Listening effort: The impact of simulated hearing loss on cognitive functions in young adults

By

Taylor Burt

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The undersigned recommend the acceptance of this thesis

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Submitted by

Taylor V. Burt

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Peter Stewart

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Thesis Supervisor

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Alternate Reader

Grenfell Campus

Memorial University of Newfoundland

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Abstract

Previous research has suggested that hearing loss significantly impacts cognition in both school-age children and the elderly (e.g. Hicks & Tharpe, 2002; Lin, 2011). This study is the first to report the potential cognitive impacts of simulated, mild hearing loss for a young adult population. The current study investigated the effect of simulated mild, high-frequency hearing loss on performance and effort in a sample of 43 young adults (aged 18-23) who claimed to have normal hearing. On a standardized Speech-in-Nosie (SIN) Task, a significant effect of simulated hearing loss was found for both the sentence repetition accuracy, as well as the listening effort necessary to complete the task. Further, to test the interaction of cognitive load and hearing loss on accuracy and effort, participants completed a Memory Task under single- and dual-task conditions. While question response accuracy significantly decreased under dual-task conditions, accuracy was not significantly affected across hearing loss conditions. However, task effort was significantly increased in the simulated hearing loss condition. Analysis of order effects also suggested the employment of cognitive strategy, particularly in the SIN Task where the hearing conditions did not facilitate the recruitment of additional cognitive resources. All results are discussed from the standpoint of the Resource Allocation Hypothesis (Rabbitt, 1968). Overall, results suggested that mild hearing loss does negatively impact cognition and listening effort in young adults. However, young adults may be largely unable to detect this loss by themselves (Le Prell, Hensley, Campbell, Hall, and Guire., 2011; Widen, Holmes, Johnson, Bohlin and Erlandson., 2009). The Canadian healthcare system is also ill-equipped to detect such an impairment if it is not diagnosed in early childhood. Future research should place the spotlight on young adults to help remedy these problems.

Listening effort: The impact of simulated hearing loss on cognitive functions in young adults

Forty percent of Canadian adults (aged 20 to 79), and 8% of Canadian children 6 and older have hearing loss (Statistics Canada, 2016). Hearing loss refers to the required elevation of sound thresholds so that a sound is audible (Wolfe et al., 2015). According to the American Speech-Language-Hearing Association (ASHA), hearing loss can be broken down into three broad categories: conductive, sensorineural, and mixed hearing loss which differ in terms of the cause and treatment of the loss (ASHA, 2015). However, any type of hearing loss can have a significant impact on everyday functioning. For instance, increased occurrences of depressive symptoms and loneliness have been observed in older adults with hearing loss (Gopinath et al., 2009; Pronk et al., 2011). Moreover, there is evidence to support that hearing aid use in the elderly improves overall health, and social interaction (Boi et al., 2012). For younger individuals, hearing loss has been said to impact academic performance spanning primary to post-secondary education. For example, Bess, Dodd-Murphy, and Parker (1998) found that third grade children who had minimal hearing loss performed significantly worse than children with normal hearing on a basic skills test. This was further supported by Daud, Noor, Rahman, Sidek, and Mohamad (2010) who also found an association between poorer academic performance and mild hearing loss in primary school children. This association carries into post-secondary education as well. Richardson, Long, and Foster (2004) found that communication with, and learning from, classmates was more difficult for students with hearing loss in a distance education setting.

While the influence of hearing loss on academic performance has been investigated in young children and its influence on cognition has been examined in older adults, the population of young adults is often completely ignored. Although the current study examined the impact of simulated hearing loss on cognition in young adults, it is important to discuss the influence of hearing loss on cognition in the typically examined populations.

Hearing Loss Impacts Cognition in Older Adults

With regard to the impact of hearing loss on cognition in older adults, many researchers have come to the same conclusion: hearing loss is associated with lowered scores on cognitive tasks (Lin, 2011; Lin et al., 2011; Lindenberger, Scherer & Baltes, 2001; Lindenberger & Baltes, 1994). However, the causality of this phenomenon has yet to be determined. There are 4 common hypotheses, often separated into two groups, which are commonly used in the literature to explain the connection between hearing loss and cognition (Wong, Rapport, Billings, Ramachandran & Stach, 2018). The first group contains the Sensory Deprivation Hypothesis and the Common Cause Hypothesis. The Sensory Deprivation Hypothesis states that decreased sensory functioning leads to decreased cognitive engagement in one's environment, ultimately causing underperformance on cognitive tasks (Lindenberger & Baltes, 1994). Meanwhile, the Common Cause Hypothesis states that because both cognition and sensory functioning decline with age they are both caused by age-related changes in the structure of the brain (Lindenberger & Baltes, 1994). These hypotheses are difficult to tease apart in a cross sectional study as one cannot determine if the decline in sensory functioning caused the decline cognitive functioning, or if the decline in sensory and cognitive functioning occurred simultaneously due to changes in brain structure (Lindenberger & Baltes, 1994). The second group of hypotheses is comprised of the Perceptual Degradation Hypotheses and the Resource Allocation Hypothesis. The Perceptual Degradation Hypothesis states that those with decreased sensory functioning would show decreased performance on cognitive tasks because they misperceive the stimuli (Lindenberger, Scherer & Baltes, 2001). Whereas the Resource Allocation Hypothesis claims that hearing loss causes the diversion of cognitive resources to increased listening effort rather than to the completion of a given task, negatively impacting task performance (Rabbit, 1968). The main issue with differentiating these hypotheses comes from being unable to test exactly how auditory stimuli are being comprehended; is there an initial misperception or are additional cognitive resources being diverted to perception?

Two of these hypotheses were highlighted in a study by Lindenberger and Baltes (1994). In focusing on older adults, they found that visual and auditory acuity could account for 49.2% of the total variance in cognitive abilities and suggested that both the Sensory Deprivation Hypothesis and the Common Cause Hypothesis could explain their results (Lindenberger & Baltes, 1994). However, they claimed that their results provided more support for the Common Cause Hypothesis and stated that if the Sensory Deprivation Hypothesis were to be supported they would have observed a distinct relationship between basic sensory functioning and cognitive functioning, meaning those with severe sensory impairments would have poorer cognitive functioning, and this was not the case (Lindenberger & Baltes, 1994).

The effect of the Perceptual Degradation Hypothesis was explored in a later study when Lindenberger, Scherer, and Baltes (2001) simulated a decline in both visual and auditory acuity in 30 to 50 year olds. Their results showed that decreased visual and auditory acuity did not negatively impact participants' performance on cognitive tests, however, there was one exception (Lindenberger et al., 2001). They observed that deceased auditory acuity led to a slight decrease in working memory performance (Lindenberger et al., 2001). Therefore, they could not rule out the Perceptual Degradation Hypothesis entirely (Lindenberger et al., 2001).

Other studies provide stronger support for the Perceptual Degradation Hypothesis. For example, Murphy, Craik, Li, and Schneider (2000) conducted 5 related experiments comparing the recall abilities for word pairings across young and older adults (Murphy et al., 2000). They found that young adults exhibited the same recall abilities when listening to babble as older adults did in quiet, and when both groups faced the same level of stimulus degradation, they showed similar impairments in recall abilities (Murphy et al., 2000). However, their fifth experiment made it equally difficult for young and older adults to hear the auditory stimuli (Murphy et al., 2000). They found that younger adults still had better recall abilities which potentially supports the Resource Allocation Hypothesis as the result may have been caused by younger individuals having greater processing capacity which helped them perform better despite the noisy conditions (Murphy et al., 2000). In line with past research, the authors stated that these processes are difficult to differentiate, and it is likely that more than one hypothesis is correct (Murphy et al., 2000).

The findings of Rabbitt (1968) serve to ultimately distinguish the Resource Allocation Hypothesis from the Perceptual Degradation Hypothesis in this population. In the first of three experiments, it was reported that recall accuracy decreased for lists of digits when stimuli were presented with background noise (Rabbitt, 1968). Similar again to previous research, it was difficult to explain these results with one hypothesis leading Rabbitt (1968) to conclude that the Perceptual Degradation Hypothesis or the Resource Allocation Hypothesis may explain the results. A second experiment attempted to differentiate between the two competing hypotheses. Words lists, broken into two halves of some combination of noise and quiet were presented (Rabbitt, 1968). It was found that when the first list item was presented in noise the recall of the second item was unaffected (Rabbitt, 1968). This was taken as evidence against the Perceptual Degradation Hypothesis as recall of subsequent items was not affected by misperceived initial stimuli (Rabbitt, 1968). Rather, the results supported the Resource Allocation Hypothesis as the recall of the first stimuli was inhibited if the second stimuli was presented in noise, meaning that if more cognitive resources had to be allocated to comprehending the second stimulus through background noise, more resources were taken away from maintaining the initial stimulus, thus inhibiting the recall of that initial stimulus (Rabbitt, 1968). In a third, more ecologically valid experiment, it was tested if regular conversations were too low in cognitive resource requirements for noise levels to interfere with recall of information (Rabbitt, 1968). Again, these passages were broken into two halves with each half being presented in noise or quiet (Rabbitt, 1968). Results indicated that when the second half of a passage was presented in noise, the recall of the information in the first part of the passage suffered (Rabbitt, 1968). It was suggested that anything which makes the process of recognizing salient information more complicated than it already is will decrease the efficiency of recall (Rabbitt, 1968). This explanation is, again, supported by the Resource Allocation Hypothesis, which served as the theoretical standpoint of the current study.

Hearing Loss and Cognition in Children

While the Sensory Deprivation Hypothesis and the Common Cause Hypothesis may be difficult to tease apart in older adults, they are actually quite distinct when applied to the population of children. This distinction is made largely because, in children, age-related changes to the structure of the brain is not a factor. However, sensory deprivation leading to a decrease in cognitive engagement can be explored. Conway, Pisoni, Anaya, Karpicke, and Henning (2011) observed a significant difference in sequential learning in children who were pre-lingually deaf compared to age-matched children with normal hearing. However, Torkildsen, Arciuli, Haukedal, and Wie (2018) found that when verbal rehearsal strategies were not facilitated, there was no significant difference in the amount of learning between those with hearing loss and those with normal hearing. These hypotheses however, could not be used in the current study as a simulation of hearing loss was employed, and therefore it was not possible to mimic extended sensory deprivation or age-related changes in the structure of the brain.

The Perceptual Degradation Hypotheses and the Resource Allocation Hypothesis provide a much better theoretical framework for the current methodology. Hicks and Tharpe (2002) used the Resource Allocation Hypothesis when comparing school-age children with and without hearing loss in terms of listening effort. They carried out dual-task testing in quiet, +20 dB, +15 dB, and +10 dB signal-to-noise ratios (SNR) (Hicks & Tharpe, 2002). Since they suspected children with hearing loss may expend more cognitive resources on the primary task, it was hypothesized that those with hearing loss should have decreased performance on the secondary task if performance on the primary task was kept constant (Hicks & Tharpe, 2002). The results were in support of this hypothesis for subjective ratings of listening effort (Hicks & Tharpe, 2002). However, there was no significant decrease in performance on the secondary task in children with hearing loss across the SNR conditions, suggesting that a +10 dB SNR may not have been large enough to recruit significantly more cognitive resources (Hicks & Tharpe, 2002).

In a more recent study, Lewis et al. (2016) used verbal response time to compare listening effort in normal hearing school age children (8-12 years) to those with mild bilateral, or unilateral hearing loss in a speech recognition task. When the children attempted to recognize consonants, words, and sentences through varying SNRs it was found that those with hearing loss had fewer correct responses for consonants and sentences than those with normal hearing (Lewis et al., 2016). The authors suggested that for consonants, those with normal hearing had better access to acoustic-phonetic information (i.e. less perceptual degradation) than those with hearing loss, allowing them to perform better (Lewis et al., 2016). However, for full sentences they claimed those with normal hearing could avail of contextual information with less effort than those with hearing loss, allowing them to perform better (Lewis et al., 2016). These performance findings implicate both the Perceptual Degradation Hypothesis and the Resource Allocation Hypothesis. However, when they measured listening effort there was no difference found in verbal response time, suggesting that listening effort was not impacted by hearing loss, and thus the results did not support the Resource Allocation Hypothesis (Lewis et al., 2016). Together with the results of Hicks and Tharpe (2002), there seems to be a difference in listening effort across differing degrees of hearing loss (Lewis et al., 2016). Hicks and Tharpe (2002) were able to show that mild to moderate hearing loss had an effect on listening effort, whereas Lewis et al. (2016) did not have the same results for those with mild bilateral, and unilateral loss. The current study continued to examine performance and listening effort using SNRs of +10 dB, +5 dB, and 0 dB in a sample of young adults with simulated mild hearing loss.

Hearing Loss and Cognition in Young Adults

Compared to children and the elderly, the association between hearing loss and cognition in young adults (18-25 years) has not been as extensively studied. When used in experiments relating hearing loss to cognitive deficits, this age group is typically used only as a comparison group for the older adult population in order to illustrate the effects of aging (e.g. Baldwin & Ash, 2011; Murphy et al., 2000; Pichora-Fuller, Schneider & Daneman, 1995). One rare exception to this trend is a study conducted by Rakerd, Seitz, and Whearty (1996) comparing young adults with normal hearing to those with heterogeneous hearing loss (i.e. heterogeneous in severity). Participants performed dual-task testing such that they memorized a digit list and then listened to either noise or a passage (Rakerd et al., 1996). Results showed that both groups had more trouble remembering the list of digits after listening to the passage as the passage drew more cognitive resources away from digit remembering than the noise (Rakerd et al., 1996). It was also found that those with hearing loss showed significantly more digit forgetting overall as hearing loss diverted even more cognitive resources away from digit remembering (Rakerd et al., 1996). All of their results served to support the Resource Allocation Hypothesis and therefore the current study built upon this research.

