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Costs of Hearing Loss Relating to Listening Effort, Fatigue, and Stress

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Abstract

There are many known negative impacts of hearing loss including difficulty communicating, especially in noise, avoidance or withdrawal from social situations, social rejection, strain on relationships with family members and friends, emotional effects, including anxiety, depression, and a decline in self-esteem and confidence. While a large amount of research exists regarding the financial, social, and physical costs of hearing loss, the relationship between hearing loss and listening effort, fatigue, and stress are not as well understood. The aim of this paper is to review research regarding the interrelationship of listening of listening effort, stress, and fatigue, as well as a review of subjective and objective measurements of listening effort, stress, and fatigue. A literature review was conducted using research papers obtained from Pubmed and ComDisDome. It has been inferred that increased mental effort associated with hearing loss can lead to an increase in stress, tension, and fatigue. Although self-report, behavioral, and physiological measurements have shown a relationship between hearing loss and listening effort, stress, and fatigue, there is not a consensus on how best to measure and its clinical implications. It can also be argued that hearing-impaired individuals do not experience increased listening effort, fatigue, and stress, simply because they ignore these types of unfavorable listening environments. Overall, more research is needed to obtain a better understanding of the relationship between hearing loss and listening effort, fatigue, and stress.

Introduction

Hearing loss, along with background noise and reverberation, can make speech understanding extremely difficult. There are many known negative impacts of hearing loss including difficulty communicating (especially in noise), avoidance or withdrawal from social situations, social rejections, strain on relationships with family members and friends, emotional effects, including anxiety, depression, and a decline in self-esteem and confidence. These negative impacts can be described as the costs of hearing loss. These costs of hearing loss can be broken down into the following categories: financial costs, social/lifestyle costs, and physical health/well-being costs.

The financial costs of hearing loss refer to the monetary costs of services and treatment of hearing loss including audiologic hearing evaluations, hearing aids, assisted listening devices, and other treatment related services. Many insurances do not cover the cost of hearing aids and it is therefore a costly purchase for many hard of hearing individuals. A study conducted by Mohr, Feldman, Dunbar, McConkey-Robbins, Niparko, Rittenhouse, & Skinner (2000) indicated that severe to profound hearing loss is expected to cost society $297,000 over the lifetime of the individual. Included in these costs to society may be special education, social services, etc.

There are many known social and lifestyle costs of hearing loss. One social cost that we are aware of is that hearing disabilities strongly affect intimate relationships (Hetu, Jones, & Getty, 1993). A hearing loss can cause a strain on relationships due to a break-down in communication. When individuals are not able to effectively communicate with one another, it can cause frustration from both parties and can even lead to avoidance of conversations. Along with a strain on relationships, hearing loss can also cause a strain on the hearing-impaired individual’s work environment. McGarrigle, Munro, Dawes, Stewart, Moore, Barry, & Amitay (2014) indicated that hearing-impaired workers are found to be more likely than normal hearing individuals to take sick-leave from work due to reasons such as fatigue and mental distress.

