \text{partial } \eta^2 = .51, p < .01$ . This finding reflects decreased parasympathetic activity and supports the notion that effortful listening causes an

autonomic stress response, though there was no observed difference in older adults  $p > .05$ . Also in both young and older adults, low frequency power and total HRV ( $SD R-R$ ) was unaffected by the manipulation, all  $p > .05$ . Time did not have a significant effect on any of the three cardiovascular measures in either age group, all  $p > .05$ . HRV did not significantly predict performance in either age group, all  $p > .05$ .

**Figure 1.** HF spectrum power during listening conditions in young and older adults.

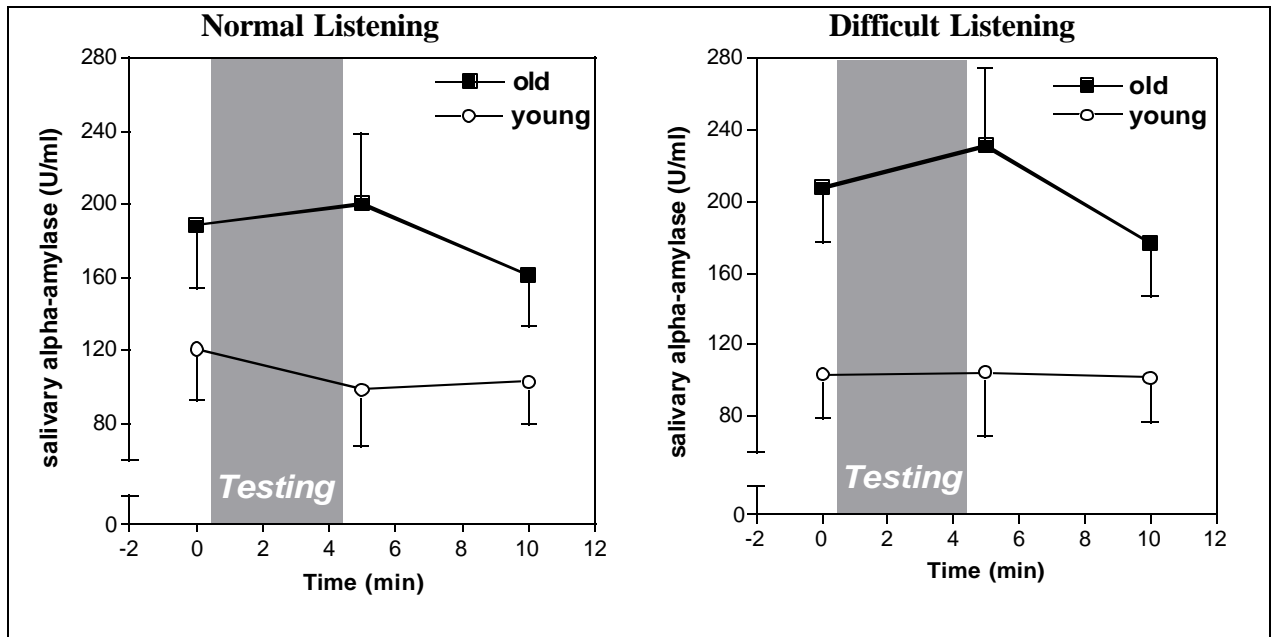


### Salivary Alpha-Amylase

Salivary alpha amylase concentration (U/mL) was calculated as relative change across condition. A general linear model was fit comparing effects of condition and time

within subjects and age between subjects. The model reflected a significant main effect of age on amylase levels  $F(1, 18) = 4.46, p < 0.05$ . Furthermore, we detected interactive effects between listening condition and age group on amylase secretion  $F(1, 18) = 6.23, p < 0.05$ . Significant differences in amylase levels over time were found as well as an interaction between time point and age group  $F(2, 36) = 3.57, p < 0.05$ ;  $F(2, 36) = 3.31, p < 0.05$ . Additionally, correlational analysis revealed a significant relationship between hearing acuity and difficult but not normal listening wherein poor hearing is associated with higher alpha-amylase levels  $r = .51, p < .05$ ;  $r = .16, p > .05$ .

