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Training to avoid distractions

Cara E. Sanderson
James Madison University

Training to Avoid Distractions

Cara Elizabeth Sanderson

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Acknowledgements

Introduction to the Reader

  The first part of this dissertation is in a manuscript format for the purpose of future publication. It includes a structured abstract, introduction, methods, results, and discussion written in a manuscript format. The second part of this dissertation consists of three appendices that contain false alarm rate data, reaction time data and subsequent analysis and discussion. Please refer to the Table of Contents for specific page numbers.

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Part I: Manuscript

Transference of Learning Across Two Non-sensory Masking Tasks

Abstract

Introduction: Auditory training has been extensively studied and applied to training software that is currently available for children with attention, hearing, or speech/language difficulties. The extent to which training generalizes, or transfers to an untrained task, is of great theoretical value. To our knowledge, there has not been a study that examines transference to a non-sensory masking task.

Methods: 16 adults without ADHD were trained in a contralateral masking task over the course of two days, with 900 trials per day. False alarm rates, thresholds, and reaction times were measured. Pre- and post-tests of contralateral and informational masking were conducted to evaluate improvement on the untrained task following training.

Results: Training generalized to the untrained task of informational masking. The results showed that informational and contralateral thresholds significantly improved following training.

Discussion: This paper demonstrates transference of learning across two non-sensory masking tasks. This is the beginning of determining the extent of generalization and limiting distractibility in non-sensory masking, and how that may influence the development of auditory training software.

I. Introduction

        Auditory learning is defined as an improvement in performance on a trained task that involves detection, discrimination or categorization of a particular stimulus or sound. Learning occurs after a period of auditory training, and can occur rapidly over the course of one training session (Ortiz & Wright, 2009; Hawkey, Amitay, & Moore, 2004), or over a longer time course. Learning can even occur when the trained task is impossible (Amitay et al., 2006). Auditory training has been studied extensively due to its potential to be developed into an interactive program for children and adults with hearing impairment, attention difficulties, and speech and/or language impairments. However, some researchers have argued that the extent to which the training transfers, or results in the improvement of an untrained task, is of greater theoretical importance (Halliday et al., 2012). By studying the transference of learning to an untrained task, the neural processes that are involved in auditory learning can be identified. In a clinically applicable sense, examining how generalization occurs may aid in the development auditory training programs that can effectively train certain populations, such as children with communication disorders or hearing impaired listeners (Wright & Zhang, 2009).

        Some studies have found limited generalization to untrained tasks, while others have had success. In frequency discrimination tasks, generalization has occurred to at least some degree across frequency, across stimulus duration, and between ears in adult listeners (Wright & Zhang, 2009). Temporal discrimination tasks, such as temporal-interval discrimination, relative-timing tasks, and amplitude modulated rate discrimination tasks have also been shown to generalize in adult subjects (Wright & Zhang, 2009; Fitzgerald & Wright, 2011). In children, some studies have found that

learning does not generalize to different stimuli or different presentation patterns (Halliday et al., 2008). However, research has shown that generalization does occur when children are trained on higher level language tasks (Moore et al., 2005). There is a relative paucity of research investigating generalization following training in signal detection tasks (Wright & Zhang, 2009). Three investigations to note involve tone detection in quiet, in a noise masker, and in a tone sequence, but these studies yielded mixed results. To our knowledge, there is no literature on the transference to a non-sensory masking task.

Maturation of learning and generalization is another area of interest when developing therapeutic software with auditory training, especially those designed for children. There is evidence that the extent to which performance improves after auditory training depends on maturation. Adolescent subjects respond to training differently than adults (Wright, Wilson & Sabin, 2010; Huyck & Wright, 2013). The processes underlying perceptual training will continue to develop into adulthood, as shown by improving performance with increasing age. In a backwards-masking training regimen, adults showed marked improvement while only half of adolescents improved. Those who did improve did so at a slower rate than adults. However, both adults and adolescents exhibited similar patterns of generalization to untrained tasks (Huyck & Wright, 2013). Therefore, maturation of learning and generalization take place over a different time course.

The purpose of the present study is to extend an analysis of transference of learning in two signal detection tasks in adults with no attentional or hearing difficulties. In a study by Gray, Miller, and Evans (2012), seven children with ADHD and three

adults without ADHD underwent four consecutive days of auditory training. The subjects were trained, over 900 trials per day, to detect a pure tone in the presence of a masker in the contralateral ear ("contralateral masking"). To investigate generalization, this study included an adaptive pre- and post-test of informational masking, in which a pure tone is detected in the presence of a random, multi-frequency masker. This study found no transfer of learning to the untrained informational masking task; that is, the children with ADHD did not improve their performance in the informational masking task after four days of training in contralateral masking. The previous data approached statistical significance (p=.07), so with additional subjects evidence for transference of learning from contralateral to informational masking is likely to reach the .05 level of significance.

The present study follows the methods from Gray et al. (2012). Subjects are college-aged students with no history of ADHD. Due to the known and differing time course for adults and children to maximize performance after a period of auditory training, the false alarm rates, reaction times, and transference of learning to an informational masking task were all examined. The research hypothesis is that learning will generalize to the untrained informational masking task with a period of intensive perceptual training in contralateral masking over the course of two consecutive days. Additionally, false alarm rates in the trained contralateral masking task are expected improve over a period of two consecutive days of auditory training.

II. Materials and Methods

Participants were unpaid volunteers recruited through the Communication Sciences and Disorders department at James Madison University. The first group of participants ("Undergraduate group") consisted of six undergraduate students, three of whom completed three consecutive days of auditory training and three who completed two days of training. The second group ("Graduate group 1") consisted of six graduate students who completed two consecutive days of auditory training. The third group ("Graduate group 2") consisted of four graduate students who also completed two consecutive days of training. Graduate group 2 completed the training one year after the Graduate group 1. This cohort was in the same point in their education, in the same graduate program, and had the same educational experiences as Graduate Group 1 when completing the training. All participants were native English speakers with normal hearing and no current diagnosis of ADHD, psychosis, or obsessive compulsive disorder.

Auditory training was completed in a double-walled sound booth in the Psychoacoustics Research Laboratory at James Madison University in Spring 2012 and Summer 2013. A computer was located within the sound booth and used a computer program developed by researchers in the Psychoacoustic Research Laboratory. Methods were similar to Gray et al. (2012), which aimed to minimize impulsivity in youth with ADHD through auditory training using contralateral masking.

On each day of testing, a hearing screening was conducted from 250 to 8000 Hz to ensure normal hearing across these frequencies (< 25 dB HL). Tympanometry was also performed to assess middle ear function. In order to proceed with auditory training, all

hearing thresholds and tympanograms had to be within normal limits on all days of testing.