Hearing impaired older adults often lead a more isolated lifestyle (Smith & Kampfe, 1997). This can be due to the hearing-impaired individual avoiding situations in which they have difficulty hearing or communicating. Although elderly listeners with hearing impairment have more performance-based disability than younger listeners with comparable hearing loss, older listeners report fewer communication problems, less hearing disability, and less social and emotional impact from hearing loss on their daily lives (Gatehouse, 1994). Wu and Bentler (2012) characterized and compared the auditory lifestyle of younger and older adults with hearing impairment and examined the relationship between age, social lifestyle, and auditory lifestyle. The individuals in this study carried noise dosimeters to measure sound levels in their daily lives for a week in order to objectively measure auditory lifestyle. They were also asked to describe their listening activities and environments. The Auditory Lifestyle and Demand Questionnaire (ALDQ) was given to the participants in order to obtain a subjective measure of auditory lifestyle. Three self-report inventories including, Social Network Index score, Welin Activity Scale, and Social Convoy Questionnaire, were also used to characterize participants social lifestyles. Although younger and older participants reported spending comparable time in a given category of listening condition, the dosimeter-measured sound level was higher for younger listeners. This study also revealed that older age was associated with lower Social Network Index scores (smaller social networks) and fewer listening demands. Another study conducted by Gordon-Salant, S., Lantz, J., & Fitzgibbons, P. J. (1994) indicated that older individuals with hearing loss may perceive less overall difficulty with hearing as they age due to older adults having a less demanding auditory lifestyle. While the reason that these older hearing-impaired individuals have a less demanding auditory lifestyle may be in part due to retirement, deaths of friends and family members, and changes in residence, hearing loss is still likely a significant factor. This meaning that older age does not always lead to a less active social lifestyle. Older individuals may still be socially active and frequently encounter noisy communication situations, while reporting fewer listening problems as a result of their tendency to minimize or ignore their health problems (Idler, 1993).

Physical health and well-being is another area that is greatly affected by hearing loss. Hearing-impaired individuals often describe listening as exhausting. It has been shown that individuals with hearing loss report a need for increased attention, concentration, and listening effort and are therefore more often mentally fatigued (Hornsby, 2013). Although there are many reported experiences that listening is effortful, tiring, or stressful, even when sounds may be audible and words are recognized accurately, clinical measures of listening effort have not been readily available (Pichora-Fuller, Kramer, Eckert, Edwards, Hornsby, Humes, Lemke, Lunner, Matthen, Mackersie, Naylor, Phillips, Richter, Rudner, Sommers, Tremblay, & Wingfield, 2016). The reports of effortful listening suggest that the difficulties that are experienced by listeners in their everyday lives depends on more than sounds simply not being audible or loud enough. Successful communication may depend on the deployment of greater cognitive energy when the quality of the signal is suboptimal. When listeners are unable or unwilling to sustain a sufficiently high level of effort, it can cause them to feel fatigue and/or decide to quit the task in order to avoid becoming fatigued. If listening in everyday activities consistently demands more effort than listeners are able or willing to expend, they may develop chronic stress and withdraw from social interactions, which can have negative consequences to cognition, general health, well-being, and quality of life. Laboratory research has provided evidence that reduced cognitive performance on measures of memory and comprehension may be associated with age-related declines in supra-threshold auditory processing. Performance on memory and comprehension is reduced in older adults who have elevated speech-in-noise thresholds. Epidemiological research has provided evidence of an association between hearing loss and incident dementia and has prompted questions in regards to advantages in integrating approaches on hearing health and cognitive health.

Stress can be defined as your body's way of responding to any type of demand or threat. When your body starts to feel these demands and threats, your nervous system responds by releasing stress hormones, which include adrenaline and cortisol, in order to arouse the body for emergency action (Bess, Gustafson, Corbett, Lambert, Camarata, and Hornsby, 2015). Cortisol is a hormone secreted by the adrenal cortex and it is a part of the body's response to stress and is regulated by the body's hypothalamic-pituitary-adrenal (HPA) axis. Cortisol is considered an accurate indicator of this reactivity. Individuals with stress or fatigue may exhibit elevated levels of salivary cortisol. There is very little research available that discusses the stress perceived by hearing-impaired individuals in their long-term lifestyle. However, research suggests that individuals with a hearing loss need increased energy (cortisol) and are therefore at an increased risk for fatigue. It has been inferred that mental effort exerted due to having a hearing loss can lead to an increase in stress, tension, and fatigue (Hornsby, 2013). An increase in stress, tension, and fatigue can lead to avoidance of the situations that cause these issues. Avoiding unfavorable listening environments may limit listening induced stress. However, while avoiding these unfavorable listening environments may reduce stress, there are many detrimental aspects of having a more sedentary lifestyle including greater risk of cognitive decline, as opposed to a more active lifestyle (Lin, 2010).