The Identification of Hearing Loss in Young Adults

Many young adults believe they have normal hearing when in reality, this is not the case. According to Statistics Canada (2016), 86% of youth aged 12-19, and 87% of younger adults aged 20-39 were unaware of their hearing problems. Le Prell et al. (2011) conducted audiometric testing on college students who reported normal hearing during a preliminary telephone interview. While the observed levels of hearing loss found in their sample were not different from other unscreened samples, these students had reported normal hearing during a previous telephone interview (Le Prell et al., 2011). From these results Le Prell et al. (2011) concluded that college students were experiencing hearing loss they were not even aware of. These results were also supported by Widen et al. (2009) who found that of 25.9% of college students who failed their hearing screening, only 4.2% of them reported hearing loss. In simulating mild hearing loss in young adults with normal hearing the current study examined if this often unnoticed impairment has an impact on cognition.

The Current Study

The current study examined the effect of simulated mild hearing loss on cognitive performance in the often understudied population of young adults from a resource allocation standpoint. That is, both performance and subjective listening effort for a SIN Task and a Memory Task were examined. An additional between subjects comparison (i.e. single-task versus dual-task paradigm) was carried out in the Memory Task We chose to carry out this extra step in response to claims by Hicks and Tharpe (2002) that objective measures (i.e. dual-task performance) and subjective measures (i.e. rating scale) of listening effort were not correlated. It was hypothesized that those with simulated mild hearing loss would perform more poorly on the SIN Task and the Memory Task. Also, that subjective ratings of listening effort would increase from normal hearing to simulated mild hearing loss. For the between subjects comparison, it was hypothesized that when the Memory Task was completed with simulated mild hearing loss under dual-task conditions performance would be even less accurate, and listening effort would be further increased compared to a single-task paradigm. The goal of the current study was to provide research on the effect hearing loss may have on the cognition of an undergraduate student, specifically the effect of a mild loss which a typical student may not even be aware they have.

Method

Participants

Forty-three English-speaking participants from Grenfell Campus with a mean age of 20.07 years (*SD* = 1.42) voluntarily completed two cognitive tests in two distinct Hearing Conditions: a simulated mild, high-frequency hearing loss condition (Loss), and a no hearing loss condition (Normal). Prior to testing, participants were screened via email (see Appendix B) for all pre-existing hearing impairments, as well as any cognitive impairment and drug/medication use that they felt would impact cognitive performance. Potential participants who reported any past/current hearing impairment, impactful cognitive impairment, or drug/medication use did not proceed to sensory or cognitive testing. All participants were also required to have normal hearing with all octave frequency thresholds at or below 15 dB hearing level (HL) (ASHA, 2015). This was established before cognitive testing began using pure tone audiometry. There were six participants who had thresholds above 15 dB HL, and while they completed the study, their data was excluded from the data analysis as simulated hearing loss in addition to pre-existing hearing loss would result in a greater hearing impairment than desired during cognitive testing.

Materials

Recruitment.

The poster, and script used for recruitment purposes can be seen in Appendix A.

Screening.

Exclusion Email. Participants were screened for enrollment at Grenfell Campus, age, cognitive impairment, drug/medication use, hearing impairment, and native language via email which can be seen in Appendix B.

Informed Consent.

The informed consent form can be seen in Appendix C.

Sensory Testing.

Audiometric Evaluation. Audiometric thresholds were measured using a calibrated Amplivox 260 portable diagnostic audiometer. Pure-tone air conduction thresholds were obtained at 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz via over-the-ear headphones. All testing occurred in a sound-proof booth.

Hearing Loss Simulation. Mild high-frequency hearing loss for the SIN and the Memory Tasks was simulated using Audacity® computer editing and recording software version 2.3.0. Audacity® was used to create a high frequency roll-off of 12 dB HL per octave starting at 1000 Hz (Audacity Team, 2018). This roll-off effectively attenuated sound by 12 dB Full Scale (FS) at 2000 Hz, 24 dB FS at 4000 Hz, and 36 dB FS at 8000 Hz providing a simplistic simulation of mild sensorineural hearing loss (Audacity Team, 2018; Summers & Al-Dabbagh, 1982)

Cognitive Testing.

Speech-in-Noise (SIN) Task. Participants completed modified QuickSIN testing using over-the-ear headphones. The original QuickSIN test was modified for our testing purposes by only including three sets of three sentences spoken by a female talker with 5 key words per sentence as opposed to the usual five sets of five sentences (Etymotic

Research, 2006). Each sentence was also presented individually rather than in sequence to allow time for the measurement of listening effort. The sentences were presented at 70 dB sound pressure level (SPL) with background noise commencing at 60 dB SPL increasing by 5 dB with each sentence to reach 70 dB SPL, this meant that the three sentences had a SNR of +10 dB, +5 dB, and 0 dB respectively (Etymotic Research, 2006). Sentences were played for participants using Windows Media Player which were presented through the audiometer to ensure proper calibration.

Memory Task. Participants used over-the-ear headphones to listen to three pre-recorded phone messages spoken by a female talker. The messages were all approximately 20-30 seconds in length and included 6 specific details each. Four of these details were chosen to be questions that would be used measure participants' recall accuracy. Again, messages were played using Windows Media Player which were presented to participants via the audiometer. The scripts of the messages can be seen in Appendix D.

Listening Effort Scale. For all cognitive tests in both Normal and Loss conditions participants were asked to rate their listening effort on a scale of 1 (*Absolutely No Effort*) to 5 (*Maximum Effort*) following the completion of each individual sentence or passage (see Appendix E).

Demographics.

Questionnaire. Participants were asked to fill out a short questionnaire regarding demographic information (i.e. age, and gender). As well, participants were asked to rate how often they had been exposed to noise on a scale of 1 (*Not At All*) to 5 (*Very Often*).

Finally, participants were asked if they have an immediate family member with a diagnosed hearing impairment.

Debriefing.

The information sheet can be seen in Appendix F.

Procedure

This study examined the impact of simulated mild, high-frequency hearing loss on two cognitive tasks. The study was advertised to potential participants via posters, brief advertising in psychology classes, as well as utilizing the psychology research participant pool.

All participants signed an informed consent form. After providing consent participants entered the sound-proof booth to complete pure tone audiometry testing and ensure normal hearing thresholds were met. Once this preliminary sensory test was complete, participants progressed cognitive testing which was composed of a SIN Task followed by a Memory Task.

Each participant completed three sets of three QuickSIN sentences with background noise increasing in amplitude with each sentence. Participants were asked to repeat each sentence to the best of their ability and were instructed to take an educated guess if they were unsure as to what the talker had said. Participants were then scored by the experimenter on the number of predetermined key words correctly repeated per sentence. Following the repetition of each sentence, participants were asked to rate the listening effort required to complete the previous task (i.e. listen to the talker and repeat the sentence). The first set of sentences and the associated listening effort ratings were used as a practice run for each participant and contained no simulated hearing loss.

For the Memory Task participants listened to three passages pre-recorded to sound like voicemail messages. Following each message participants were asked four high-context questions about the information in the passage, and were instructed to answer them to the best of their ability, making guesses if necessary. They were also notified before listening to the messages that they would be required to answer questions afterward. After listening to each message and completing the subsequent four questions, participants were asked to rate the listening effort required to complete the previous task (i.e. listen to the message and answer the questions). As in the SIN Task, the first message and associated listening effort rating were used as a practice run for each participant and contained no simulated hearing loss.

Within the Memory Task, a between subjects manipulation was also carried out. While the first 20 participants completed the Memory Task in a single-task paradigm (as outlined above), the second 23 participants completed the task in a dual-task paradigm, creating two Task Groups: a Dual Task Group and a Single Task Group. In the Dual Task Group, participants were verbally presented with and asked to remember a list of five digits prior to listening to each message. They were informed that following the completion of the four high-context questions they would be asked to recall the list of digits. Participants were also instructed that recalling the list of digits was their main priority. Once again, all cognitive tasks were completed in both Loss, and Normal Hearing Conditions and participants were given a practice run for each of the tasks without any simulated hearing loss. Following the practice run either the first or second message contained the hearing loss simulation. Whether the participant experienced the Loss Hearing Condition first or the Normal Hearing Condition first was counterbalanced.

In general, participants were sorted into a Loss First or Normal First order which spanned all cognitive tasks.

After cognitive testing, participants were given an information sheet which included the contact information for the researchers if they had any questions or concerns about the study following their participation, as well as the contact information for Western Health's Audiology Department in case the study raised any concerns about their hearing (see Appendix F).

Results and Discussion

SIN Task Analysis

Sentence repetition accuracy.

Based on the Resource Allocation Hypothesis, it was expected that SIN accuracy scores would be negatively impacted by simulated hearing loss. Descriptive statistics for the repetition accuracy at three decreasing SNRs, across Loss and Normal Hearing Conditions, are shown in Table 1.

Table 1

Descriptive Statistics for Repetition Accuracy of SNR across Hearing Conditions

	Hearing condition		
SNR	Loss	Normal	Overall
+10dB			
M	4.38	4.52	4.45
SE	0.17	0.16	0.11
n	37	37	37
95% CI	[4.04, 4.17]	[4.18, 4.84]	[4.32, 4.66]
+5dB			
M	3.30	3.87	3.58
SE	0.25	0.21	0.19
n	37	37	37
95% CI	[2.80, 3.80]	[3.44, 4.29]	[3.19, 3.97]
0dB			
M	0.00	0.22	0.11
SE	0.00	0.09	0.04
n	37	37	37
95% CI	[0.00, 0.00]	[0.04, 0.39]	[0.02, 0.20]
Overall			
M	2.56	2.87	
SE	0.11	0.10	
n	37	37	
95% CI	[2.34, 2.78]	[2.66, 3.07]	

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

A 2 (Hearing Condition) by 3 (SNR) repeated measures analysis of variance (ANOVA) was conducted. Mauchly’s test indicated that the assumption of sphericity had been violated, $\chi^2 (2) = 11.05$, $p = .004$. Therefore, Huynh-Feldt tests are reported ($\varepsilon = .81$).

There was no significant interaction between Hearing Condition and SNR on sentence repetition accuracy, $F(1.77, 63.74) = 1.23$, $p = .295$, $\eta_p^2 = .03$. However, there was a significant main effect of SNR on repetition accuracy, $F(1.63, 58.80) = 368.48$, $p < .001$, $\eta_p^2 = .91$. Planned contrasts revealed that repetition accuracy was significantly higher at a SNR of +10 dB ($M = 4.45$, $SE = 0.11$) than at +5 dB ($M = 3.58$, $SE = 0.19$), $p < .001$, and significantly higher at +5 dB ($M = 3.58$, $SE = 0.19$) than at 0 dB ($M = 0.11$, $SE = 0.04$), $p < .001$. This effect is consistent with the function of the QuickSIN test, as each sentence within a set is intentionally more difficult to comprehend than the last (Killion et al., 2004). There was also a significant main effect of Hearing Condition on repetition accuracy, $F(1.00, 36.00) = 5.90$, $p = .020$, $\eta_p^2 = .14$. Repetition accuracy was significantly higher in the Normal Hearing Condition ($M = 2.87$, $SE = 0.10$) than the Loss Hearing Condition ($M = 2.56$, $SE = 0.11$), providing evidence supporting that simulated hearing loss has a negative impact on cognition in this population. Importantly, this also supports the validity of the simulated hearing loss manipulation.

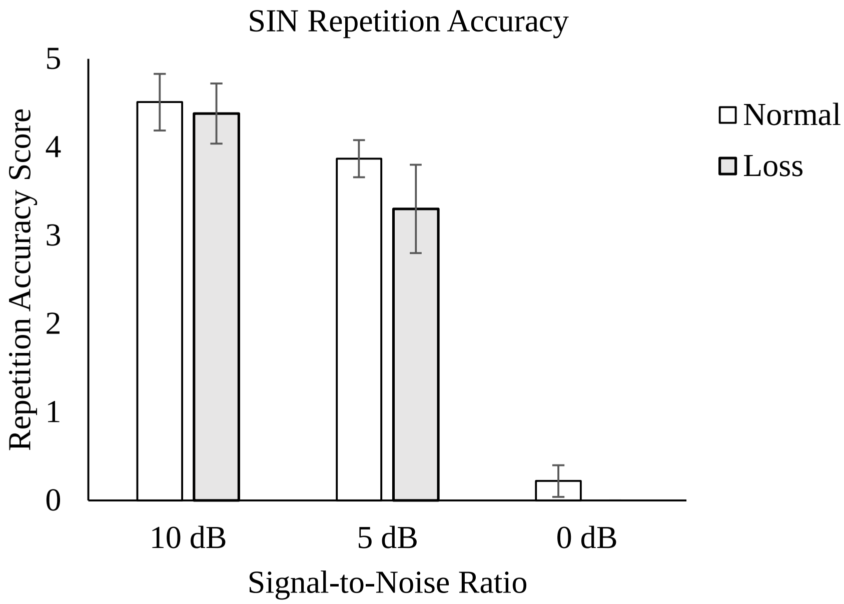

Figure 1. Repetition accuracy based on Hearing Condition and SNR.

Listening effort.