Participants were given written instructions which were reinforced verbally by the tester to ensure understanding. They were instructed to favor a low false-alarm rate over a low threshold; however, instructions were to keep both values as low as possible. Testing began with a practice condition to familiarize the participant with the task. The participant completed a brief procedural training with an easily detectable stimulus in the presence of a contralateral masker. Levels of the signal never went below anticipated thresholds, so subjects could perform perfectly if they understood the task. The participant was instructed to repeat this learning task until it was completed with 100% accuracy. Next, a 40 trial adaptive test of contralateral masking ("pre-test") was completed to estimate threshold and false alarm rate prior to training.

Contralateral masking was the primary task required of the participants. Contralateral masking tests consisted of the detection of a 500 Hz tone in a randomly selected ear, while a band of noise was presented to the opposite ear. The frequency band of the broadband noise was 250-1000 Hz and was presented in the contralateral ear at 80 dB on every trial. The training was adaptive, as the intensity of the pure tone increased or decreased based on a maximum likelihood algorithm (described by Gray et al. (2006)) depending on participant performance on the previous trial. Fifty percent of the trials were "catch" trials in which no pure tone stimulus was presented. Participants were asked to determine if the tone was present or absent in the presence of the masker using a single-interval, yes-no detection paradigm. This was used to estimate threshold, false alarm rate, and reaction time.

Before the pre-test, each participant completed a 10 trial procedural training test of informational masking, followed by a 40 trial adaptive pre-test. The stimulus was loud enough to be easily detectible within the masker during the initial procedural learning. When the procedural learning task was completed with 100% accuracy, the participant could move onto a 40 trial adaptive test of informational masking to estimate threshold and false alarm rates prior to training. In informational masking trials, used in pre- and post-tests only, a 500 Hz pure tone was the target stimulus. The masker was composed of ten random tones within a frequency range of 1000-2500 Hz. These masking components were no less than 5 Hz apart during each presentation, and the level of the masker was kept constant at 60 dB SPL. The ten frequency components of the masker were random from trial-to-trial, but never changed within a single trial. Presentations occurred in three bursts per trial; the first burst was the target only, followed by two identical bursts of the same multifrequency masker with the target either present or absent. The subject had to identify whether the tone was present in the second two bursts. Half the trials were "catch" trials in which no stimulus was present, and this was randomly interspersed.

During all pre-tests, post-tests, and training trials, participants were prompted on the computer monitor with the visual cue, "Ready" followed by "Listen." Following the stimulus presentation, "Decide" appeared on the monitor. The participant then responded by pressing one of two keyboard buttons labeled "tone" or "no tone." Instant feedback was displayed on the monitor after a response, as "Correct" or "Wrong." Reaction time was calculated as the time it took the participant to press a response key after the stimulus ceased. There was no time limit to make a decision. If the false alarm rate rose above 40% during the training, the visual feedback, "Do NOT press the tone key unless you are

sure you heard the tone," was displayed on the monitor. If any test ended with more than 40% false alarms, the participant was instructed to repeat the test; this, however, did not occur for any of the 16 subjects.

Perceptual training included 900 training trials of contralateral masking per day, over the course of two (n=13) or three (n=3) consecutive days. The 900 trials were divided into six blocks of subtests with optional rest periods in between. The first three subtests consisted of 200 trials each and the second three subtests included 100 trials each. It took between one to two hours for each participant to complete the 900 trials each day. Previous data from Gray et al. (2012) showed that learning approached an asymptote after two days of training. Specifically, subjects achieved 89% of the four-day improvement by the end of the second day. Therefore, most subjects in this study complete two days of training, as it has proven to be sufficient and expedient.

Post-tests were completed at the end of the last testing day. Post-tests followed the same protocol as the informational masking pre-test and the contralateral masking pre-tests. Forty trials were presented under both masking conditions. It was made clear to the participant that these were not practice, and results would be recorded.

III. Results

Results from the pre- and post-tests are presented here because it addresses the primary research hypothesis. Further analysis of false alarm rates and reaction time and can be found in the appendices.

Comparison of informational masking results from both pre- and post-testing allows better visualization of the relationship between the two auditory tasks (see Figure 1).

A paired sample *t*-test comparing the improvement from pre- to post-test measures revealed a significant improvement of thresholds in informational masking tasks (t_{15}= 3.993, p=.001).
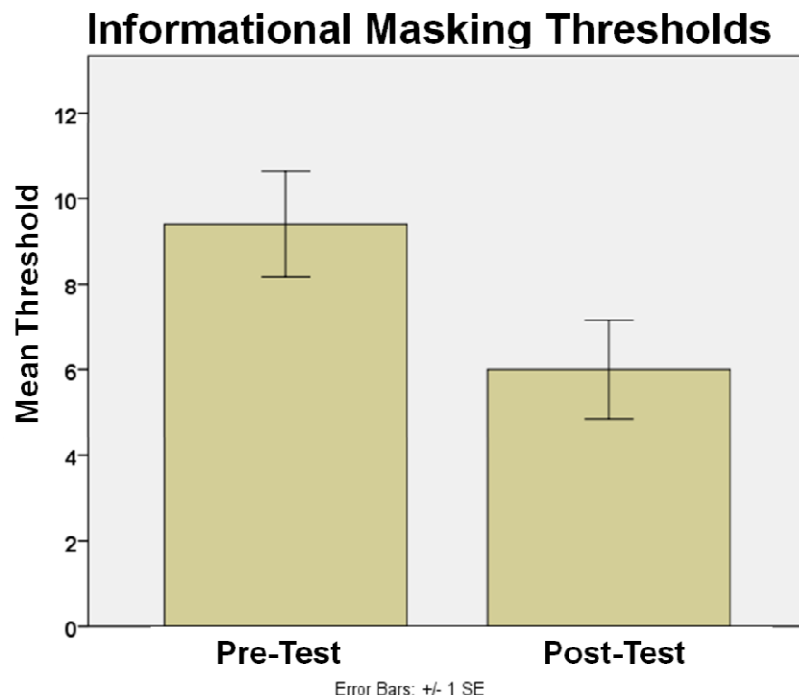

Figure 1

When the data from pre- and post-tests of the 11 subjects from Gray et al. (2012) were added to this group, there was still a significant improvement of thresholds in informational (t_{25}=4.386, p<.001) as well as contralateral masking tasks (t_{26}=2.873, p=.008). The groups from Gray et al. (2012) were four high school students with ADHD (HS), three middle school students with ADHD (MS), and four adult controls (NA).