Fatigue has been reported in individuals with hearing loss and can reduce quality of life in regards to decreased productivity and increased work-related injuries (Alhanbali, Dawes, Lloyd, & Munro, 2016). Fatigue has been linked to depression and lack of desire to engage in daily activities and social interactions. As mentioned, it has also been reported that hearing-impaired individuals tend to take more sick leave due to fatigue and mental distress compared to normal-hearing workers. Fatigue is defined as extreme tiredness resulting from mental or physical exertion (Mcgarrigle, Munro, Dawes, Stewart, Moore, Barry, & Amitay, 2014). Physical fatigue may be described as a reduced ability or desire to perform a physical task, whereas mental fatigue is described as a feeling of tiredness, exhaustion, or lack of energy due to cognitive or emotional demands (Bess & Hornsby, 2014). While listening-related fatigue has been described as "the extreme tiredness resulting from effortful listening" (Alhanbali et al, 2016). There has been limited attention on self-reported fatigue in the hearing-impaired adult population and there are currently no self-report scales that have been developed to assess self-reported listening related fatigue. Due to the negative effects fatigue can cause on an individual, it is important to gain a better understanding on how hearing loss and fatigue are correlated, as well as how to assess listening related fatigue.

Although there is no single definition of listening effort that is agreed upon by everyone, listening effort can be defined as "the mental exertion required to attend to, and understand, an auditory message" (McGarrigle et al, 2014). It has been proposed that hearing-impaired listeners may expend more listening effort in difficult listening situations when compared to their normal hearing counterparts (Alhanbali et al, 2016). When hearing-impaired individuals are in difficult listening situations on a daily basis, mental fatigue may be a result, which could be associated with a reduced ability to perform various cognitive tasks and concentrate. Similar to fatigue, it has been suggested that individuals with hearing loss who are in difficult listening conditions must exert increased effort, however, very little research exists to support this claim. Stress, fatigue, and listening effort have been measured using self-report measurements, behavioral measures, and physiological measures; however, it is often debated as to what the best method may be for obtaining these measurements.

While a large amount of research exists regarding the financial, social, and physical costs of hearing loss, the relationship of hearing loss and listening effort, stress, and fatigue are not as well understood. The aim of this paper is to review research that has been conducted regarding the correlation of hearing loss with listening effort, stress, and fatigue, as well as review subjective and objective measurements.

Literature Review

Hearing Loss and Stress

Classroom acoustics, including signal-to-noise ratio (SNR) and reverberation time are often poorer than what is needed for optimal listening (Hicks & Tharpe, 2002). High levels of background noise, which are extremely challenging for hearing impaired children, are known to increase levels of stress and fatigue in school-aged children with normal hearing (Hornsby, Werfel, Camarata, & Bess, 2014). These factors could be extremely detrimental to a child's ability to learn in a noisy classroom environment. Also mentioned earlier, an increase in stress, tension, and fatigue can lead to an avoidance of certain situations that cause these negative effects. However, while avoiding these unfavorable listening environments may reduce the stress that the individual is experiencing, there are many negative effects including cognitive decline and decreased quality of life (Lin, 2010).

Few studies have been conducted regarding the relationship between hearing loss and stress. While some studies using self-reported measures have been conducted to determine the correlation between hearing loss and stress, there is a lack of agreement on the best way to measure the correlation. Bess et al (2015) conducted a study using physiological measures. This study was administered to examine whether school-age children with hearing loss show different diurnal salivary cortisol patterns compared to normal hearing children. High levels of cortisol reflect extended activation of the HPA axis due to longstanding stressful experiences, which could be expected in children with hearing loss that are struggling to listen and understand in a noisy classroom. The rise in cortisol levels upon awakening is referred to as the cortisol awakening response (CAR). Alterations that occur in the CAR have been associated with perceived stress and various chronic health problems. Salivary samples were obtained six times per day on two separate days. The samples were obtained at the time of awakening, 60-minutes post-awakening, and three times throughout the day. Results of the study showed significant differences between children with hearing loss and children with normal hearing. The hearing-impaired children had high cortisol levels at awakening compared with the normal hearing children. However, when both groups were compared beyond the CAR, they were similar and declined throughout the day in a similar fashion. These results were similar to studies on adults experiencing high workload and job strains. Overall, these results suggest that children with hearing loss show an increased alertness and need to mobilize energy in preparation for the day. Alternatively, these results may reflect on the ability in children with hearing loss to fully recover from listening related stress during the night. While this study presents with helpful knowledge regarding the correlation between hearing loss and stress, more research is needed before we can positively determine whether salivary cortisol is a reliable measure for stress and fatigue in children with hearing loss.