It was also hypothesized that, in terms of listening effort, a negative impact of simulated hearing loss would be observed. According to the Resource Allocation Hypothesis, hearing loss would cause an increased demand on cognitive resources, subjectively increasing listening effort. Descriptive statistics for listening effort across the three decreasing SNRs, and separated by Loss and Normal Hearing Conditions, are shown in Table 2. In line with these hypotheses, the highest rating of listening effort recorded was at the 0 dB SNR in the Loss Hearing Condition.

Table 2

Descriptive Statistics for Listening Effort of SNR across Hearing Conditions

	Hearing condition		
SNR	Loss	Normal	Overall
+10dB			
M	2.30	2.05	2.18
SE	0.17	0.20	0.14
n	37	37	37
95% CI	[1.96, 2.64]	[1.65, 2.46]	[1.90, 2.45]
+5dB			
M	3.27	2.70	2.98
SE	0.18	0.18	0.13
n	37	37	37
95% CI	[2.91, 3.63]	[2.34, 3.06]	[2.72, 3.25]
0dB			
M	4.76	4.54	4.65
SE	0.12	0.13	0.12
n	37	37	37
95% CI	[4.52, 5.00]	[4.27, 4.81]	[4.41, 4.88]
Overall			
M	3.44	3.10	
SE	0.12	0.12	
n	37	37	
95% CI	[3.21, 3.68]	[2.86, 3.34]	

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

A 2 (Hearing Condition) by 3 (SNR) repeated measures ANOVA was conducted. Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (2) = 12.74, p = .002. Therefore, Huynh-Feldt tests are reported (ε = .79).

There was no significant interaction between Hearing Condition and SNR on listening effort, $F(2.00, 72.00) = 1.13$, $p = .328$, $\eta_p^2 = .03$. However, there was a significant main effect of SNR on listening effort, $F(1.59, 57.13) = 131.38$, $p < .001$, η_p^2 = .79. Planned contrasts revealed that listening effort was significantly higher at a SNR of

0 dB (*M* = 4.65, *SE* = 0.12) than at +5 dB (*M* = 2.98, *SE* = 0.13), $p < .001$, and significantly higher at +5 dB (*M* = 2.98, *SE* = 0.13) than at +10 dB (*M* = 2.18, *SE* = 0.14), $p < .001$. Where we see a decrease in repetition accuracy as SNR decreases, the effort necessary to complete the repetition task increases. This general trend was supported by significant negative correlations between accuracy and listening effort for an SNR of +10 dB and +5 dB in the Loss Hearing Condition (+10 dB SNR: $r = -.70$, $p < .001$, +5 dB SNR: $r = -.57$, $p < .001$), as well as the Normal Hearing Condition (+10 dB SNR: $r = -.41$, $p = .011$, +5 dB SNR: $r = -.60$, $p < .001$). A correlation could not be carried out for the 0 dB SNR as accuracy scores were not high enough. These results are consistent with both the Resource Allocation Hypothesis as well as the purpose of the QuickSIN test.

Most importantly, however, there was a significant main effect of Hearing Condition on listening effort, $F(1.00, 36.00) = 5.69$, $p = .022$, $\eta_p^2 = .14$. Listening effort was significantly higher in the Loss Hearing Condition (*M* = 3.44, *SE* = 0.12) than the Normal Hearing Condition (*M* = 3.10, *SE* = 0.12). These results provide evidence to support that people who are experiencing hearing loss are not only performing SIN testing with less accuracy, but it also requires more listening effort to do so.

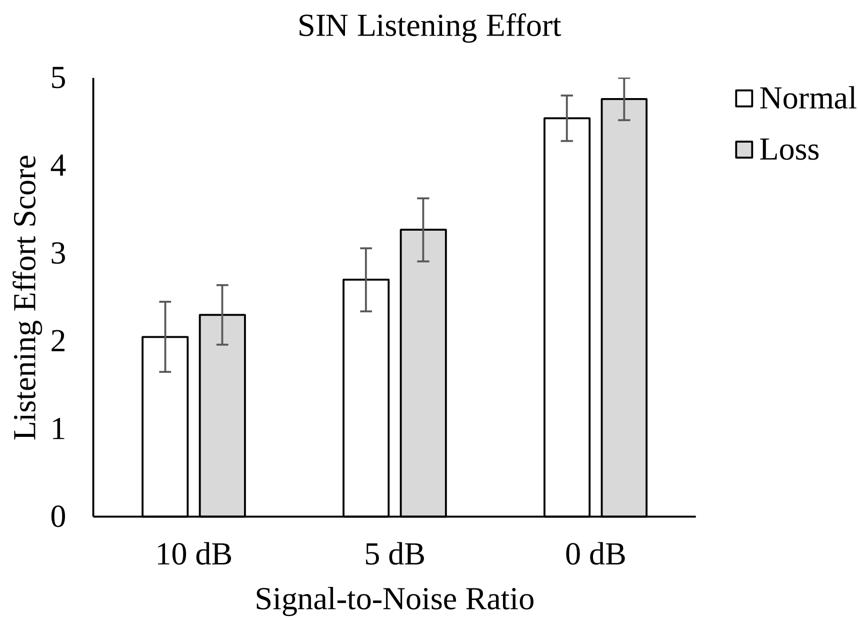

Figure 2. Listening effort score based on Hearing Condition and SNR.

Memory Task Analysis

Question response accuracy.

It was hypothesized that simulated hearing loss would also have an effect on response accuracy, similar to the SIN results (i.e. a decrease in response accuracy), on the Memory Task. Descriptive statistics for question response accuracy across Loss and Normal Hearing Conditions are shown in Table 3.

Table 3

Descriptive Statistics for Question Response Accuracy across Hearing Condition and Task Group

	Hearing condition		
Task group	Loss	Normal	Overall
Single task			
M	2.44	2.50	2.47
SE	0.27	0.24	0.20
n	18	18	36
95% CI	[1.89, 3.00]	[2.01, 2.99]	[2.06, 2.88]
Dual task			
M	1.47	1.61	1.54
SE	0.27	0.23	0.20
n	19	19	38
95% CI	[0.93, 2.01]	[1.13, 2.08]	[1.14, 1.94]
Overall			
M	1.96	2.47	
SE	0.19	0.17	
n	37	37	
95% CI	[1.57, 2.35]	[1.71, 2.39]	

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

A 2 (Hearing Condition) by 2 (Task Group) repeated measures ANOVA was conducted. There was no significant interaction between Hearing Condition and Task Group on question response accuracy, $F(1.00, 35.00) = 0.03$, $p = .866$, $\eta_p^2 = .001$. There was also no significant main effect of Hearing Condition on question response accuracy, $F(1.00, 35.00) = 0.18$, $p = .68$, $\eta_p^2 = .01$. One possible explanation for this effect is that this task was completed in quiet whereas this type of task is usually completed amongst competing noises. Therefore, the simulated hearing loss alone did not put enough of a strain on cognitive resources to elicit a deficit as was similarly observed by Hicks and Tharpe (2002) in children with an SNR of +10 dB. However, there was a significant main effect of Task Group on question response accuracy, $F(1.00, 35.00) = 10.98$, $p =$

.002, $\eta_p^2 = .24$. Question response accuracy was significantly higher in the Single Task Group (*M* = 2.47, *SE* = 0.20) than the Dual Task Group (*M* = 1.54, *SE* = 0.20). This effect was expected as a single task would not be as cognitively demanding as a dual task, allowing participants to devote more cognitive resources to the task in the single-task paradigm.

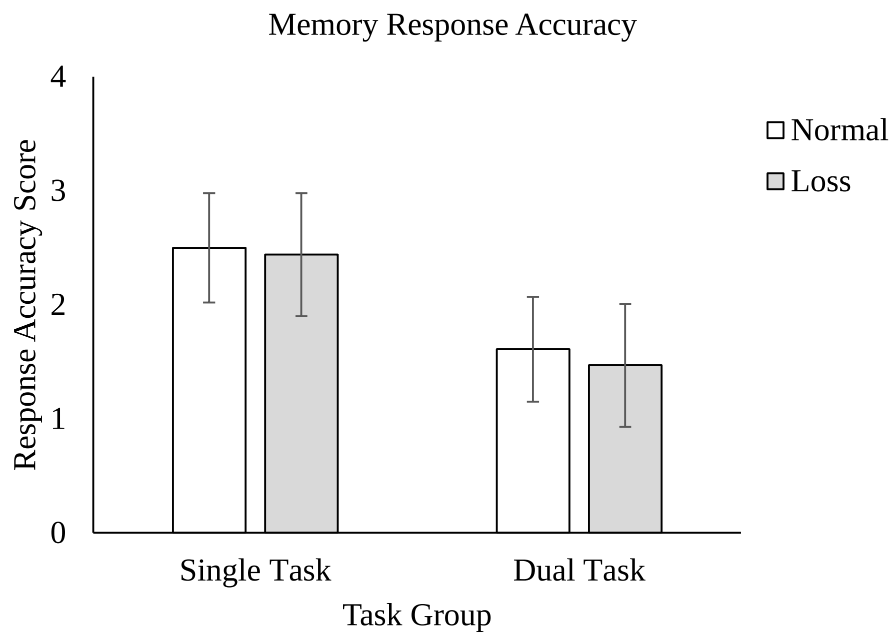

Figure 3. Response accuracy based on Hearing Condition and Task Group.

Listening effort.

An increase in listening effort was also anticipated for the Memory Task. It was hypothesized that, due to cognitive demand, listening effort would be further increased in the dual-task paradigm. Descriptive statistics for listening effort across Loss and Normal Hearing Conditions are shown in Table 4. In line with the hypotheses stated, the highest listening effort recorded was for the Dual Task Group in the Loss Hearing Condition.

Table 4

Descriptive Statistics for Listening Effort across Hearing Condition and Task Group

	Hearing condition		
Task group	Loss	Normal	Overall
Single task			
M	3.28	2.89	3.08
SE	0.27	0.31	0.26
n	18	18	36
95% CI	[2.73, 3.82]	[2.25, 3.53]	[2.55, 3.62]
Dual task			
M	3.94	3.47	3.71
SE	0.28	0.32	0.27
n	17	17	34
95% CI	[3.38, 4.50]	[2.82, 4.13]	[3.16, 4.25]
Overall			
M	3.61	3.18	
SE	0.19	0.22	
n	35	35	
95% CI	[3.22, 4.00]	[2.72, 3.64]	

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

A 2 (Hearing Condition) by 2 (Task Group) repeated measures ANOVA revealed no significant interaction between Hearing Condition and Task Group on listening effort, $F(1.00, 33.00) = 0.05$, $p = .824$, $\eta_p^2 = .002$. There was also no significant main effect of Task Group on listening effort, $F(1.00, 33.00) = 2.75$, $p = .107$, $\eta_p^2 = .08$. While it was hypothesized that the dual task would demand more cognitive resources than the single task group, both groups had relatively high ratings of listening effort ($M_{\text{single}} = 3.08$ and $M_{dual} = 3.71$ out of a possible 5). It is possible that many participants were already expending maximum cognitive resources when completing the single task, and therefore could not expend significantly more cognitive resources when completing the dual task. However, there was a significant main effect of Hearing Condition on listening effort,

$F(1.00, 33.00) = 5.53$, $p = .025$, $\eta_p^2 = .14$. Listening effort was significantly higher in the Loss Hearing Condition ($M = 3.61$, $SE = 0.19$) than the Normal Hearing Condition ($M = 3.18$, $SE = 0.22$). This suggests that those experiencing simulated hearing loss may recruit more cognitive resources (i.e. increase listening effort) to perform as well as those with normal hearing in terms of accuracy.

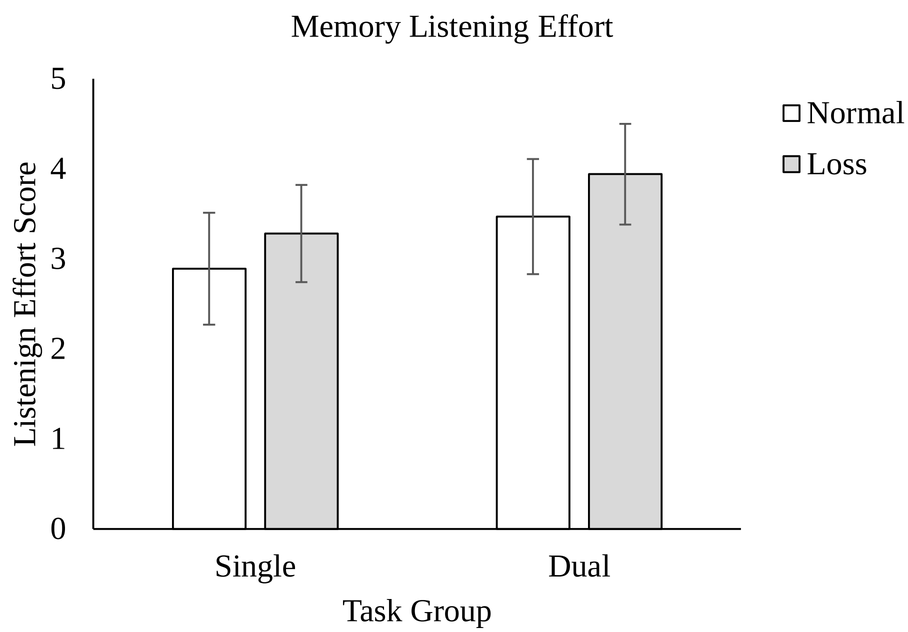

Figure 4. Listening effort score based on Hearing Condition and Task Group.