The mean change in informational masking thresholds from pre- to post-test for each group is seen in Figure 2 below. Graduate Group 1 had one of the smallest mean changes in thresholds, second only to the first Undergraduate group. This is reasonable considering Graduate group 1 had the lowest thresholds in the pre-test, and therefore had less room to improve in the post-test. Graduate group 2 had slightly more improvement from pre- to post-test, and the adult controls (NA) from Gray et al. (2012) had even more improvement. This is interesting to note, because the normal adult controls from Gray et al. (2012) had unexpected poor performance at the onset of training, and improved over the course of four days. The improvement generalized to informational masking, as they greatly improved their thresholds from pre- to-post-test. The first three undergraduates studied, who complete three days of training ("Undergrad 1") had on average the least amount of improvement.

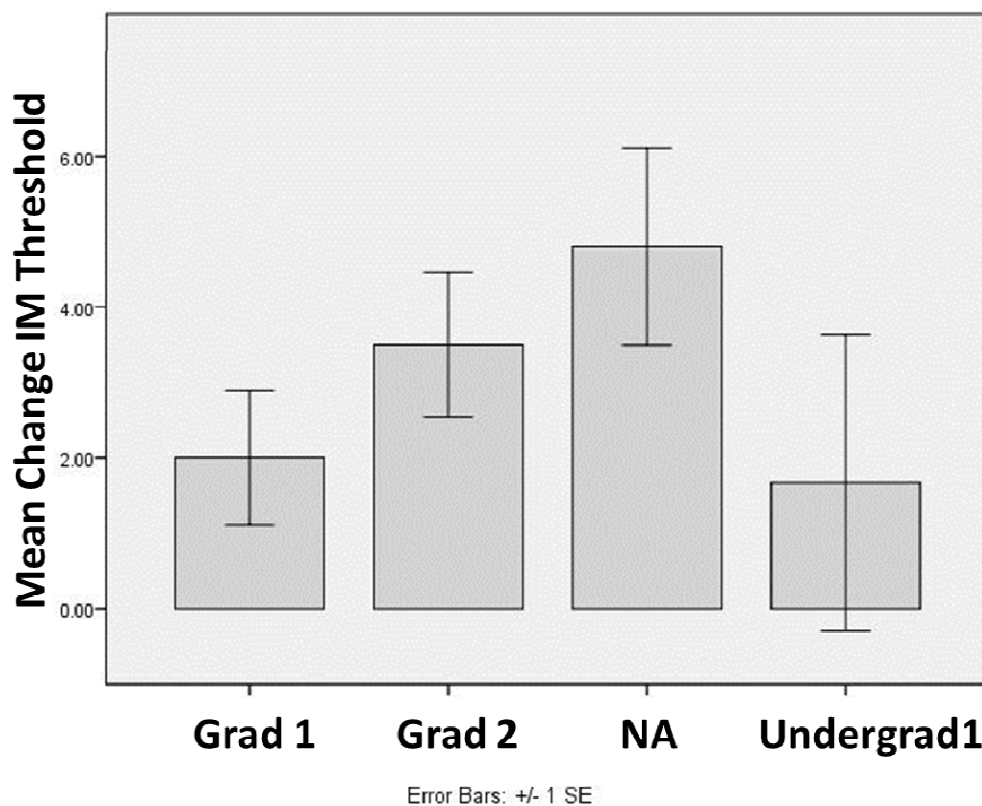## Improvement in Informational Masking Thresholds

Error Bars: +/- 1 SE

Figure 2

When the mean change in informational masking threshold from pre- to post-test from all groups from Gray et al. (2012) and the current study are graphed, other patterns are evident (see Figure 3). The second group of undergraduates who were tested ("UG2") had the highest average improvement of any group. The only subjects with a diagnosis of ADHD—those in high school (HS) and the younger group in middles school (MS)—had different generalization patterns. The older ADHD group (n=4) exhibited less variability and more improvement from pre- to post-test. The younger ADHD group (n=3) had the least amount of improvement of any group; in fact, their thresholds got worse (increased) on the post-test. This was the youngest group to be tested, and they had a diagnosis of

ADHD. Their older peers, however, performed similarly to the adults without ADHD and

exhibited less variability. These results indicate that maturation as well as attention

problems could contribute to the lack of generalization seen in this group.
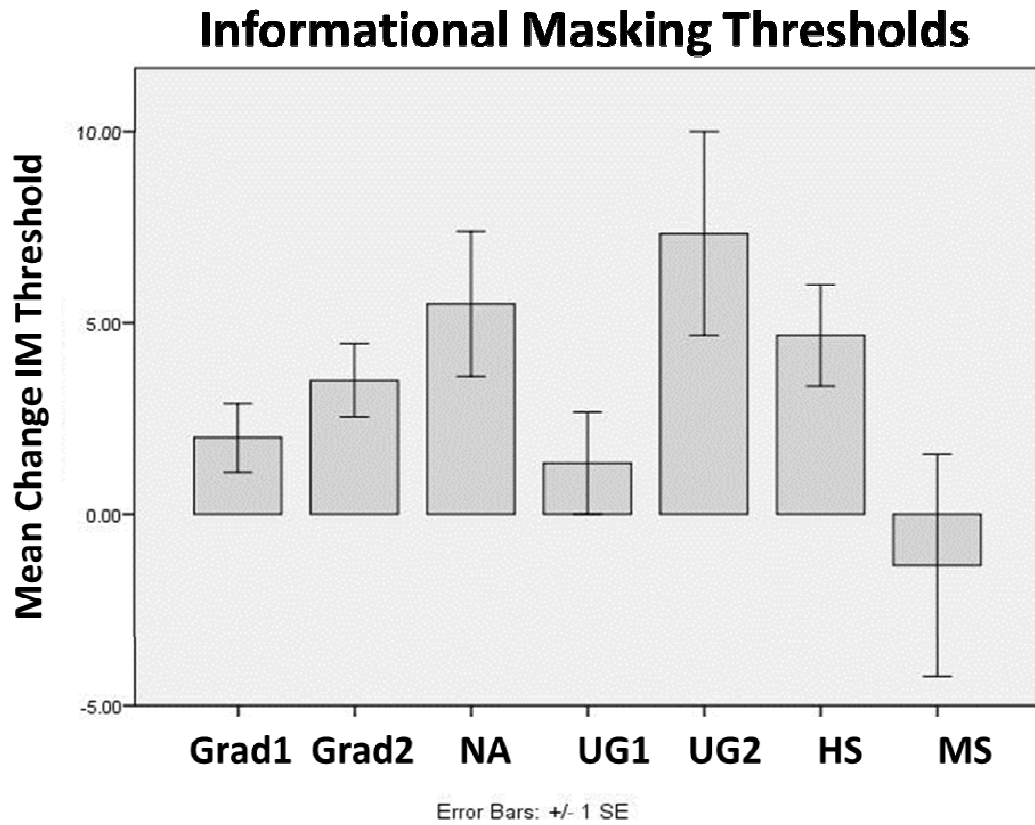

Figure 3

Contralateral masking thresholds also decreased (improved) from pre- to post-test

(t_{26}=2.873, p=.008). The normal adult controls (NA) exhibited the greatest improvement

from pre- to post-test (see Figure 4).