**Figure 2:** Alpha-amylase concentrations before and after listening conditions in young and older adults.



## Experiment 2

### Methods

#### Participants

Participants were ten healthy community-dwelling older adult volunteers ( $M = 75.7$  years,  $SD = 5.83$ ). Eligibility screening, cognitive and hearing tests were conducted according to method described in Experiment 1, with the exception that hearing acuity was measured by SRT only. Five older adults had age-normal hearing ( $M = 11$  dB HL,  $SD = 7.41$ ) and five older adults had mild to moderate hearing loss ( $M = 32$  dB HL,  $SD = 2.73$ ). Exclusion criteria from experiment 1 were followed. Protocol was approved by the local institutional review board, and written informed consent was provided by all participants. As in experiment 1, participants self-reported chronic stress, depressive symptoms, and subjective communication beliefs using the perceived stress scale (PSS; (Cohen, 1988 24, 385-96)), the Center for Epidemiologic Studies Depression Scale (CES-D; (Radloff, 1977 1, 385-401) and the self assessment of communication questionnaire (Schow, 1982).

#### Stimuli and Procedure

Stimuli consisted of 70 six-word lists replicated from experiment 1 and identical listening conditions were used.



Study protocol followed that of experiment 1. The only changes to procedure were that word lists were heard through over-the-ear headphones instead of insert earphones and that no saliva samples were collected.

### **Physiological Measures**

A Polar Heart Rate Monitor (Polar Electro Oy, Kempele, Finland) was fitted at the start of the experiment and continuous heart rate measurement lasted for the duration of the study. Heart rate data was collected and analyzed according to the method described in experiment 1. Cardiovascular measures served as the only index of physiological activity in this experiment.

### **Results**

The following sections present evidence of the autonomic response to challenging listening conditions and recall performance, self-reports of stress, and relationships between performance and indicators of stress.

#### **Behavioral and Self-Report Data**

Difficult listening resulted in significantly worse recall performance compared to normal listening  $t(9) = 5.7, p < .01$ . Scores on the perceived stress scale (PSS;  $M = 14.4$ ,

$SD = 7.02$ ) and self-reported depression index (CES-D;  $M = 8.6$ ,  $SD = 5.10$ ) were within the normal range and no significant difficulties in communication were reported.

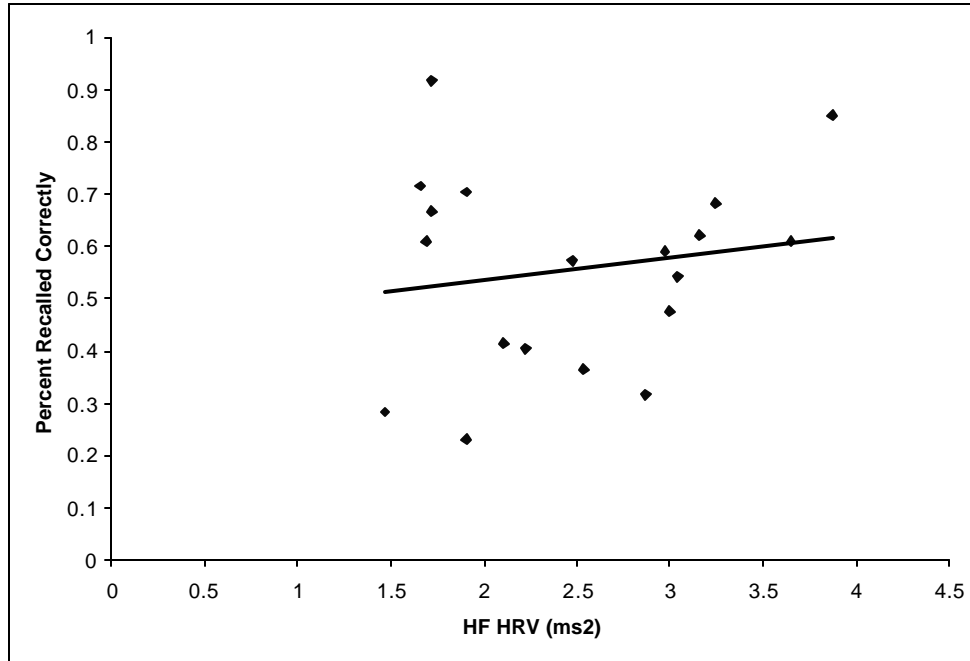
Participants reported significantly higher levels of experienced stress and fatigue during difficult listening compared to normal listening  $t(9) = 2.37$ ,  $p < .05$ . Subjective stress levels and recall performance are not significantly correlated  $p > .05$ .