General Discussion

Using the Resource Allocation Hypothesis, Wong et al. (2018) suggested that the impact of hearing loss on speech comprehension was due to the diversion of cognitive resources to increased listening effort rather than to the completion of a given task (Rabbit, 1968). The hypotheses for the current study were formed in accordance with this theoretical standpoint, and the results showed consistent support for the Resource Allocation Hypothesis, even when hearing loss was simulated at a mild severity with a relatively simplistic simulation (i.e. no temporal or spatial jitter).

In the SIN Task participants with simulated hearing loss reported increased listening effort as well as decreased repetition accuracy. It seems they had to recruit more cognitive resources to complete the task of listening which in turn limited their ability to repeat the key words as accurately as they did with normal hearing. In the Memory Task, participants with simulated hearing loss reported increased listening effort in order to complete the task with a similar response accuracy as they did with normal hearing. It is important to point out here that the Memory Task was completed in quiet, so while there was no decrease in accuracy as there was in the SIN Task, this could be due to the fact that participants completed this task in optimal listening conditions (i.e. in a sound proof-booth) which is not often the case for a university student listening environment (Cheesman, Jennings, & Klinger, 2013). Future research should have participants complete a task of similar cognitive load (i.e. 20-30 second passage) under various SNR conditions to see if there is an effect on response accuracy in this population.

While there were no hypothesized order effects, a check of the counterbalancing was conducted (See Appendix G for results). In terms of order effects there seems to have been a strong effect of cognitive strategy. Though not intended, the observed order effects are in line with the Resource Allocation Hypothesis. The Framework for Understanding Effortful Listening (FUEL) model by Pichora-Fuller et al. (2016) outlines the important and necessary connection between cognition and listening. They stated that input-related demands, which includes both listener factors (i.e. sensory impairments such as hearing loss) as well as context factors (i.e. situational scripts such as understanding a pattern), dictate the cognitive capacity available to devote to a particular response, which they claimed can be self-reported listening effort or accuracy of recall (Pichora-Fuller et al., 2016). This model supports the SIN results as participants were less accurate for the repetition of key words at the +10 dB SNR in the first set of sentences they completed. A negative impact of hearing loss (i.e. decreased accuracy) was hypothesized, however, Hicks and Tharpe (2002) observed that hearing loss had no impact on performance accuracy at the +10 dB SNR because the task was not challenging enough to require those with hearing loss to recruit more cognitive resources. Instead, results seemed to suggest a cognitive strategy effect. Participants did not yet have a situational script formed for the pattern of the task. They may have been more vigilant in completing the first set of sentences as they were unsure of the difficulty they would encounter next. However, by the second set of sentences there was an increase in accuracy because they grasped the pattern, allowing them to allocate less resources to context factors (i.e. the pattern) and more to actually completing the task.

This framework can also be used to explain the effect of order on listening effort in the SIN Task. There was an increase in effort for the +10 dB SNR sentence within the first set of sentences in both Hearing Conditions. This can also be attributed to the impact of context factors. When presented with the +10 dB SNR sentence in the first set of sentences, the participants had just completed a difficult practice sentence (i.e. 0 dB SNR) and therefore likely adopted a strategy that would help them deal with another difficult sentence. That is, they would recruit more cognitive resources because they had planned for another potentially difficult sentence. However, this does not explain why the effect observed did not match the hypothesized impact of hearing loss (i.e. increased listening effort). For this, the difficulty associated with the each SNR must be examined. According to Meriweather (2016) previous exposure to a difficult task can cause the recruitment of the effort necessary to complete a difficult task in subsequent trials, meaning exposure to a difficult task facilitates the adoption of a strategy in preparation for that difficulty level. The combination of the lack of situational script and carry-over effort from the 0 dB SNR repetition of the practice led to the increased listening effort for both Orders of Hearing Conditions at the first +10 dB SNR sentence. There was a similar effect of cognitive strategy within listening effort for the Memory Task. However, in this case there was no difficult practice task previous to the first analyzed task so a decrease in effort was observed.

While the standpoint of the Resource Allocation Hypothesis was used to form all of the hypotheses and explain the results of the current study, Wong et al. (2018) use a number of different hypotheses to describe the theoretical connection between hearing loss and cognition in older adults. As previously stated, due to the methodology employed by the current study the results could not be used to provide evidence for or against the Sensory Deprivation Hypothesis or the Common Cause Hypothesis. However, the Perceptual Degradation Hypothesis can be explored. While this framework cannot fully explain listening effort scores, as it does not discuss how effort plays a role in performance, the SIN Task accuracy results are consistent with this hypothesis as simulated hearing loss caused a decreased accuracy for sentence repetition. However, the Memory Task results do not show any significant difference in terms of accuracy, and when examined alone they would suggest that degraded sensory perceptions did not have any impact on the Memory Task.

It is much more challenging to explain the order effects observed in the SIN Task. If we examine accuracy alone at the +10 dB SNR in the Normal First Condition it would seem that degraded sensory perception had a positive effect on accuracy, and then somehow switched to have a negative impact at the +5 dB SNR, 0 dB SNR, and for all SNRs of the Loss First Order. The impact of order effects on listening effort in general cannot be examined further as the Perceptual Degradation Hypothesis places all emphasis on the stimulus itself, not the effort exerted by the person to counteract the taxation of cognitive resources.

When we assess both of these theoretical perspectives it is clear that the Resource Allocation Hypothesis provides a better explanation in terms of accuracy and listening effort for these cognitive tasks in this population of young adults. This does not mean that this theoretical perspective, or the current study in general is not without its limitations. To exhibit the recruitment of cognitive resources the current study used the subjective measure of listening effort. As with all subjective measures there are a number of different ways in which the rating can be perceived. While participants were instructed to rate their listening effort these instructions could be misconstrued as a measure of hardness of the task. To avoid this problem, the between subjects manipulation employed an objective approach in the form of a dual-task paradigm in the Memory Task, which lessened question response accuracy but had no impact on listening effort. This disconnect however, may be explained by the methodology of the dual task. Regardless of performance on the primary task (remembering the 5 digits) participants' scores were included in the analysis, assuming they devoted some cognitive resources to remembering the numbers. This is not typically the case for dual task studies, and future research should examine the impact of hearing loss on both subjective (i.e. listening effort ratings) and objective (i.e. dual-task performance) measures where the primary task in dual-task paradigm can easily be kept constant.

Conclusion

Pichora-Fuller et al. (2016) stress the need for understanding auditory cognition as the basic function of hearing is achieved through the ear, however our brain, and thus, cognition, is necessary to make meaningful interpretations of what has been heard. They also highlight the clinical relevance of auditory cognition to the rehabilitation and assessment of those who are experiencing hearing impairment (Pichora Fuller et al., 2016). Hearing care in Canada has yet to recognise this important connection in young adults. For example, Canada has employed early hearing detection and intervention programs, which could facilitate follow-up care throughout childhood and even into young adulthood (Speech-Language and Audiology Canada, 2019). However, these programs were considered to be insufficient in 7 of the 13 provinces/territories by Speech-Language and Audiology Canada (2019). Also, the diagnosis of hearing loss by a health professional is much more common in older individuals in Canada. In 2013, hearing loss was diagnosed in 19.9%-26.8% of adults aged 40-79 years, while diagnosis only occurred in 13% of younger adults aged 20-39 years (Statistics Canada). Taken together, if hearing loss is not diagnosed in childhood, it is unlikely that it will be recognised until older adulthood. This leaves the young adults having to deal with undiagnosed and uncorrected hearing loss.

Considering the results of the current study, mild hearing loss has an impact on some basic, and vital, aspects of cognition. Regular hearing screening is not currently a part of student life, and it is a possibility that a young adult would not recognize the hearing loss themselves. This possibility has been documented by Widen et al. (2009), Le Prell et al. (2011), and it was also supported by the current finding of 6 individuals who reported normal hearing thresholds when responding to the call for participants, however, upon pure tone audiometry testing had hearing thresholds above 15 dB HL. Future research should be conducted on young adults with hearing impairment to further understand its impact on cognition and how the health care system in Canada can be adjusted to better care for this population.

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2019 Report Card on Early Hearing Detection and Intervention Programs, Canadian Infant Hearing Task Force: Speech-Language & Audiology Canada, Canadian Academy of Audiology, Online resource.

Appendix A

Participant Recruitment Script

Hi everyone, my name is Taylor Burt and I'm a fourth year BSc. psychology student. This year I'm participating in the honours program and conducting research on hearing loss in undergraduate students. I'll be looking for people ages 17-25 with normal hearing to participate so I can simulate hearing loss and measure performance on two cognitive tests. The testing will only take about an hour of your time, and you will receive course credit for participating. I'm also very flexible with scheduling, so you will be able to participate whenever you're free. If you would like to participate, or would like to know more about the study you can write your name and email on the sign-up sheet and I will email you to set up a time, or you can email me at tvburt@grenfell.mun.ca! Thank you!

Research Participants Needed!

- Are you between the ages of 17 and 25?
- Have you ever wondered how hearing loss affects our everyday lives?

You may be eligible to participate in a psychology honours project studying hearing loss and cognition!

Please contact Taylor Burt to participate!

Contact Information:

tvburt@grenfell.mun.ca
tvburt@grenfell.mun.ca
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tvburt@grenfell.mun.ca

Appendix B

Hi there,

Thanks again for your interest in my project! Before we arrange a time I have to inform you that there are several exclusion criteria associated with the study, some of which you may have seen on the Participant Pool or my poster, but there are few others you need to be aware of.

Do any of the following statements apply to you?

1) I am not a Grenfell Campus student.
   - This study's main focus is undergraduate students

2) I am under the age of 17, or over the age of 25.
   - The study's main focus is young adults

3) I have taken drugs or medications that would interfere with cognitive performance in the last 24 hours.
   - This applies only for test day as any sort of altered cognitive state could impact measured performance

4) I have been diagnosed with a condition that would interfere with cognitive performance.
   - The study measures cognitive performance

5) I have been diagnosed with a hearing impairment.
   - The study involves simulated hearing loss

6) English is not my native language.
   - This study involves reading, comprehending, and listening to sentences in English

Unfortunately, if you feel any of these statements apply to you, you will not be able to participate in the study. These criteria have been approved by the ethics review process in the psychology program at Grenfell Campus, Memorial University of Newfoundland and has been found to be in compliance with Memorial University's ethics policy.

If none of the above statements apply to you I will set up a time for testing this week.

Thanks,

Taylor Burt

Appendix C

Informed Consent Form

The purpose of this Informed Consent Form is to ensure you understand the nature of this study and your involvement in it. This consent form will provide information about the study, giving you the opportunity to decide if you want to participate.

Researchers: This study is being conducted as part of the course requirements for Psychology 4951 and 4959: Honours Project in Psychology. This research is being conducted under the supervision of Dr. Peter Stewart.

Purpose: The study is designed to investigate the effect of simulated hearing loss on basic cognitive performance in young adults.

Task Requirements: You will be asked to complete a preliminary pure tone audiometry test to determine hearing thresholds. This test is not diagnostic in nature. Then you will be asked to complete a speech-in-noise task, and a message memory task, each time with a differing degree of simulated hearing loss. Following each task you will be asked to rate listening effort on a scale provided. By participating in this study, you acknowledge that you are a college/university student.

Duration: The study will take approximately 1 hour to complete.

Risks and Benefits: There are no obvious risks involved with your participation in this study. If you are currently taking a psychology course at Grenfell Campus you may receive course credit for your participation in this study as stipulated by your instructor.

Anonymity: All information will be analyzed and reported on a group basis. Thus, individual responses cannot be identified in any reporting of the results. All participant information will be kept on a password protected computer or in a locked cabinet.

Right to Withdraw: Your participation in this research is totally voluntary and you are free to stop participating at any time. However, once you complete this study and leave the testing area, your data cannot be removed because we are not collecting any identifying information and therefore we cannot link to individual responses.

Contact Information: If you have any questions or concerns about the study, please feel free to contact Taylor Burt at tvburt@grenfell.mun.ca or Dr. Peter Stewart at pstewart@grenfell.mun.ca. If you have any concerns regarding the ethics of this study, you can contact the Grenfell Campus Research Ethics Board Chair, Dr. Daniel Nadolny, at dnadolny@grenfell.mun.ca. Also, if you are interested in the results of this study, they will be presented at the Nick Novakowski Senior Project Conference on April 3rd, 2019.

This study has been approved by an ethics review process in the psychology program at Grenfell Campus, Memorial University of Newfoundland and has been found to be in compliance with Memorial University's ethics policy.

By signing this form, I acknowledge that I am a college or university student and I have been informed of, and understand, the nature and purpose of the study, and I freely consent to participate.

____________________	____________________	____________________
Signature	Student #	Date

Appendix D

Message Memory Task Script

Hi there, this is Karen calling from Dr. Michael's office. I'm calling to let you know that your appointment for May 25th has been cancelled as Dr. Michael will be out of the office. Your appointment has been rescheduled for June 7th. If you are not available during this time you can call our office anytime from Monday to Friday from 9:00 AM to 4:00 PM at 456-7201 to change your appointment. Thank you and have a great day!

What was the name of the person calling?

When was the date of the original appointment?

What is the date of the new appointment?

When can you call the office?

Good morning. My name is Rachel and I am returning your call regarding where to drop off your forms. Simply drop by our office at 45 Aspen Drive. Place all forms that must be signed by an administrator in the green box on the counter at our front office. Once your forms are ready for pick up an administrator will contact you directly, this process usually takes 10 to 14 business days. If you have any more questions regarding these forms please call 222-6708. Thanks, bye!