Contralateral Masking Thresholds

Error Bars: +/- 1 SE
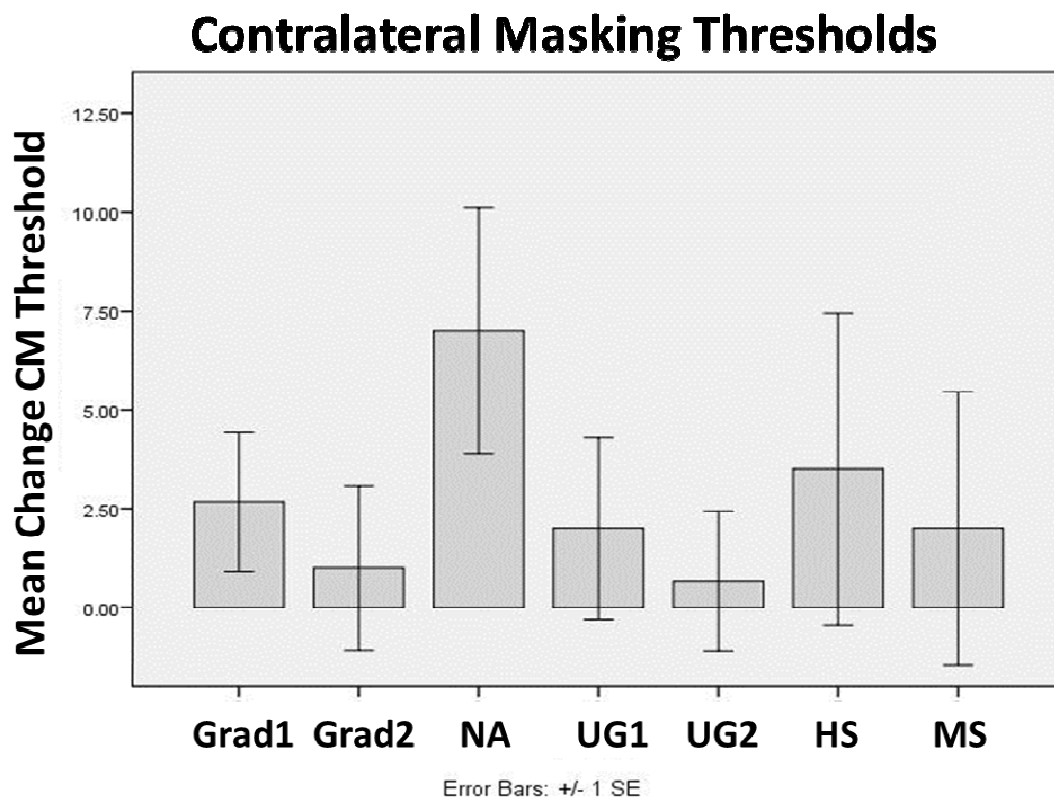
Figure 4

It was also noted that there was greater threshold improvement in the condition in which the subjects were not trained (informational masking). This was an interesting finding, as it was postulated that the trained task would show greater improvement. The instructions provided to the subjects, however, were to keep false alarm rates as low as possible during training and to select "no tone" if unsure whether the tone was present. These instructions may have discouraged subjects from maximally reducing their thresholds, as they were focused on keeping the false alarm rate low. Informational masking tasks, however, were only conducted during pre- and post-tests, and therefore subjects would not have had as much practice reducing false alarm rates during this new task.

IV. Discussion

The results of this study showed that training in contralateral masking generalized to informational masking after 2 days of auditory training in normal adult listeners. All subjects with and without ADHD showed some degree of improvement, and there was statistically no difference between subjects with and without ADHD in the change in informational masking thresholds (t_{24}=1.17, p=.25). This finding suggests that auditory training using contralateral masking could be a valid paradigm for those who want to improve listening skills in noise. School-aged children are often in unpredictable background noise, and attentional difficulties may exacerbate the effect of background noise. Informational masking is a type of masking that occurs in everyday life, and the finding that training in contralateral masking will improve the ability to hear in an unpredictable, multifrequency (informational) masker is of great interest and applicability.

The literature shows that informational masking has a higher level of unpredictability, and children with ADHD have higher false alarm rates in tasks involving informational masking (Gray, Breier, Foorman, and Fletcher, 2002). The attentional difficulties and hyperactivity that are the hallmark symptoms of ADHD are presumed to result in higher levels of impulsivity in this highly unpredictable task. In contralateral masking tasks, children with ADHD still exhibited higher false alarm rates than age-matched controls, but had fewer false alarms than in the informational masking tasks (Gray et al., 2002). This provides evidence of a continuum of impulsivity, as the predictability of the masker will affect impulsivity in children with ADHD. The data shown here suggests that training in the more predictable masking task will result in

improvement in the more unpredictable task. This should be considered when developing auditory training exercises designed to improve the ability to listen in background noise.

This study will also add to the literature of generalization in signal detection tasks. The few studies that have examined this studied signal detection in quiet, in a noise masker, and in a tone sequence (Wright & Zhang, 2009). In quiet, signal detection was shown not to generalize to other frequencies (Zwislocki et al., 1958). Extensive training on signal detection in a noise masker did not generalize to stimuli with different duration (Tucker et al., 1968). Signal detection in a tone sequence successfully generalized to new sequences (Leek & Watson, 1984). This study adds to the literature that training on signal detection in a non-sensory masker will transfer to a more unpredictable scenario of tone detection in a random, multifrequency masker.

Literature also shows that training may take time to mature, but generalization is similar between adults and children (Huyck & Wright, 2013). Our study suggests that the youngest ADHD group may not have generalized as well as older children with ADHD and adults. However, with only a few children tested with ADHD this difference did not reach statistical significance (t_4=1.9; p=.13). There may be an effect of age in the ADHD population when it comes to generalization, but more subjects and further study is required to draw definite conclusions. The youngest ADHD group tested in the similar previous study improved the least, and some subjects did not improve at all in the untrained task. Given that the untrained task was more unpredictable, and the literature shows that children with ADHD have more difficulty with impulsivity in this task, perhaps there is an age effect on the extent of generalization.