Kramer, Teunissen, & Zekveld (2016) conducted a pilot study looking at pupillometry to measure processing load expended during speech understanding. With increasing speech understanding difficulty, pupil diameter increases. This increase in pupil size reflects increased deployment of the sympathetic branch of the autonomic nervous system and when this branch is activated in response to stress, there is also activation of the neuroendrocrine system, which includes the sympathetic-adrenomedullary (SAM) axis and the HPA axis. These two stress response pathways and their activation leads to the secretion of catecholamine and cortisol. These activations can be biochemically assessed by measuring chromogranin A (CgA) and cortisol in saliva, both of which are indices of psychological stress. In this study, speech testing was conducted in quiet and noise for both normal hearing and hard-of-hearing individuals. A saliva sample was obtained from each participant before testing, as well as after the speech testing in quiet, speech testing in noise, and at the end of the test session. The pupillometric equipment was used during testing to obtain pupil measurement. The results indicated that hearing-impaired listeners had smaller peak pupil dilations (PPDs) than normal hearing listeners in the speech in noise condition only. No group or condition effects were observed from the cortisol data, but hearing-impaired listeners tended to have higher cortisol levels across conditions. CgA levels were larger at the pretesting time than at the three other test times and hearing impairment did not affect CgA. Overall, the three physiological indicators of cognitive load and stress (PPD, cortisol, and CgA) were not equally affected by speech testing or hearing impairment and each of them seem to capture different dimensions of sympathetic nervous system activity.

Hearing Loss and Listening Effort/Fatigue

Increased listening effort and fatigue has been thought to be linked to individuals with hearing loss. More mental effort may be required for hearing-impaired individuals in order to identify the relationship between the different items in a sentence (Alhanbali et al, 2016).

Increasing effort may benefit individuals with hearing loss in terms of understanding speech in difficult listening situations, however, high levels of listening effort on a consistent basis could result in mental fatigue, which could be associated with increased difficulty in concentration and the ability to perform cognitive tasks. In addition, experiencing hearing loss-induced fatigue on a consistent basis can have poor long-term consequences affecting the quality of life for individuals with hearing loss (Alhabali et al, 2016). For children with hearing loss, classrooms are especially difficult for them to hear and understand their teachers and peers. These classroom environments can pose the potential for fatigue in hearing-impaired children (Hornsby, Werfel, Camarata, & Bess, 2014). Children that suffer from recurrent fatigue tend to miss more school and are at increased risk for poor academic performance.

In a study conducted by Hornsby et al (2014), the Pediatric Quality of Life Inventory Multidimensional Fatigue Scale (PedsQL MFS) was used to assess children's self-reported perceptions of fatigue. The Peds QL MFS is a standardized measure which uses three subscales (each subscale including six items): (1) general fatigue, (2) sleep/rest fatigue, and (3) cognitive fatigue. The participants in this study include 10 hearing-impaired children and 10 normal hearing children. The children were asked how much of a problem each item has been over the past month. The results of this study showed that subjective fatigue is increased in school-aged children with hearing loss and the impact of hearing loss on fatigue appears pervasive across all three domains assessed. However, a limitation of this study that was noted was the small sample size that was utilized. Therefore, more research is needed to determine underlying mechanisms for the increase in fatigue in hearing-impaired children.