What was the name of the person calling?

What is the address of the administrator's office?

Where should you place all forms that must be signed by an administrator?

Approximately how long will it take for the forms to be processed?

Hello, we are pleased to inform you that after reviewing your resume we would like to invite you to come in for an interview. Ms. Nancy Smith will be conducting your interview at 1:45 PM on Thursday. The interview will be taking place in our board room on the third floor, it's the 5th door on the right. Please bring a printed copy of your resume with you. We are excited to meet with you, bye bye!

What day of the week is the interview?

What floor is the board room on?

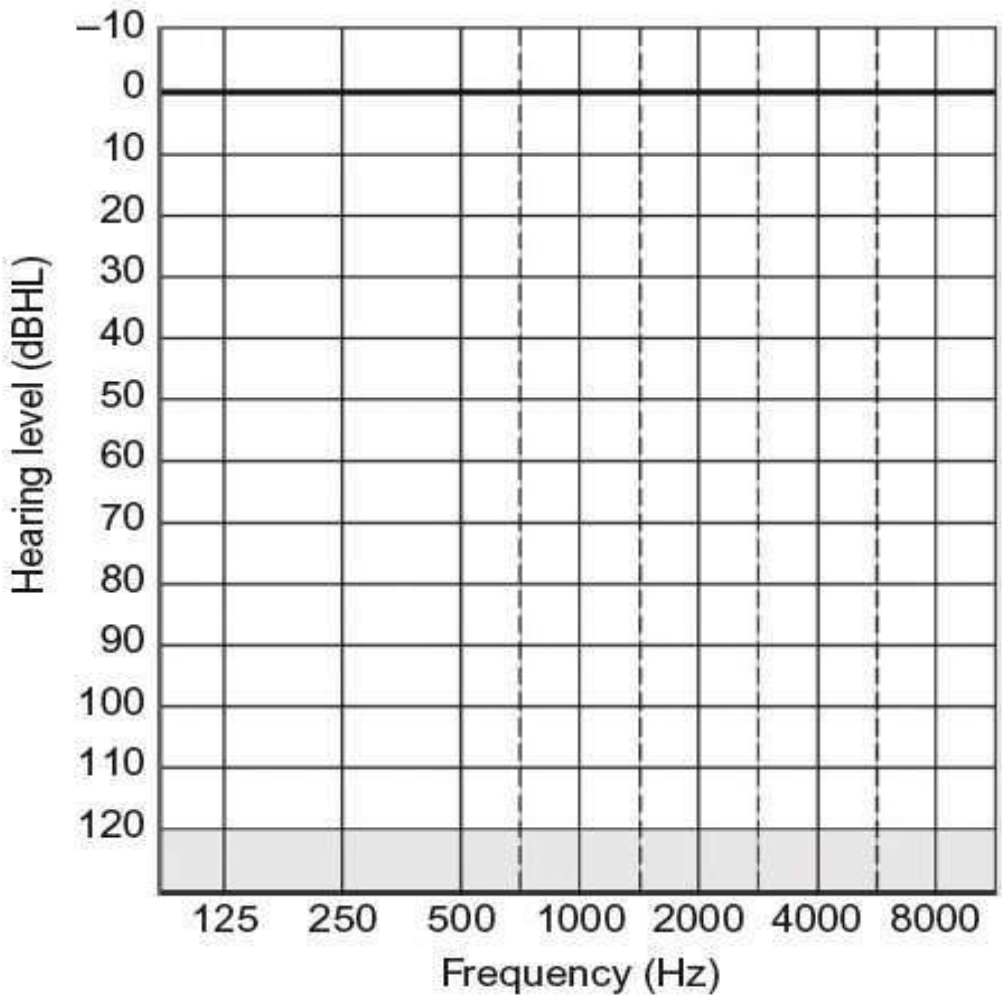
What do you need to bring with you?

What is the name of the person conducting your interview?

Appendix E

Experimenter Score Sheet

Task 1: Pure Tone Audiometry



Above Selected Threshold:

Y N

Task 2: Speech-in Noise

Practice A (N) **Score**

1) North winds bring colds and fevers. S/N 10 ______

Effort Questionnaire

2) A sash of gold silk will trim her dress. S/N 5 ______

Effort Questionnaire

3) Fake stones shine but cost little. S/N 0 ______

Effort Questionnaire

TOTAL______

List 1 (L) **Score**

1) A vent near the edge brought in fresh air. S/N 10 ______

Effort Questionnaire

2) It is a band of steel three inches wide. S/N 5 ______

Effort Questionnaire

3) The weight of the package was seen on the high scale. S/N 0 ______

Effort Questionnaire

TOTAL ______

List 2 (N) **Score**

1) It was done before the boy could see it. S/N 10 ______

Effort Questionnaire

2) Crouch before you jump or miss the mark. S/N 5 ______

Effort Questionnaire

3) The square peg will settle in the round hole. S/N 0 ______

Effort Questionnaire

TOTAL______

Task 3: Message Memory

1) **Practice (N)**
   Hello, we are pleased to inform you that after reviewing your resume we would like to invite you to come in for an interview. Ms. Nancy Smith will be conducting your interview at 1:45 PM on Thursday. The interview will be taking place in our board room on the third floor, it's the 5th door on the right. Please bring a printed copy of your resume with you. We are excited to meet with you, bye bye!

   What day of the week is the interview?

   What floor is the board room on?

   What do you need to bring with you?

   What is the name of the person conducting your interview?

Effort Questionnaire

2) **Doctor (L)**
   Hi there, this is Karen calling from Dr. Michael's office. I'm calling to let you know that your appointment for May 25th has been cancelled as Dr. Michael will be out of the office. Your appointment has been rescheduled for June 7th. If you are not available during this time you can call our office anytime from Monday to Friday from 9:00 AM to 4:00 PM at 456-7201 to change your appointment. Thank you and have a great day!

   What was the name of the person calling?

   When was the date of the original appointment?

   What is the date of the new appointment?

   When can you call the office?

Effort Questionnaire

3) **Administrator (N)**
   Good morning. My name is Rachel and I am returning your call regarding where to drop off your forms. Simply drop by our office at 45 Aspen Drive. Place all forms that must be signed by an administrator in the green box on the counter at our front office. Once your forms are ready for pick up an administrator will contact you directly, this process usually takes 10 to 14 business days. If you have any more questions regarding these forms please call 222-6708. Thanks, bye!

   What was the name of the person calling?

   What is the address of the administrator's office?

   Where should you place all forms that must be signed by an administrator?

   Approximately how long will it take for the forms to be processed?

Participant Score Sheet

Please do not make any identifying marks on any of these pages.

Task 2: Speech-in Noise

Please circle the amount of listening effort required to complete the previous task.

Practice A

Sentence 1)

1	2	3	4	5
No Effort				Maximum Effort

Sentence 2)

1	2	3	4	5
No Effort				Maximum Effort

Sentence 3)

1	2	3	4	5
No Effort				Maximum Effort

List 1

Sentence 1)

1	2	3	4	5
No Effort				Maximum Effort

Sentence 2)

1	2	3	4	5
No Effort				Maximum Effort

Sentence 3)

1	2	3	4	5
No Effort				Maximum Effort

List 2

Sentence 1)

1	2	3	4	5
No Effort				Maximum Effort

Sentence 2)

1	2	3	4	5
No Effort				Maximum Effort

Sentence 3)

1	2	3	4	5
No Effort				Maximum Effort

PLEASE DO NOT TURN THIS PAGE UNTIL INSTRUCTED

Task 3: Message Memory

Please answer the following questions regarding each phone message.

Practice

1) What day of the week is the interview?

2) What floor is the board room on?

3) What do you need to bring with you?

4) What is the name of the person conducting your interview?

5) How much listening effort was required to complete the previous task?

1	2	3	4	5
No Effort				Maximum Effort

PLEASE DO NOT TURN THIS PAGE UNTIL INSTRUCTED

Doctor

1) What was the name of the person calling?

2) When was the date of the original appointment?

3) What is the date of the new appointment?

4) When can you call the office?

5) How much listening effort was required to complete the previous task?

1	2	3	4	5
No Effort				Maximum Effort

PLEASE DO NOT TURN THIS PAGE UNTIL INSTRUCTED

Administrator

1) What was the name of the person calling?

2) What is the address of the administrator's office?

3) Where should you place all forms that must be signed by an administrator?

4) Approximately how long will it take for the forms to be processed?

5) How much listening effort was required to complete the previous task?

1	2	3	4	5
No Effort				Maximum Effort

Questionnaire

1) How often have you been exposed to noisy events? (Please circle your response)

1 2 3 4 5

Not At All Very Often

2) Has anyone in your immediate family been diagnosed with a hearing impairment? (Please circle your response)

Yes No Unsure Prefer Not to Specify

3) What is your age? ___________

4) What is your gender? ___________

Appendix F

Information Form

If you have any questions or concerns about the study, or if you are interested in the results of the study, please feel free to contact Taylor Burt at tvburt@grenfell.mun.ca, or Dr. Peter Stewart at pstewart@grenfell.mun.ca. If this study raises any potential concerns about your hearing, we suggest making an appointment with an audiologist. To do so please contact your general practitioner or Western Health at 709-637-5374 or http://westernhealth.nl.ca/index.php/programs-and-services/services-a-z/audiology to fill out a referral form (self-referrals are accepted). The results of the study will also be presented on April 3rd, 2019 at the Nick Novakowski Senior Project Conference at Grenfell Campus, you are invited to attend. Thank you for your participation. We appreciate it.

Appendix G

SIN: Order Effects Analysis

Sentence repetition accuracy.

While there were no hypothesized order effects on SIN accuracy, a check of the counterbalancing was conducted. Descriptive statistics for repetition accuracy at three SNRs across Hearing Condition and Order of Hearing Condition are shown in Table 5.

Table 5

Descriptive Statistics for Repetition Accuracy of Hearing Condition by SNR by Order of Hearing Condition

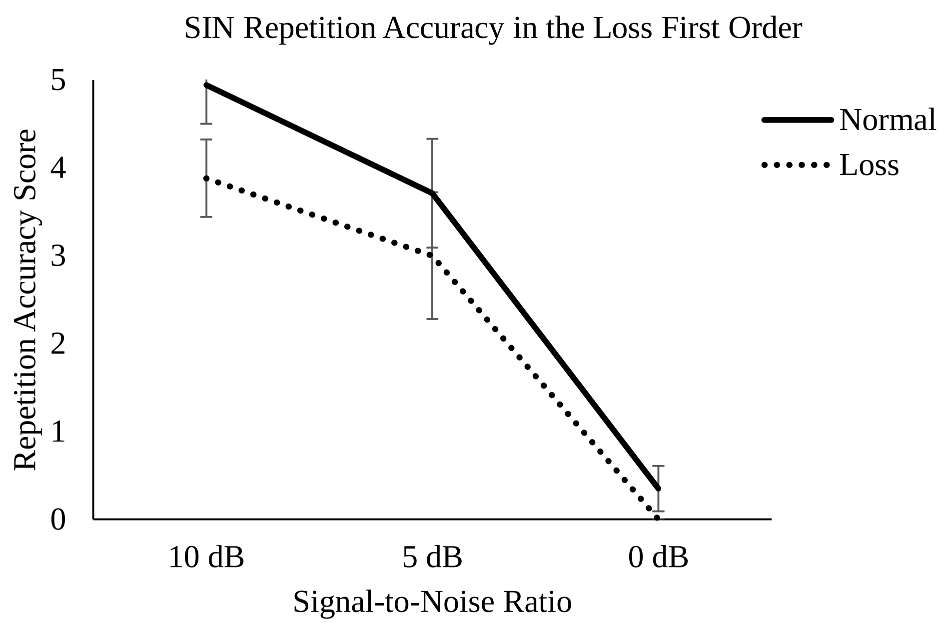
			Hearing condition	
SNR	Order of hearing condition		Loss	Normal
+10dB				
	N/L			
		M	4.80	4.15
		SE	0.20	0.21
		n	20	20
		95% CI	[4.39, 5.21]	[3.73, 4.57]
	L/N			
		M	3.88	4.94
		SE	0.22	0.22
		n	17	17
		95% CI	[3.43, 4.33]	[4.49, 5.39]
+5dB				
	N/L			
		M	3.55	4.00
		SE	0.34	0.29
		n	20	20
		95% CI	[2.87, 4.23]	[3.42, 4.58]
	L/N			
		M	3.00	3.71
		SE	0.36	0.31
		n	17	17
		95% CI	[2.26, 3.74]	[3.08, 4.34]
0dB				
	N/L			
		M	0.00	0.10
		SE	0.00	0.12
		n	20	20
		95% CI	[0.00, 0.00]	[-0.14, 0.34]
	L/N			
		M	0.00	0.35
		SE	0.00	0.13
		n	17	17
		95% CI	[0.00, 0.00]	[0.01, 0.61]

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

A 2 (Hearing Condition) by 2 (Order of Hearing Condition) by 3 (SNR) factorial ANOVA was conducted. As in the SIN analysis there were significant main effects of Hearing Condition and SNR (See Appendix H for ANOVA summary tables). Interestingly, there was also a significant Hearing Condition by SNR by Order of Hearing Condition interaction for repetition accuracy, $F(2.00, 70.00) = 4.49$, $p = .015$, $\eta_p^2 = .11$.