In the future, examining this age effect with children with ADHD may provide more evidence for training in this population. Additionally, the extent to which training generalizes in adults with ADHD could also provide more insight into the maturational time course of generalization. Since informational masking is present in everyday life, it is greatly applicable to train children and adults with and without ADHD to listen in the presence of unpredictable, multifrequency maskers. Further research will reveal the extent of generalization and the real-world benefit of being trained to listen in the presence of background noise.

V. Conclusions

After a period of auditory training (at least 1800 trials over two days) using a contralateral masking paradigm, learning transferred to the untrained task (informational masking). Although some studies have shown that there is limited generalization in signal detection tasks, there is a relative lack of research in this area. The real-world applicability of listening in unpredictable background noise and limiting the distractibility of such noise may be the driving factor in auditory training using informational masking. More research must be completed on the generalizability of signal detection tasks, especially in the context of developing auditory training programs.

Part II: Appendices

Appendix A: A Continuum of Impulsivity in Auditory Masking

a. Introduction

Single-interval, maximum likelihood methods are effective in estimating impulsivity and sensitivity. This is achieved through catch trials, where a subject must decide if a tone is or is not present in the presence of a masker. Impulsive subjects are more likely to have false alarms, or deciding the tone was present when in fact it was not. The level of impulsivity can be effectively measured by examining false alarm rate. Sensitivity can also be effectively measured using threshold. This method has been used to study children with ADHD, because the difficulty with attention and impulsivity that is the hallmark of this disorder could potentially be measured using false alarm rates in signal detection tasks.

Higher false alarm rates have been reported in children with ADHD during informational and contralateral masking tasks (Gray et al., 2002). Impulsivity is higher in informational masking tasks, due to the highly unpredictable nature of the masker. In informational masking, the masker is a random set of frequencies that are separated from the target tone in frequency so there is no effect of energetic (or peripheral) masking. Neff (1995) had shown that the maximum masking effect is seen with ten frequencies, thus ten random maskers are used in these studies. The effects seen will be primarily due to distraction or attentional effects that mask the target tone. Therefore, children with ADHD have difficulty with this task, which is reflected in high false alarm rates (Gray et al., 2002). Children and adults without ADHD also exhibit higher false alarm rates when

a masker is introduced. Children without ADHD have higher false alarm rates in the more unpredictable informational masker, and fewer false alarms with the more predictable contralateral masking (Gray et al., 2002).

In several interesting conditions, adults without ADHD have exhibited similar false alarm rates as children with ADHD (Gray et al., 2012). A study showed surprisingly high false alarm rates over a period of auditory training using contralateral masking. A group of adults was intended to be the control group, but instead mimicked the impulsivity of the children with ADHD (see Figure 5). This suggests that the level of impulsivity may lie on a continuum; false alarm rates fluctuate not only with predictability of the masker, but between groups that we would expect would be vastly different in levels of impulsivity. There were only three normal adults in that previous study, so the surprising finding of similarity with ADHD kids in non-ADHD adult controls deserves further investigation.

The current study will compare groups of adults without ADHD and compare them to the children with ADHD and adult "controls" from Gray et al. (2012) and examine the possibility that impulsivity lies on a continuum.

b. False Alarm Rates

False alarm rates were reported after each block of training trials. It was hypothesized that subjects could be trained to minimize their false alarm rates over the course of two days. In Gray et al. (2012), both children with ADHD and adult controls reduced their false alarm rates over time. Using the same methods, the three groups of graduate and undergraduate adults without ADHD were trained to minimize their false alarm rates.

Graduate Group 1 had markedly lower false alarm rates than any of the other groups during all days of training. The group maintained low false alarm rates over all trials, and were less variable than any other group. The false alarm rate decreased over time, but because their impulsivity at the onset of training was so low, there was less room to improve, as the other groups were able to demonstrate. In Figure 5, below, the performance of Graduate Group 1 can be seen in contrast to the children with ADHD and the adult controls in Gray et al. (2012).
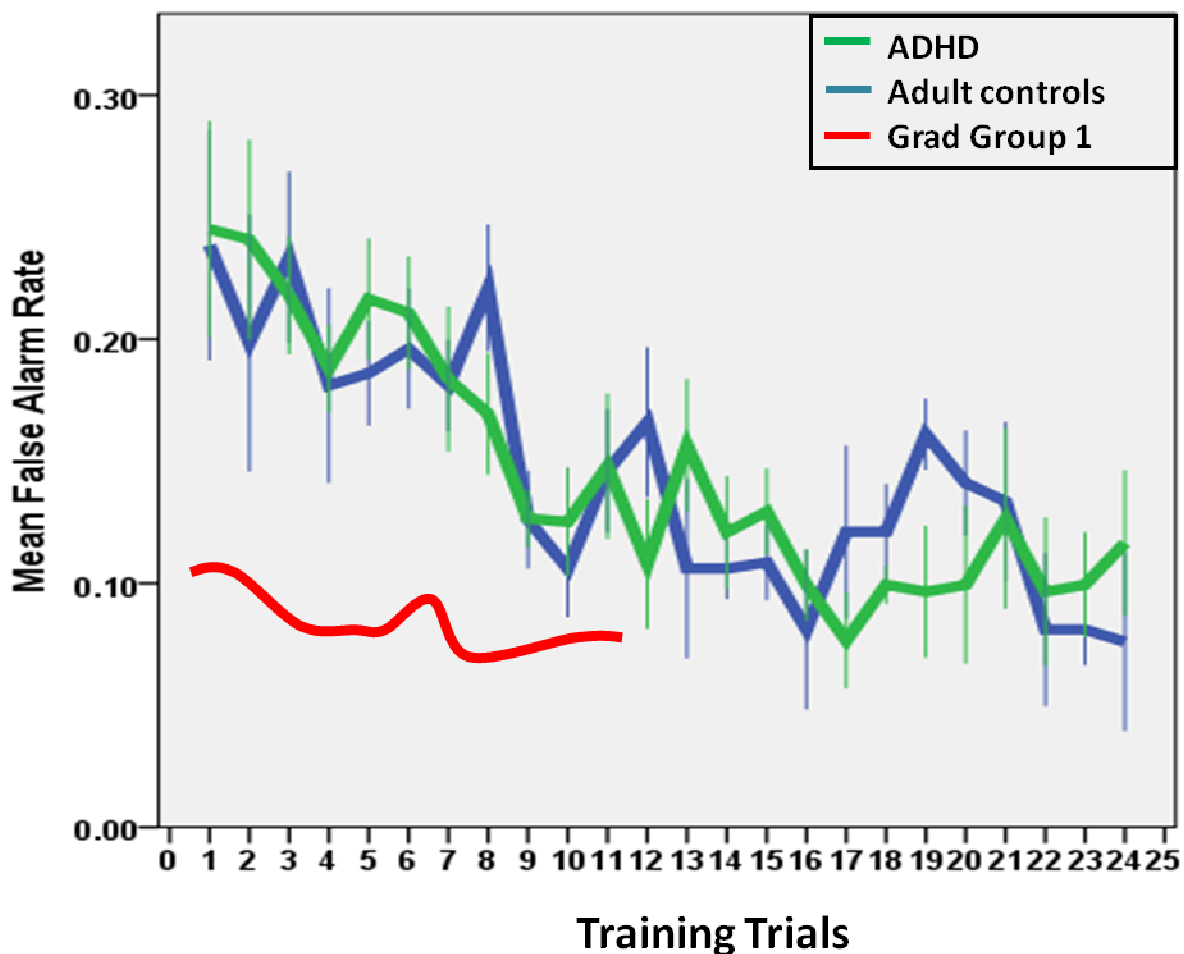
Figure 5