Alhanbali et al (2016) aimed to quantify self-reported effort and fatigue in listeners with hearing loss, as well as investigate the relationship between the self-reported levels of effort and fatigue. Both normal hearing and hearing-impaired participants completed the fatigue assessment scale (FAS) and the effort assessment scale (EAS). The FAS is a standardized self-report scale with 10 items that are scored using a five-point Likert scale and the EAS is a six-question scale with responses provided on a visual analog scale which ranges from 0 to 10. All of the individuals with hearing loss reported significantly increased effort and fatigue compared to their normal hearing counterparts. However, the study found that listening-related effort and fatigue are not predicted by the severity of hearing impairment. There was also a low correlation between FAS and EAS, indicating that fatigue cannot be reliably predicted by self-reported effort in individuals. The authors stated that future studies are needed to determine the reliability and sensitivity of FAS and EAS before they are able to be used as an outcome measure.

In another study conducted by Hicks & Tharpe (2002), two experiments were conducted to assess both school-age children with and without hearing loss. In the first experiment, salivary cortisol levels and self-rating measures were used to measure fatigue in school-age children. The Dartmouth Primary Care Cooperative Information Project Scales (COOP) was used for the self-rating measure. The COOP consists of nine self-rated charts designed to determine a child's self-perceptions in a variety of areas, such as health habits, emotional feelings, and communication. The results revealed that neither cortisol measurements nor self-rating measures of fatigue showed significant differences between the normal hearing children and the hearing-impaired children. Hicks & Tharpe (2002) mentioned however that the majority of the children with hearing loss in the study wore amplification and speculated that adequate amplification reduces stress and fatigue related to listening, opposed to no amplification. In the second experiment, a dual-task paradigm was utilized. The primary task consisted of speech-recognition testing in varying levels of background noise and the secondary task consisted of pushing a button in response to random presentations of a probe. The results indicated that children with hearing loss expend more effort in listening than children with normal hearing. Based on these results, it is reasonable to assume that children with hearing loss are at risk for expending more effort listening in typical classroom environments compared to the normal hearing counterparts. Dual-task paradigms have been used in other studies to measure listening effort as well. In a study conducted by Downs (1982), a dual-task study was used to examine listening effort using adult listeners with hearing loss and they found that adults had better secondary-task performance for aided results than for unaided results. This suggests that less effort was exerted when the individuals were wearing their hearing aids.

Hornsby (2013) conducted a study to examine effects of hearing aid use on listening effort and fatigue. Hearing aids are known to have benefits including improving intelligibility, however, their impact on listening effort and mental fatigue are less understood (Hornsby, 2013). There is some evidence that suggests that hearing aid use can reduce the cognitive resources needed to process speech and therefore reduce listening effort in some conditions (Downs, 1982). In the study conducted by Hornsby (2013), subjective and objective measures were used to examine the effects of hearing aid use and hearing aid features on listening effort and mental fatigue in adults with sensorineural hearing loss. A dual-task paradigm was used to assess word recognition, word recall, and visual reaction times to quantify listening effort and fatigue. The participants in the study were fitted with hearing aids and tested unaided and in two aided conditions consisting of omnidirectional and with directional processing and digital noise reduction active. Subjective ratings of listening effort that was experienced throughout the day were obtained, as well as fatigue and attentiveness before and after the dual-task. Results of the study showed that word recall was better and dual-task reactions times were significantly faster in the aided conditions compared to the unaided conditions. This suggests a decrease in listening effort when listening aided. Word recognition and recall in both the aided and unaided conditions remained relatively stable over the duration of the dual-task. This suggests that these processes were resistant to mental fatigue. Dual-task reaction times were prolonged towards the end of the experiment for unaided conditions, indicating fatigue. Conversely, the dual-task reaction times, however, remained stable over time in both aided conditions, suggesting that hearing aid use reduced susceptibility to mental fatigue. The subjective ratings of fatigue and attentiveness increased significantly after the dual-task, but there were no significant differences observed between the unaided and aided subjective ratings.