Two 2 (Hearing Condition) by 3 (SNR) factorial ANOVAs for each of the Orders of Hearing Conditions, were conducted as post-hoc analyses. There was no significant Hearing Condition by SNR interaction for repetition accuracy when participants experienced the Loss Hearing Condition followed by the Normal Hearing Condition (Loss First), $F(2, 32) = 1.55$, $p = .228$, $\eta_p^2 = .09$ (See Figure 5a). However, there was a significant Hearing Condition by SNR interaction for repetition accuracy when participants experienced the Normal Hearing Condition followed by the Loss Hearing Condition (Normal First), $F(2, 38) = 4.18$, $p = .023$, $\eta_p^2 = .18$ (See Figure 5b).

5a)



5b)

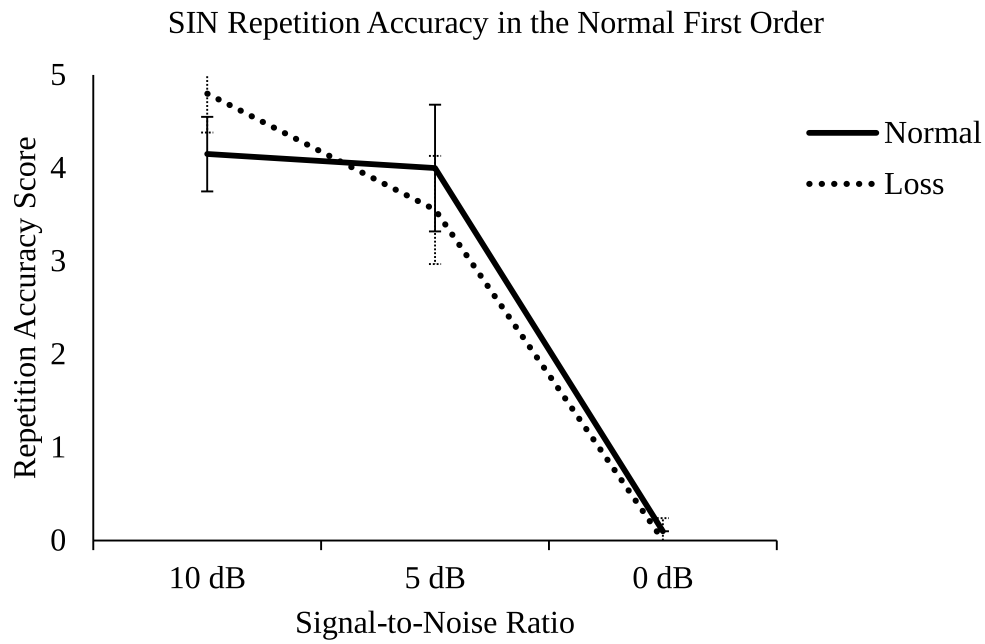


Figure 5. Repetition accuracy scores across Loss First and Normal First Orders.

A comparison between the Loss and Normal Hearing Conditions within each SNR revealed that the Normal Hearing Condition (*M* = 4.15, *SE* = 0.21) was significantly less accurate than the Loss Hearing Condition (*M* = 4.80, *SE* = 0.20) at the +10 dB SNR, *t*(19) = -2.22, *p* = .039. However, at the +5 dB SNR, accuracy in the Normal Hearing Condition (*M* = 4.00, *SE* = .29) and the Loss Hearing Condition (*M* = 3.55, *SE* = 0.34) were similar, *t*(19) = -1.18, *p* = .251. Finally, at the 0 dB SNR, accuracy in the Normal Hearing Condition (*M* = 0.10, *SE* = 0.12) and the Loss Hearing Condition (*M* = 0.00, *SE* = 0.00) were also similar, *t*(19) = -1.45, *p* = .163.

The next set of post-hoc analyses compared each SNR within the Loss Hearing Condition, the +10 dB SNR (*M* = 4.80, *SE* = 0.20) was significantly more accurate than the +5 dB SNR (*M* = 3.55, *SE* = 0.34), *t*(19) = 4.08, *p* = .001. The +10 dB SNR (*M* = 4.80, *SE* = 0.20) was also significantly more accurate than the 0 dB SNR (*M* = 0.00, *SE* =

0.00), *t*(19) = 41.03, $p < .001$. Finally, the +5 dB SNR (*M* = 3.55, *SE* = 0.34) was significantly more accurate than the 0 dB SNR (*M* = 0.00, *SE* = 0.00), *t*(19) = 11.38, $p < .001$. As for the Normal Hearing Condition, the +10 dB SNR (*M* = 4.15, *SE* = 0.21) was not significantly more accurate than the +5 dB SNR (*M* = 4.00, *SE* = 0.29), *t*(19) = 0.40, *p* = .697. However, the +10 dB SNR (*M* = 4.15, *SE* = 0.21) was significantly more accurate than the 0 dB SNR (*M* = 0.10, *SE* = 0.12), *t*(19) = 14.67, $p < .001$. Finally, the +5 dB SNR (*M* = 4.00, *SE* = 0.29) was also significantly more accurate than the 0 dB SNR (*M* = 0.10, *SE* = 0.12), *t*(19) = 13.08, $p < .001$.

Three 2 (Hearing Condition) by 2 (Order of Hearing Condition) factorial ANOVAs, one for each SNR were also conducted. There was a significant Hearing Condition by Order of Hearing Condition interaction for the +10 dB SNR, *F*(1, 35), $p < .001$, $\eta_p^2 = .32$. Comparing the Loss and Normal Hearing Conditions within each Order of Hearing Condition (i.e. Loss First Order or Normal First Order), the Normal Hearing Condition (*M* = 4.15, *SE* = 0.21) was significantly less accurate than the Loss Hearing Condition (*M* = 4.80, *SE* = 0.20) for the Normal First Order, *t*(19) = -2.22, *p* = .039. However, in the Loss First Order, the Normal Hearing Condition (*M* = 4.94, *SE* = 0.22) was significantly more accurate than the Loss Hearing Condition (*M* = 3.88, *SE* = 0.22), *t*(16) = 3.50, *p* = .003.

When comparing Order of Hearing Conditions within Hearing Condition (i.e. Loss or Normal), the Normal First Order (*M* = 4.80, *SE* = 0.20) was significantly more accurate than the Loss First Order (*M* = 3.88, *SE* = 0.22) within the Loss Hearing Condition at +10 dB SNR, *t*(20.97) = 2.89, *p* = .009. However, the Loss First Order (*M* = 4.94, *SE* = 0.22) was significantly more accurate than the Normal First Order (*M* = 4.15, *SE* = 0.21) within the Normal Hearing Condition at +10 dB SNR, $t(20.74) = 2.82$, $p = .010$.

There was a significant main effect of Hearing Condition for the SNR of +5 dB where the Normal Hearing Condition ($M = 3.85$, $SE = 0.21$) was significantly more accurate than the Loss Hearing Condition ($M = 3.28$, $SE = 0.25$), $F(1, 35) = 5.21$, $p = .029$, $\eta_p^2 = .13$. However, there was no significant main effect of Order of Hearing Condition, $F(1, 35) = 1.20$, $p = .280$, $\eta_p^2 = .03$. There was also no significant interaction between Hearing Condition and Order of Hearing Condition, $F(1, 35) = 0.26$, $p = .617$, $\eta_p^2 = .01$.

Finally, for the 0 dB SNR, the Normal Hearing Condition ($M = 0.23$, $SE = 0.09$) was significantly more accurate than the Loss Hearing Condition ($M = 0.00$, $SE = 0.00$), $F(1, 35) = 6.82$, $p = .013$, $\eta_p^2 = .16$. However, there was no significant main effect of Order of Hearing Condition, $F(1, 35) = 2.13$, $p = .154$, $\eta_p^2 = .06$. There was also no significant interaction between Hearing Condition and Order of Hearing Condition, $F(1, 35) = 2.13$, $p = .154$, $\eta_p^2 = .06$.

Interpreting order effects.

There was a change in pattern between the Normal First and the Loss First Orders largely isolated to +10 dB SNR. According to the Resource Allocation Hypothesis it was expected that the Normal condition would have higher repetition accuracy than the Loss condition for each SNR. However, results have shown that this was not the case at +10 dB. One possible explanation for this difference in accuracy could be the cognitive strategy adopted by the participant when completing the task. For +10 dB in both the Normal First and the Loss First conditions participants were less accurate in the first set of sentences than the second set of sentences. It is possible that participants became more accurate in repeating the sentences as they got more practice with the order. Regardless of Hearing Condition, sentences were presented at +10 dB, then +5 dB, and finally, 0 dB SNR. The nature of this task is for the sentences to be increasingly more difficult, limiting accuracy and requiring more effort as participants progress through the sentences. Once the participants completed both the practice set, and the first set of sentences they could have a better grasp of this pattern and were able to complete the second set of sentences with more accuracy despite the Hearing Condition. This is only the case at the +10 dB SNR because it may not have been challenging enough to cause the recruitment of significantly more cognitive resources in the Loss Hearing Condition. This effect was also observed in the study by Hicks & Tharpe (2002) who reported no hearing loss effect on task performance in children also at a SNR of +10 dB.

Listening effort.

There were also no hypothesized order effects on SIN listening effort yet, as with the accuracy data, a check of the counterbalancing order was necessary. Descriptive statistics for listening effort at three SNRs across both Hearing Condition and Order of Hearing Condition are shown in Table 6.

Table 6

Descriptive Statistics for Listening Effort of Hearing Condition by SNR by Order of Hearing Condition

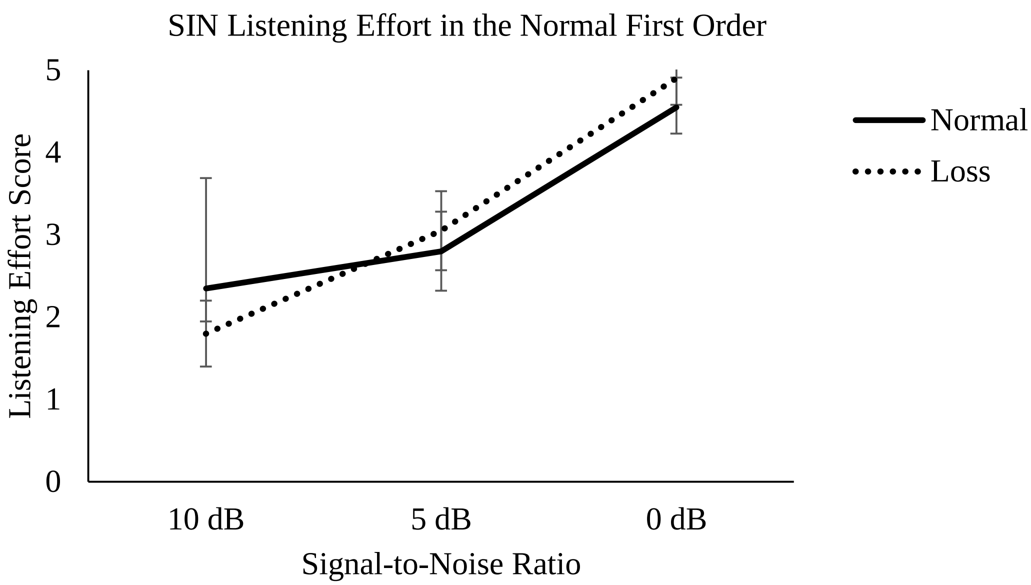
SNR	Order of hearing condition		Hearing condition: Loss	Hearing condition: Normal
+10dB				
	N/L			
		M	1.80	2.35
		SE	0.20	0.67
		n	20	20
		95% CI	[1.40, 2.20]	[1.81, 2.89]
	L/N			
		M	2.88	1.71
		SE	0.21	0.29
		n	17	17
		95% CI	[2.45, 3.31]	[1.12, 2.23]
+5dB				
	N/L			
		M	3.05	2.80
		SE	0.24	0.24
		n	20	20
		95% CI	[2.57, 3.53]	[2.31, 3.29]
	L/N			
		M	3.53	2.59
		SE	0.26	0.26
		n	17	17
		95% CI	[3.01, 4.05]	[2.05, 3.12]
0dB				
	N/L			
		M	4.90	4.55
		SE	0.16	0.18
		n	20	20
		95% CI	[4.58, 5.53]	[4.18, 4.92]
	L/N			
		M	4.59	4.53
		SE	0.17	0.20
		n	17	17
		95% CI	[4.24, 4.94]	[4.13, 4.93]

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

Results of a 2 (Hearing Condition) by 2 (order of Hearing Condition) by 3 (SNR) factorial ANOVA showed a significant Hearing Condition by SNR by Order of Hearing Condition interaction for listening effort, $F(2.00, 70.00) = 9.21$, $p < .001$, $\eta_p^2 = .21$. Post-hoc testing consisted of two 2 (Hearing Condition) by 3 (SNR) factorial ANOVAs, one for each of the Orders of Hearing Conditions. There was a significant Hearing

Condition by SNR interaction for listening effort when participants experienced the Loss Hearing Condition followed by the Normal Hearing Condition (Loss First), $F(2, 32) = 5.22$, $p = .011$, $\eta_p^2 = .25$ (See figure 6b).