Graduate Group 2 was selected for study because of the similarity in educational experience. Because the subjects from Graduate Group 1 are all students in the same audiology program, they were accustomed to listening to stimuli at threshold level. Additionally, they were familiar with the procedure of auditory research and participation. Due to this unique set of experiences, a similar group with the same background was selected to complete the same training regimen a year later, when they were at the same point in their education as Graduate Group 1 was when they completed

the training. If Graduate Group 1 had an advantage due to the familiarity of participating

in auditory research or the experience of listening to threshold-level stimuli, we expected

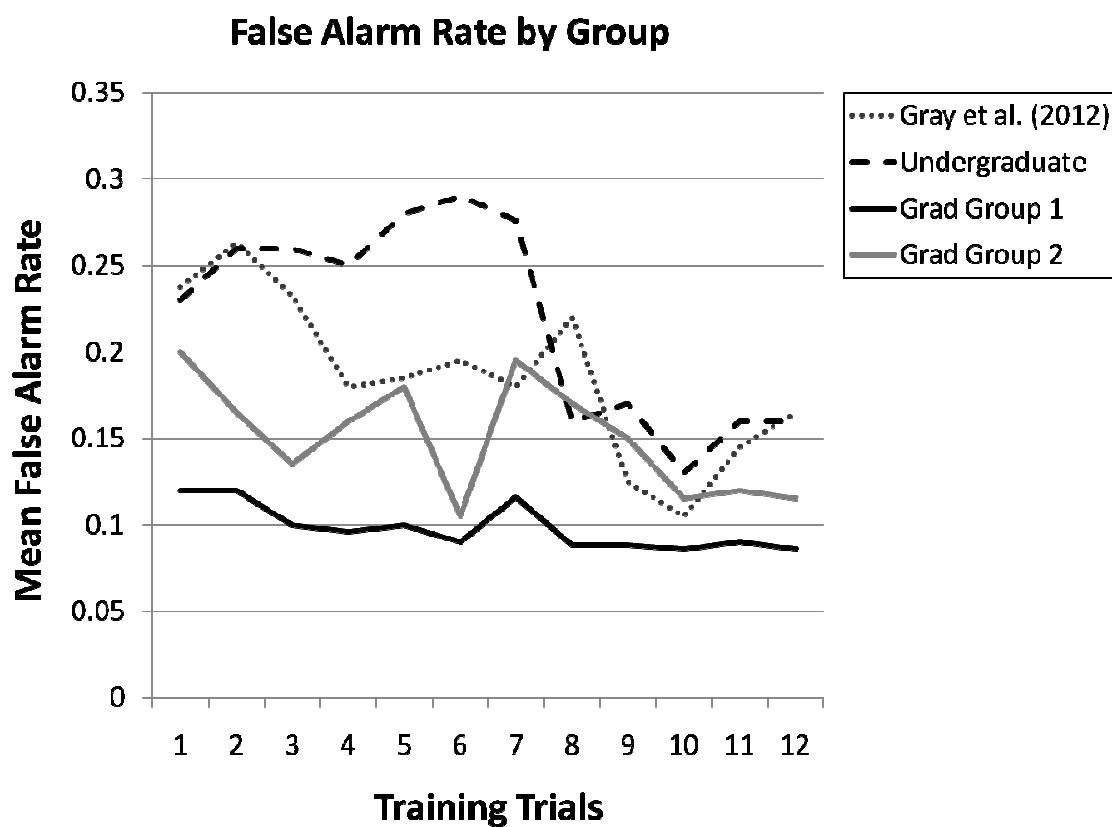to see a similar, exceptional ability to maintain low false alarm rates during all trials of

training.

False Alarm Rate by Group

Figure 6

Graduate Group 2, however, did not exhibit such a pattern, as can be seen in

Figure 6. While the group did decrease their overall false alarm rates over time, as

expected due to the sufficient amount of training on the task, they did not initiate the

training with very low false alarm rates as did Graduate Group 1. The question remains

whether this is an effect of varying levels of attention or motivation, or perhaps due to the

Hawthorne Effect. Because the participants in Graduate Group 1 were aware that the data

would be used later in their curriculum, it is reasonable to assume they were more

motivated to persevere through attentional lapses during the lengthy training regimen in order to maximize performance. Since they were aware that they were being evaluated on these tasks and would eventually face the data that resulted, the Hawthorne Effect may have been a motivating factor in keeping their false alarm rates exceptionally low. The participants in Graduate Group 2, although in the same stage of their education, had no direct investment in the data; they did not expect to evaluate the results at a future time.

Data from three participants in the Undergraduate group were obtained first, and these participants underwent three days of training. The other three participants in this group underwent two days of training, like the two graduate groups. The first three undergraduate data sets showed surprisingly high false alarms rates and high variability. In contrast to Graduate Group 1, who were highly motivated to keep false alarm rates low, these participants appeared highly impulsive. All groups received the same instructions, both written and verbal, and completed the study following the same protocol. However, the three undergraduates exhibited higher false alarm rates than the children with ADHD in the Gray et al. (2012) study.

When three more undergraduate students underwent training, the average false alarm rate of this group decreased, and more closely mimicked the ADHD group and adult controls from Gray et al., (2012). In Figure 6, the false alarm rates of the Undergraduate group, Graduate Group 1, and Graduate Group 2 are plotted with the ADHD group from Gray et al. (2012).