Measuring listening effort, fatigue, and stress

Daily listening is often essentially effortless for the normal-hearing population; however, listening is often described as considerably taxing for individuals with a hearing loss (McGarrigle et al, 2014). These hearing-impaired individuals often complain of fatigue due to the greater amount of effort and concentration required to understand speech in daily listening environments. It is often debated as to how to best assess and characterize listening effort and listening-related fatigue. One common reason as to why there is controversy regarding the best method of assessing listening effort, fatigue, and stress is due to the lack of agreement on a clear definition of the terms. Without a clear definition and better understanding of the terms, the pursuit of better interventions will be difficult (Pichora-Fuller et al., 2016). Measuring listening effort and fatigue could provide a more comprehensive evaluation of each individual’s hearing disability and be used to inform counseling sessions, inform intervention strategies, and shed light on cases where there may be uncertainty as to whether intervention is needed.

McGarrigle et al (2014) describes various ways in which listening effort and listening-related fatigue are measured. In this study, techniques for measuring listening effort and fatigue were categorized into three subgroups; (1) self-report, (2) behavioral measures, and (3) physiological measures. For the purposes of this study, each of these subgroups will be reviewed in regards to the measurement of stress, fatigue, and listening effort.

Self-Report

Self-report measures rely on the participant to answer questions regarding their feelings, beliefs, attitudes, etc. They are quick and easy to deliver and do not require particular expertise in order to administer or interpret; however, a limitation of self-report measures is that they are subjective and therefore effort may differ on an individual basis (McGarrigle et al, 2014). Most self-report measures that are used in the field of audiology do not include items about listening related effort and fatigue (Alhanbali et al, 2016). Self-report measures have included condition-specific questionnaires to assess listening effort, generic questionnaires of workload performance and scaling techniques (Hughes et al, 2017). Validated self-reported measures are also known as patient-reported outcome measures (PROMs), which are used widely in clinical research and clinical practice to obtain the patient's perspective regarding their symptoms, functional status, quality of life, satisfaction or experience. Self-report measures of listening effort and fatigue can be in the form of a closed-set questionnaire or rating scale, such as the speech, spatial, and qualities (SSQ) hearing scale which measures listening difficulties experienced in a variety of real-world settings. A scale of 0 to 10 is used with lower numbers indicating more difficulty or effort. Self-report measures of listening effort are often used during experimental listening tasks. McGarrigle et al (2014) describe a study that was conducted in which participants were asked to indicate on a 100-point scale how 'effortful' they found each trial in an auditory profile test battery. In this study, hearing-impaired participants gave significantly higher ‘effort’ ratings than the normal-hearing individuals in all conditions. In a study that was mentioned earlier, self-report measures were used to measure fatigue, and hearing-impaired workers were found to be more likely than their normal-hearing counterparts to take sick-leave due to reasons such as fatigue and mental distress. Also mentioned earlier, in the study conducted by Alhanbali (2016), there was also a low correlation between FAS and EAS, which indicates that fatigue cannot be reliably predicted by self-reported effort in individuals. There are a large number of questionnaires utilized in the field of audiology. In order to select an appropriate PROM, a careful review of its measurement properties should be conducted to determine the most viable measurement tool (Hughes et al, 2017).

Measuring the magnitude of the listening effort that is expended by a listener is not the only relevant issue. It is also important to assess how much effort a listener is motivated to expend. Pichora-Fuller et al. (2016) provided an example of how self-report measures can be used to determine a listener’s lowest acceptable performance level and thereby gauging when a listener is likely to give up listening. In order to measure the lowest acceptable performance level, listeners were given a description of a common hypothetical scenario in various SNR conditions that corresponded to recently experienced speech-in-noise test conditions in which word recognition accuracy had been measured. Listeners then estimated their expected performance in terms of percent correct word recognition and they also indicated how long they would be able to sustain attention and how long they would be willing to sustain attention to listening in the scenario. This type of self-report measure could enable clinicians to consider input-related demands and an individuals’ motivational focus in relation to their likelihood of sustaining effort.