6a)



6b)

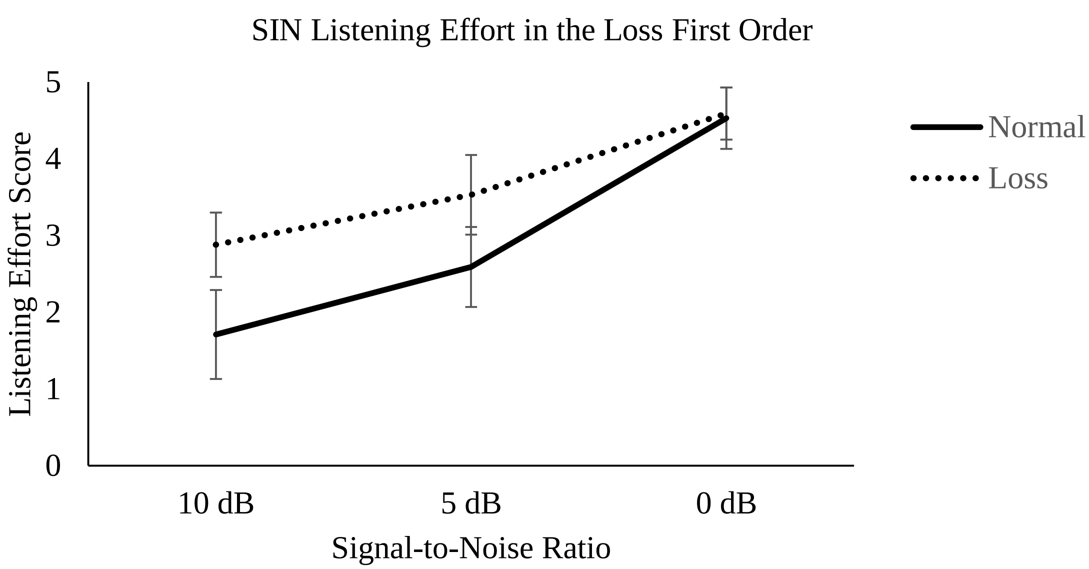


Figure 6. Listening effort scores across Loss First and Normal First Orders.

T-tests revealed that when comparing the Loss and Normal Hearing Conditions within each SNR, the Loss Hearing Condition (*M* = 2.88, *SE* = 0.21) was significantly more effortful than the Normal Hearing Condition (*M* = 1.71, *SE* = 0.29) at the +10 dB SNR, $t(16) = 3.21$, $p = .005$. The Loss Hearing Condition (*M* = 3.53, *SE* = 0.26) was also significantly more effortful than the Normal Hearing Condition (*M* = 2.59, *SE* = .26) at the +5dB SNR, $t(16) = 2.49$, $p = .024$. Finally, while the Loss Hearing Condition (*M* = 4.59, *SE* = 0.17) was more effortful than the Normal Hearing Condition (*M* = 4.53, *SE* = 0.20) at the 0dB SNR, this was not a significant difference, $t(16) = 0.57$, $p = .579$.

When comparing SNR within the Loss Hearing Condition the +5 dB SNR (*M* = 3.53, *SE* = 0.26) was not significantly more effortful than the +10 dB SNR (*M* = 2.88, *SE* = 0.21), $t(16) = 1.89$, $p = .077$. However, the 0dB SNR (*M* = 4.59, *SE* = 0.17) was significantly more effortful than the +10dB SNR (*M* = 2.88, *SE* = 0.21), $t(16) = 5.36$, $p < .001$. The 0dB SNR (*M* = 4.59, *SE* = 0.17) was also significantly more effortful than the +5 dB SNR (*M* = 3.53, *SE* = 0.26), $t(16) = 4.52$, $p <.001$. Within the Normal Hearing Condition the +5 dB SNR (*M* = 2.59, *SE* = 0.26) was significantly more effortful than the +10 dB SNR (*M* = 1.79, *SE* = 0.29), $t(16) = 3.45$, $p = .003$. The 0dB SNR (*M* = 4.53, *SE* = 0.20) was also significantly more effortful than the +10dB SNR (*M* = 1.79, *SE* = 0.29), $t(16) = 5.63$, $p < .001$. Finally, the 0dB SNR (*M* = 4.53, *SE* = 0.20) was significantly more effortful than the +5 dB SNR (*M* = 2.59, *SE* = 0.26), $t(16) = 5.42$, $p < .001$.

There was also a significant Hearing Condition by SNR interaction for listening effort when participants experienced the Normal condition followed by the Loss condition (Normal First), $F(2, 38) = 5.29$, $p = .009$, $\eta_p^2 = .22$ (See figure 6a).

For this Normal First group t-tests revealed that the Normal Hearing Condition (*M* = 2.35, *SE* = 0.67) was significantly more effortful than the Loss Hearing Condition (*M* = 1.80, *SE* = 0.20) at the +10 dB SNR, $t(19) = 2.34$, $p = .030$. However, at the +5 dB SNR the Normal Hearing Condition (*M* = 2.80, *SE* = .24) and the Loss Hearing Condition (*M* = 3.05, *SE* = 0.24) were similar, $t(19) = 0.87$, $p = .398$. Finally, at the 0 dB SNR, the Loss Hearing Condition (*M* = 4.90, *SE* = 0.16) was significantly more effortful than the Normal Hearing Condition (*M* = 4.55, *SE* = 0.18), $t(19) = 2.33$, $p = .031$.

Comparing across levels of SNR within the Loss Hearing Condition, the +5 dB SNR (*M* = 3.05, *SE* = 0.24) was significantly more effortful than the +10 dB SNR (*M* = 1.80, *SE* = 0.20), $t(19) = 7.11$, $p < .001$. The 0dB SNR (*M* = 4.90, *SE* = 0.16) was also significantly more effortful than the +10dB SNR (*M* = 1.80, *SE* = 0.20), $t(19) = 21.64$, $p < .001$. Finally, the 0dB SNR (*M* = 4.90, *SE* = 0.16) was significantly more effortful than the +5 dB SNR (*M* = 3.05, *SE* = 0.24), $t(19) = 10.18$, $p <.001$. Within the Normal Hearing Condition, the +5 dB SNR (*M* = 2.80, *SE* = 0.24) was not significantly more effortful than the +10 dB SNR (*M* = 2.35, *SE* = 0.67), $t(19) = 1.92$, $p = .070$. However, the 0dB SNR (*M* = 4.55, *SE* = 0.18) was significantly more effortful than the +10dB SNR (*M* = 2.35, *SE* = 0.67), $t(19) = 8.22$, $p < .001$. Finally, the 0dB SNR (*M* = 4.55, *SE* = 0.18) was significantly more effortful than the +5 dB SNR (*M* = 2.80, *SE* = 0.24), $t(19) = 7.68$, $p < .001$.

Post-hoc testing, using three 2 (Hearing Condition) by 2 (Order of Hearing Condition) factorial ANOVAs, one for each SNR showed a significant Hearing Condition by Order of Hearing Condition interaction for the +10 dB SNR, $F(1, 35)$, $p < .001$, $\eta_p^2 = .32$.

Following up with comparisons between the Loss and Normal Hearing Conditions within each Order of Hearing Condition, revealed that the Normal Hearing Condition (*M* = 1.80, *SE* = 0.20) was significantly more effortful than the Loss Hearing Condition (*M* = 2.35, *SE* = 0.67) for the Normal First group, $t(19) = 2.34$, $p = .030$. However, in the Loss First group the Loss Hearing Condition (*M* = 2.88, *SE* = 0.21) was significantly more effortful than the Normal Hearing Condition (*M* = 1.71, *SE* = 0.29), $t(16) = 3.21$, $p = .005$.

In terms of the comparison between Hearing Condition Order within Hearing Condition (i.e. Loss or Normal), the Loss First Order (*M* = 1.71, *SE* = 0.29) and the Normal First Order (*M* = 2.35, *SE* = 0.67) were similar within the Normal Hearing Condition at +10 dB SNR, $t(35) = 1.63$, $p = .112$. However, the Loss First Order (*M* = 2.88, *SE* = 0.21) was significantly more effortful than the Normal First Order (*M* = 1.80, *SE* = 0.20) within the Loss Hearing Condition at +10 dB SNR, $t(24.06) = 3.58$, $p = .002$. There was a significant main effect of Hearing Condition for the SNR of +5 dB where the Loss Hearing Condition (*M* = 3.29, *SE* = 0.18) was significantly more effortful than the Normal Hearing Condition (*M* = 2.69, *SE* = 0.18), $F(1, 35) = 6.46$, $p = .016$, $\eta_p^2 = .16$. However, there was no significant main effect of Order of Hearing Condition, $F(1, 35) = 0.26$, $p = .617$, $\eta_p^2 = .01$. There was also no significant interaction between Hearing Condition and Order of Hearing Condition, $F(1, 35) = 2.17$, $p = .149$, $\eta_p^2 = .06$. Finally, for the 0 dB SNR, the Loss Hearing Condition (*M* = 4.74, *SE* = 0.12) was significantly more effortful than the Normal Hearing Condition (*M* = 4.54, *SE* = 0.13), $F(1, 35) = 4.68$, $p = .037$, $\eta_p^2 = .12$. However, there was no significant main effect of Order of Hearing Condition, $F(1, 35) = 0.50$, $p = .483$, $\eta_p^2 = .01$. There was also no significant interaction between Hearing Condition and Order of Hearing Condition, $F(1, 35) = 2.37$, $p = .132$, $\eta_p^2 = .06$.

Interpretation of order effects.

There are several explanations as to why these order effects are isolated to the SNR of +10 dB. However, the most plausible is again the influence of the possible cognitive strategy utilized by the participants. During SIN testing all participants completed a practice set of 3 sentences (at +10 dB, +5 dB, and 0 dB) regardless of the Order of Hearing Condition thereafter. This means that each participant completed a difficult task (i.e. repetition at 0 dB) before each of the +10 dB SNR sentences. According to Meriweather (2016), effort required to complete a difficult task can be carried over to subsequent tasks, regardless of the subsequent task's difficulty. This provides an explanation as to why each group rated listening effort as higher in the first task they encountered after the difficult task of the practice. Following this discrepancy at +10 dB all trends return to what was expected – listening with simulated hearing loss is rated as more effortful than listening with normal hearing.

Memory: Order Effects Analysis

Question response accuracy.

Exploration of order effects continued for the Memory Task with descriptive statistics for response accuracy for task and Order of Hearing Condition across the Loss and Normal Hearing Conditions being shown in Table 7. A 2 (Hearing Condition) by 2 (Order of Hearing Condition) by 2 (Task Group) factorial ANOVA was conducted. As in the previous Memory Task analysis there was no significant main effect of Hearing Condition, however, there was a significant main effect of Task Group (See Appendix H for ANOVA summary tables). When examining the effect of the Order of Hearing Conditions no significant Hearing Condition by Task Group by Order of Hearing Condition interaction was found for response accuracy, $F(1, 33) = 0.06$, $p = .814$, $\eta_p^2 = .002$ (See figure 7). Unlike the SIN accuracy task, those who experienced simulated hearing loss first and normal hearing first had similar performance trends for Memory Task response accuracy.

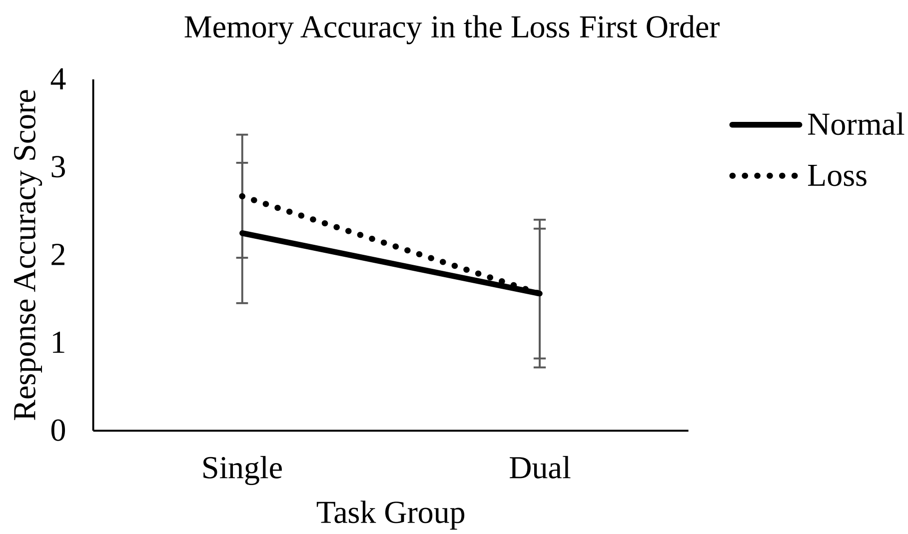
Table 7

Descriptive Statistics for Response Accuracy of Hearing Condition by Task by Order of Hearing Condition

			Hearing condition	
Task	Order of hearing condition		Loss	Normal
Single				
	N/L			
		M	2.22	2.50
		SE	0.39	0.35
		n	9	9
		95% CI	[1.42, 3.03]	[1.79, 3.21]
	L/N			
		M	2.67	2.50
		SE	0.39	0.35
		n	9	9
		95% CI	[1.86, 3.47]	[1.79, 3.21]
Dual				
	N/L			
		M	1.41	1.64
		SE	0.36	0.32
		n	11	11
		95% CI	[0.68, 2.14]	[0.99, 2.28]
	L/N			
		M	1.56	1.56
		SE	0.42	0.37
		n	8	8
		95% CI	[0.71, 2.41]	[0.81, 2.32]

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

7a)



7b)

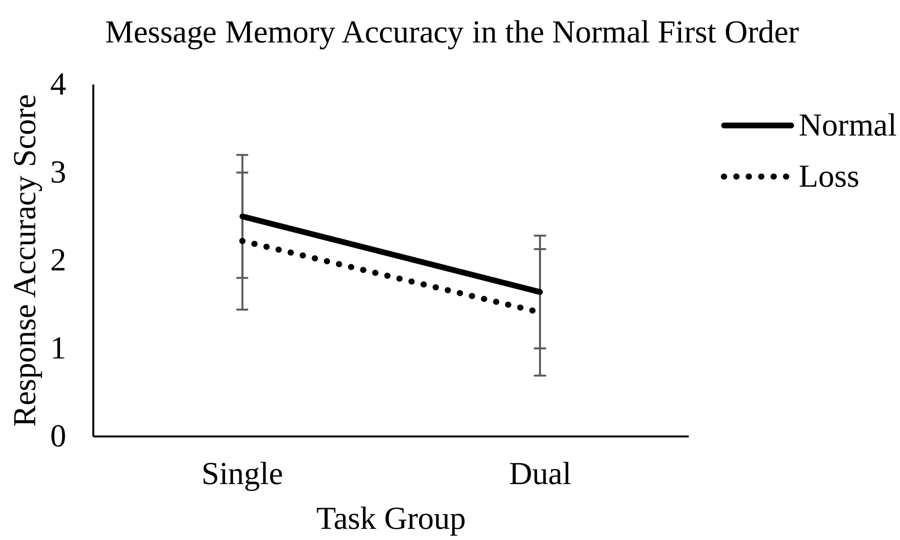


Figure 7. Repetition accuracy scores across Loss First and Normal First Orders.