These patterns of false alarm rates contribute to the idea of the Hawthorne Effect, as well as motivation and attention as driving factors in auditory training. Attention is considered a mitigating factor for auditory training effectiveness, and it has been

demonstrated by studying subjects with ADHD. However, the adult controls in Gray et al. (2012) as well as the undergraduate group studied here show that a diagnosis of ADHD may not isolate groups of performers precisely.

c. Results

To determine if there was a significant difference between the ADHD group and the high-performing Graduate Group 1, further statistical analysis was warranted. A repeated-measure ANOVA between the Grad Group 1 and the children with ADHD from Gray et al. (2012) very closely approached statistical significance in the group-by-test interaction ($F_{1,11}=4.35$; $p=.06$). Such an interaction suggests that the learning curves of the two groups are not parallel; the graduate students' false alarm rates start low and thus remain relatively unchanged over training, while the false alarm rates of the children with ADHD improve. A plot of the marginal means (Figure 7) suggests that one group improves more over time than the other.
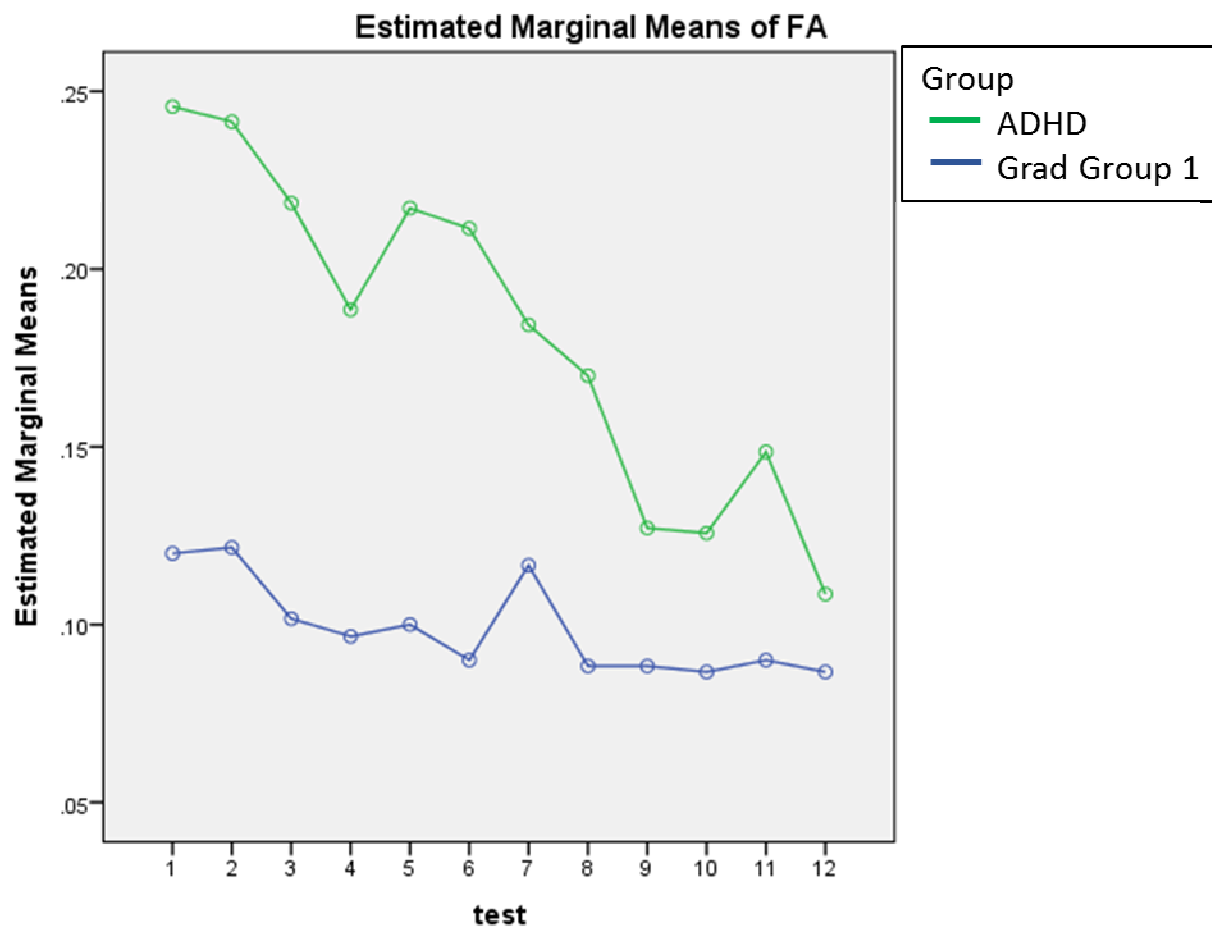
Figure 7