Behavioral Measures

Behavioral responses in listening tasks have also been utilized to measure listening effort by using single-task and multi-task paradigms. In single-task paradigms, participants respond to stimuli either by verbally identifying the word/sentence heard or by pressing a button (McGarrigle et al, 2014). When assessing amplification benefit in individuals with hearing loss, speech identification in noise performance is assessed by accuracy (correct responses given in each listening condition by each individual). Multi-tasking paradigms, such as the ‘dual-task’ paradigms were developed to measure attention allocation. When performing two tasks at the time, if one becomes more taxing, then it will result in a performance decrement on the other task. Therefore, the secondary task may be interrupted, reflecting the amount of effort allocated to the primary task (McGarrigle et al, 2014). According to McGarrigle et al (2014), the multi-tasking method appears to have good face validity with regard to speech processing in realistic environments. Behavioral mental fatigue is characterized by the slowing or decline of cognitive functions following concerted and/or prolonged mental effort (McGarrigle et al, 2014). This is typically detected by using a task in which the subject sustains their attention for a prolonged period of time. A study using self-report and behavioral measures of listening effort and fatigue was conducted in a dual-task study with hearing-impaired individuals by Hornsby (2013). In this study, word recognition served as the primary task with visual response time and word recall as secondary tasks. Both listening effort and fatigue were found to be reduced in aided listening conditions, compared to unaided. This finding was the first link in the assumed relationship between incidences of effortful listening and cognitive fatigue. However, Hornsby (2013) stated that the self-report measures of fatigue taken before and after each block of trials did not show the same change between aided and unaided conditions and more research is needed to ascertain the extent to which this behavioral effect is related to extreme tiredness in individuals with hearing loss.

Physiological Measures

Physiological measurement refers to the recording of changes in central and/or autonomic nervous system activity during task performance. Listening effort related changes in central nervous system activity has been investigated through the use of functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and event-related potentials (ERPs). fMRI is a neuro-imaging technique that provides information about brain activity by exploiting metabolic consequences of neuronal activity and the changes in blood oxygenation level that results. Cortical EEG involves measuring electric potential fluctuations associated with neural activity through a series of electrodes places on the scalp. The autonomic nervous system response has also been considered for listening effort related changes in skin conductance and pupil dilation. With pupil dilation, the size of the pupil may fluctuate based on changes in mental task load and has also thought to be modulated by changed in attention, stress, and memory. Skin conductance reflects the amount of moisture on the surface of the skin and is assessed by measuring the skin’s capacity to conduct an electrical current. The eccrine sweat glands, which are mainly found on the palm of the hands or the soles of the feet, are where measurements are made. Increased sweat gland activation is associated with greater stress. When conducting an experimental task involving one of the above mentioned behavioral measurements, they typically involve a task with a number of conditions varying in difficulty. Any systematic physiological changes that occur in the more challenging condition are generally attributed to listening effort.

Physiological measures are even less researched and understood. As mentioned, Hicks and Tharpe (2002) used a physiological measure by looking at cortisol levels between hearing-impaired and normal-hearing children for markers of fatigue since high cortisol levels are typically associated with stress and low cortisol levels are typically associated with fatigue. Although no significant differences in average cortisol levels were found, they mentioned that some possible explanations as to why there was a lack of significance were limited sensitivity of the measurement technique, increased stressful listening has not yet accumulated to fatigue in the children, and amplification may have reduced stress and fatigue. While no significant differences were found in the study conducted by Hicks and Tharpe (2002), the study conducted by Bess et al (2015), mentioned earlier, shows different results. Bess et al (2015) conducted their study to examine whether school-age children with hearing loss show different diurnal salivary cortisol patterns than normal hearing children in order to examine stress due to hearing loss. The results of this study showed significant differences, with higher levels of salivary cortisol in children with hearing loss. Though both of these studies show differences in how they were conducted, and what they found, it is a clear that more research is needed defining physiological changes related to hearing loss associated with stress, listening effort and fatigue.