Listening effort.

Descriptive statistics for listening effort for task and Order of Hearing Condition across the Loss and Normal Hearing Conditions are shown in Table 8. A 2 (Hearing Condition) by 2 (Order of Hearing Condition) by 2 (Task Group) factorial ANOVA was conducted. As in the Memory analysis there was a significant main effect of Hearing Condition, however, there was no significant main effect of Task Group. When examining the effect of the Order of Hearing Conditions, no significant Hearing Condition by Task Group by Order of Hearing Condition interaction was found for response accuracy, $F(1, 31) = 0.76$, $p = .389$, $\eta_p^2 = .02$ (See figure 8).

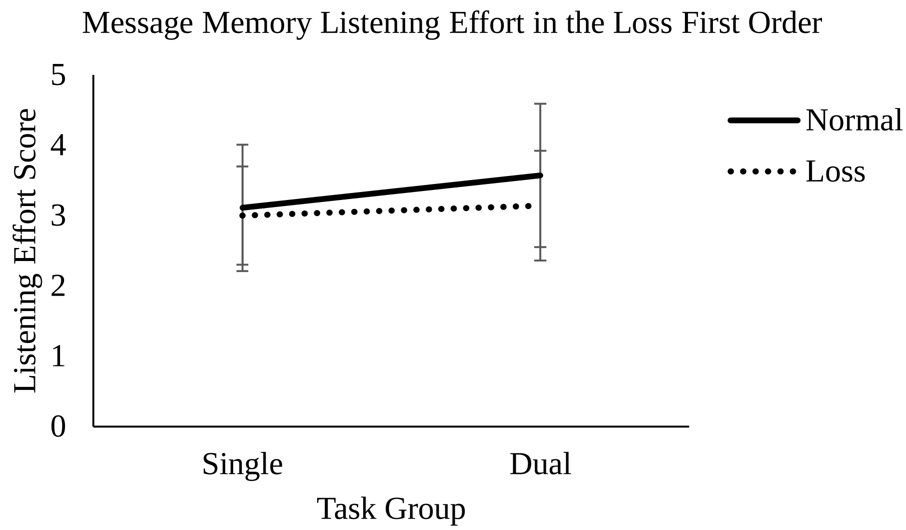
Table 8

Descriptive Statistics for Listening Effort of Hearing Condition by Task by Order of Hearing Condition

			Hearing condition	
Task	Order of hearing condition		Loss	Normal
Single				
	N/L			
		M	3.56	2.67
		SE	0.35	0.39
		n	9	9
		95% CI	[2.85, 4.26]	[1.75, 3.59]
	L/N			
		M	3.00	3.11
		SE	0.35	0.45
		n	9	9
		95% CI	[2.29, 3.71]	[2.19, 4.03]
Dual				
	N/L			
		M	4.50	3.40
		SE	0.33	0.43
		n	10	10
		95% CI	[3.83, 5.17]	[2.53, 4.28]
	L/N			
		M	3.14	3.57
		SE	0.39	0.51
		n	7	7
		95% CI	[2.34, 3.95]	[2.53, 4.62]

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

8a)



8b)

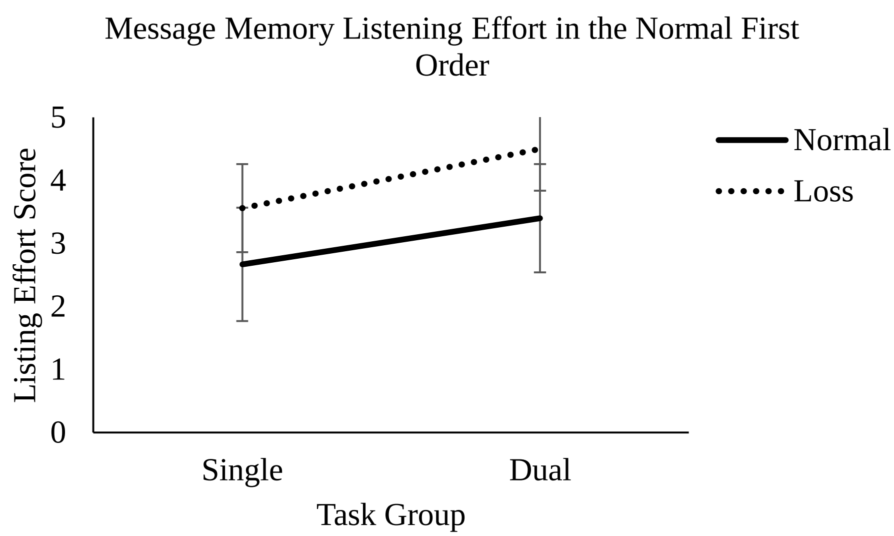


Figure 8. Listening effort scores across Loss First and Normal First orders.

However, this order analysis did reveal a significant Hearing Condition by Order of Hearing Condition interaction, $F(1, 31) = 17.47$, $p < .001$, $\eta_p^2 = .36$. Descriptive statistics for listening effort for Order of Hearing Condition across the Loss and Normal Hearing Conditions are shown in Table 9. Post-hoc testing, using a 2 (Hearing Condition) by 2 (Order of Hearing Condition) factorial ANOVA was conducted. Again, there was a significant Hearing Condition by Order of Hearing Condition interaction $F(1, 33) = 17.91$, $p < .001$, $\eta_p^2 = .35$ (See figure 9).

Table 9

Descriptive Statistics for Listening Effort of Hearing Condition by Order of Hearing Condition

	Hearing condition		
Order of hearing condition	Loss	Normal	Overall
Normal first			
M	4.05	3.05	3.55
SE	0.25	0.31	0.26
N	19	19	38
95% CI	[3.55, 4.55]	[2.42, 3.68]	[3.02, 4.09]
Loss first			
M	3.06	3.31	3.19
SD	0.27	0.34	0.29
n	16	16	32
95% CI	[2.52, 3.61]	[2.62, 4.00]	[2.61, 3.77]
Overall			
M	3.55	3.18	
SD	0.18	0.23	
n	35	35	
95% CI	[3.19, 3.93]	[2.72, 3.65]	

Note. CI = confidence interval [LL = lower limit, UL = upper limit].

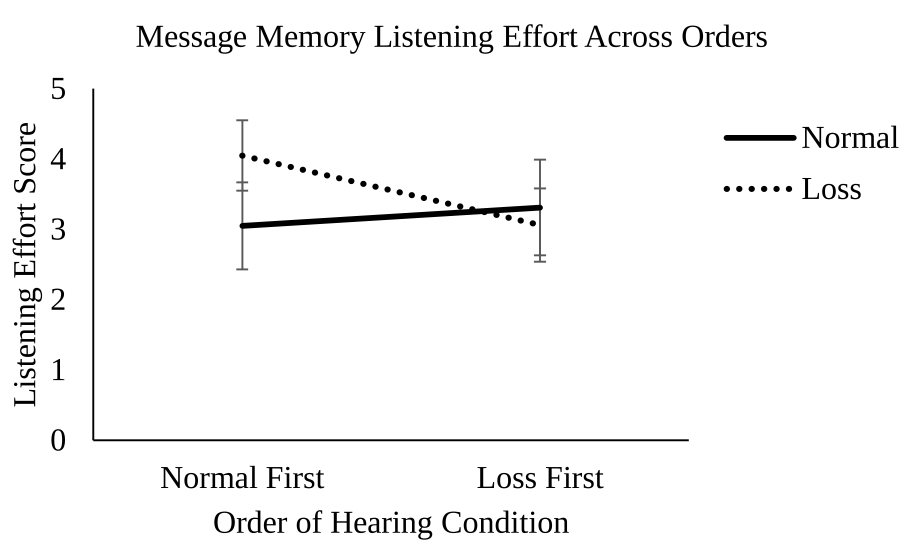


Figure 9. Listening effort scores across Loss First and Normal First Orders.

For the Normal First Order of Hearing Conditions, the Loss Hearing Condition (*M* = 4.05, *SE* = 0.25) was significantly more effortful than the Normal Hearing Condition (*M* = 3.05, *SE* = 0.31), $t(18) = 4.94$, $p < .001$. For the Loss First Order of Hearing Conditions the Loss Hearing Condition (*M* = 3.06, *SE* = 0.27) and the Normal Hearing Condition (*M* = 3.31, *SE* = 0.34) were similar in terms of listening effort, $t(15) = -1.17$, $p = .261$. Within the Loss Hearing Condition, the Normal First Order (*M* = 4.05, *SE* = 0.25) was significantly more effortful than the Loss First Order (*M* = 3.06, *SE* = 0.27), $t(34) = 2.38$, $p = .023$.Within the Normal Hearing Condition, the Normal First Order (*M* = 3.05, *SE* = 0.31) and the Loss First Order (*M* = 3.31, *SE* = 0.34) were similar in terms of listening effort, $t(34) = -0.59$, $p = .561$.

Interpreting order effects.

Again the effect of cognitive strategy is a valid explanation as we see that in both Orders of Hearing Conditions the participants rated effort as being lower in whichever task they experienced first following the practice. Since the practice task experienced immediately beforehand was not considered to be a difficult task, the lack of effort required to complete the practice was carried through into the first task of the analysis. While the participants put less listening effort into the first task, a difference in that effort was mediated by Hearing Condition. In the Normal First Order, there is a significant increase in effort from the first task to the second task because the second task was completed with simulated hearing loss, meaning they had to put significantly more effort into completing this last task than the 2 previous tasks (i.e. the practice, and the first task which were both completed with normal hearing). Meanwhile, in the Loss First condition, there is a much smaller, and not significant, increase in effort from the first task to the second task as this second task was completed with normal hearing, meaning there was no need for increased recruitment of cognitive resources.

Appendix H

ANOVA Summary Table SIN Accuracy

Source	SS	df	MS	*F*	*p*	η_p^2
Hearing	6.24	1	6.24	9.00	.005	.20
SNR	770.20	1.68	457.54	367.45	< .001	.91
Order	0.79	1	0.79	0.49	.489	.01
Hearing*SNR	1.61	1.77	0.91	1.12	.328	.03
Hearing*Order	7.53	1	7.53	10.87	.002	.24
SNR*Order	2.85	2	1.43	1.36	.263	.04
Hearing*SNR*Order	6.48	2	3.24	4.49	.015	.11

Note. Corrected degrees of freedom were used when the assumption of sphericity was violated.

ANOVA Summary Table SIN Effort

Source	SS	df	MS	F	p	η_p^2
Hearing	7.59	1	7.59	7.76	.009	.18
SNR	230.66	1.65	140.21	128.26	< .001	.79
Order	0.21	1	0.21	0.11	.738	.003
Hearing*SNR	1.50	2.00	0.75	1.48	.236	.04
Hearing*Order	6.93	1	6.93	7.08	.012	.17
SNR*Order	1.51	2	0.75	0.84	.437	.02
Hearing*SNR*Order	9.35	2	4.68	9.21	< .001	.21

Note. Corrected degrees of freedom were used when the assumption of sphericity was violated.

ANOVA Summary Table Message Memory Accuracy

Source	SS	df	MS	F	p	η_p^2
Hearing	0.13	1	0.13	0.14	.714	.004
Task	15.78	1	15.78	10.24	.003	.24
Order	0.31	1	0.31	0.20	.655	.01
Hearing*Task	0.02	1	0.02	0.02	.900	< .001
Hearing*Order	0.52	1	0.52	0.54	.469	.02
Task*Order	0.15	1	0.15	0.01	.755	.003
Hearing*Task*Order	0.05	1	0.05	0.06	.814	.002

ANOVA Summary Table Message Memory Effort

Source	SS	df	MS	F	p	η_p^2
Hearing	2.26	1	2.26	5.74	.023	.16
Task	5.59	1	5.59	2.21	.147	.07
Order	1.81	1	1.81	0.72	.404	.02
Hearing*Task	0.01	1	0.01	0.03	.862	.001
Hearing*Order	6.87	1	6.87	17.47	< .001	.36
Task*Order	1.24	1	1.24	0.49	.489	.02
Hearing*Task*Order	0.30	1	0.30	0.76	.389	.02