### **Heart Rate Variability**

Heart rate variability was calculated for both the time and frequency domains. A repeated measure ANOVA analyzing general HRV ( $SD$  R-R) reflected no marked change between conditions or rest. An ANOVA comparing effects of condition and time on mean heart also reflected no significant changes  $p > .05$ . Frequency spectrum analysis showed marginally decreased high frequency power during normal conditions as compared to difficult listening  $F(1,276) = 3.19$ ,  $p = .075$ . A similar model comparing effects of condition and time on low frequency HRV revealed a trend towards higher LF activity during normal listening  $F(1,273) = 2.48$ ,  $p = .11$ . This finding provides limited evidence of increased SNS and decreased PNS activation during normal listening. Time did not have a significant effect on any of measures of HRV, all  $p > .05$ . Also, hearing acuity did not correlate meaningfully with any cardiovascular measures.

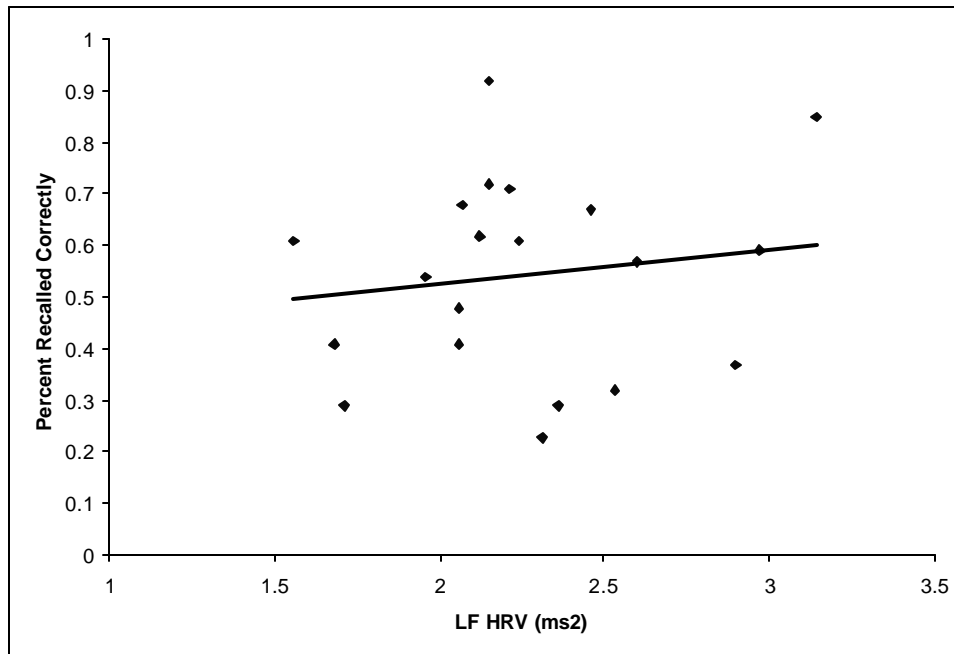
Regression analysis revealed that both HF and LF HRV significantly predict recall performance controlling for condition  $B = .044$ ,  $p < .01$ ;  $B = .094$ ,  $p < .01$ . Figure 3, below, presents the relationship between HRV and performance.