Although there is a growing interest in listening effort and fatigue by researchers, there has been a disagreement as to the nature of listening effort and its validity as a measurement tool. One reason for this is the differing opinions on the terminology used with each measure. McGarrigle et al (2014) mentions that there are consistent findings of weak relationship between: (1) self-report and dual-task measures of listening effort, (2) self-reported listening effort and speech recognition task difficulty, (3) self-report and physiological measures of listening effort, and (4) self-report and behavioral measures of fatigue. As a result, McGarrigle et al (2014) recommends researchers make the following assumptions about each measure; (1) with self-report measures of listening effort, the experience of listening effort will be accurately perceived and recognized, (2) with single-task paradigms, mental exertion is causally related to time spent on a listening task, (3) with the multi-tasking paradigm, mental exertion during listening reflects the taxing of a limited-capacity system and the mental exertion will reveal itself as a secondary task performance decrement, and (4) with physiological techniques, the processes being monitored actually mimic the physiological mechanisms that underpin listening effort.

Conclusion

The understanding of how listening effort, fatigue, and stress relate to hearing loss is thought to be extremely important in order to provide the best treatment and care to patients. Although there have been many reports of listening effort, fatigue, and stress in individuals who have a hearing loss, an accurate clinical measure has yet to be readily available. As seen in this literature review, very few research studies regarding listening effort, fatigue, and especially stress have been conducted and agreed upon in terms of how to accurately define and measure them. Although ALDQ and dosimeter measures have shown that hearing-impaired individuals avoid poor speech-to-noise ratios and have greater listening effort, fatigue, and stress, there is a discrepancy as to what is the most appropriate self-report measurement tool to use. The use of behavioral and physiological measures has shown to be promising; however, the lack of consistency between studies proves that more research is needed before these types of measurements can be utilized in the clinical setting. It can also be argued that hearing-impaired individuals do not experience increased listening effort, fatigue, and stress, simply because they ignore these types of unfavorable listening environments. The majority of individuals that have a hearing loss are older, retired adults. These older hearing-impaired individuals have more flexibility when it comes to adjusting their auditory lifestyle to avoid unfavorable listening conditions, whereas working adults and children in school cannot easily avoid these difficult conditions. Overall, more research is needed to obtain a better understanding of the relationship between hearing loss and listening effort, fatigue, and stress.

Appendix:

Literature Review Methodology

Literature for the review section was collected using first the Pubmed database. Designated limits that were utilized were "peer-reviewed" and "English". Keywords that were used were "hearing loss AND stress", "hearing loss AND fatigue", and "hearing loss AND listening effort". Articles were first excluded by title, then by abstract, then by full text, and finally by any duplicated that were noted. This system narrowed down the articles in each search. A total of 13 articles were selected for review on the Pubmed database. The same protocol was utilized using the ComDisDome database. A total of 3 articles were accepted for review on the ComDisDome database. It is important to note that 14 additional articles were used to help support or provide background on related topics.

Search Engine	Query	Search String	Hits	Results Excluded by Title	Results Excluded by Abstract	Results Excluded by Full Text	Results Excluded by Duplicates	Accepted for Review
Pubmed	#1	Hearing loss AND stress	419	408	8	0	0	3
	#2	Hearing loss AND fatigue	191	176	10	0	0	5
	#3	Hearing loss AND listening effort	55	41	9	0	0	5

ComDisDome	#1	Hearing loss AND stress	322	313	9	0	0	0
	#2	Hearing loss AND fatigue	130	121	7	0	1	1
	#3	Hearing loss AND listening effort	69	55	9	0	3	2

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