**Figure 3.** The relationship between high frequency HRV and recall performance.



Interpreting high frequency power as primarily influenced by the PNS, we see that individuals with higher PNS activity tend to perform better  $p < .01$ . Figure 4 depicts the relationship between low frequency power and performance. Interpreting LF power as primarily influenced by the SNS, there is evidence that higher levels of SNS activation are associated with better memory performance  $p < .01$ .

**Figure 4.** The relationship between low frequency HRV and recall performance



## Discussion

There is much evidence of age-related biological changes including declines in hearing acuity and cognitive declines affecting working memory and division of attention. Furthermore, cognitive effort required in comprehending hard to hear speech requires extra perceptual effort that comes at a cost to memory encoding (Wingfield, et al., 2006). Whether caused by hearing impairment or communicating in a noisy background, effortful listening poses challenges to cognitive systems. Importantly, the present study provides evidence that effortful listening also causes measurable activation of physiological stress systems. This poses serious health concerns as chronic over

activation of stress systems interferes with immune system functioning and increases susceptibility to illness (Goosens, et al., 2007).

Experiment 1 provides evidence of modest increases in sympathetic nervous system activity in older adults in response to difficult listening. Reflected primarily by changes in salivary alpha-amylase concentration, older adults experienced increases in sympathetic activity directly following listening conditions and this effect is strongest during difficult listening. Hearing acuity was found to be correlated with amylase levels during difficult listening but not normal listening. This is interpreted as older adults with a hearing loss suffer an even greater physiological stress response during the most taxing listening tasks. It is noted that the greater baseline alpha-amylase levels in older adults are in line with literature on alpha-amylase responsivity across the lifespan (Strahler, Mueller, Rosenloecher, Kirschbaum, & Rohleder, 2010). Also, there is evidence of an inverse relationship between SNS and PNS activity in young adults documented by changes in HRV spectral power and small increases in relative amylase levels. Young adults were only marginally affected by the manipulation likely because of strong cognitive ability, good hearing acuity, and low saliency of the task. In sum, experiment 1 provides compelling evidence of activation of physiological stress systems in older adults which is enhanced by mild hearing loss during effortful listening.

It is speculated that the additional effort required in effortful processing of speech coupled with feelings of over-taxation contribute to the observed physiological response. Subjective stress reports confirm the physiological data, particularly in older adults.

Experiment 2 provides puzzling evidence of little changes in cardiovascular markers of autonomic activity. Trends in spectral power of HRV suggest that autonomic activity of older adults in this experiment may in fact reflect higher alertness, attention and stress levels during normal rather than difficult listening. Further analysis suggests that higher autonomic activity, marked by both SNS and PNS influenced measures, predicts better memory performance regardless of difficulty. It is possible that older adults who are more effective at focusing and remembering the spoken words expect better performance in the easier condition. The expectation of performance may trigger greater autonomic activation and would consequently account for the unexpected cardiovascular results.

The results from this study should be interpreted as preliminary. Experiment 1 consisted of eight older adults including four with hearing loss. Further studies are necessary to determine precisely how hearing loss affects physiological stress in older adults engaged in effortful listening. Likewise, experiment 2 consisted of ten older adults and relied on continuous measurement of cardiovascular activity. Because micro fluctuations in attention, mood, and effort are captured by cardiovascular analysis and accumulated stress is more difficult to detect, the unexpected findings of experiment 2 may in fact be an artifact of the measure. It may be prudent for future studies to rely on a sensitive measure of accumulated stress, like alpha-amylase, as the primary marker of listening induced stress.

If hearing difficulties and attendant effortful listening result in elevated physiological stress levels as predicted from the present study, hearing impaired older

adults may be at special risk for illness. Moreover, this study provides added support to the need for hearing aid usage and suggests an explanation of the experienced fatigue often associated with comprehending speech in noisy conditions (Kramer, Kapteyn, Festen, & Kuik, 1997).

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