A repeated-measure ANOVA between the Grad Group 1 and the children with ADHD from Gray et al. (2012) over the first day of training reached statistical significance in the main effect of group ($F_{1,11}$=4.882; p=.049). A plot of the marginal means (Figure 8) suggests that one group started the training with a different level of impulsivity.
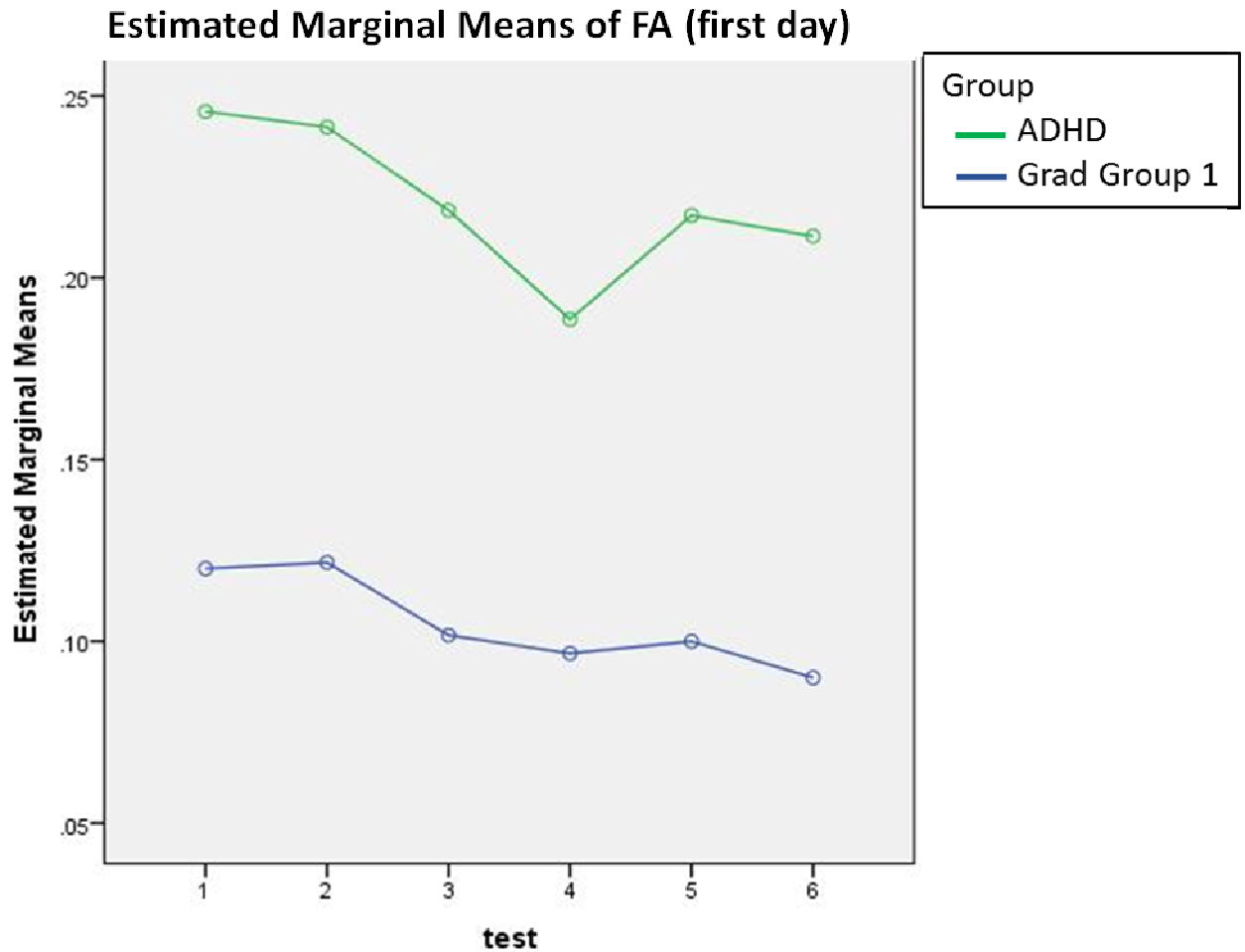
Figure 8

There was a significant difference in variance of false alarm rates between groups (p=.028 by the Kruskal-Wallis non-parametric version on the one-way ANOVA). Graduate Group 1 has significantly less variance. This group's false alarm rates were consistently low and the statistics show they were less variable as well. Graduate Group 2 also has relatively low variance, and the normal adult controls and the ADHD groups had greater variance.
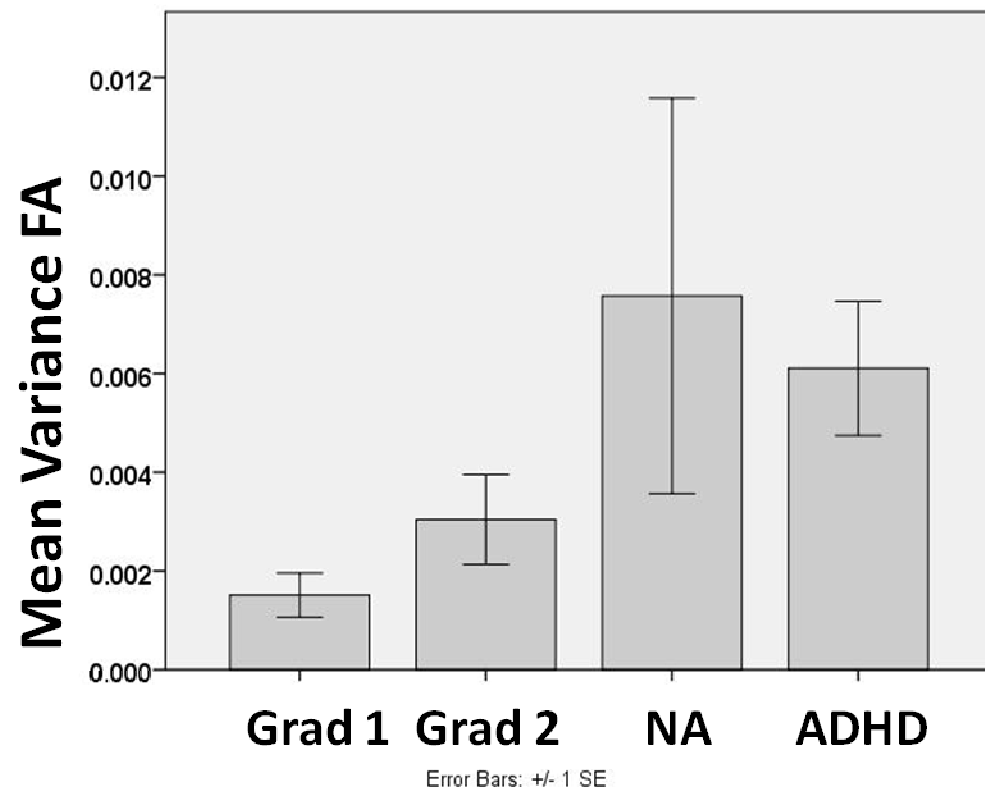
Figure 9

d. Discussion

There was a significance difference in the variance of false alarm rates during training. Motivated adults maintained more consistent performance than less motivated adults and children with ADHD. Statistical significance was almost attained in the learning curves of the low impulsive group (Grad Group 1) and the ADHD group. Because we suspect a continuum of impulsivity may exist, and because Gray et al. (2012) showed that the control adults in that study were not different than the ADHD kids, we expect difficulty showing statistically significant differences between the various groups in this comparison. For several of the tests we look only for differences between what we predicted a-priori to be our best and worst groups (Graduate Group 1 and the ADHD group). High variability and several outliers further complicated our statistical analysis. Differences in variance between the groups are clearly significant. The groups initiated training with significantly different false alarm rates, which suggests there is a spectrum of impulsivity among groups at the outset of training.

Recent research has addressed the fact that children and adults can exhibit a plethora of attentional problems, impulsivity, and hyperactivity difficulties, even in the absence of an ADHD diagnosis. Kessler et al. found that 4.4% of the adult population has an official diagnosis of ADHD but only 10% of those who meet the diagnostic criteria had been diagnosed and treated (2006). Many adults will exhibit features of ADHD but will go undiagnosed, which is important to note when studying impulsivity in adults. Children may also exhibit variable levels of impulsivity, regardless of diagnosis. Lubke et al. (2009) investigated whether subtypes of attention problems could be identified using quantitative measures, and specifically used ratings on the Child Behavior Checklist.

Evidence emerged that attention problems lie on a spectrum, and the severity of such

problems can be categorized as mild, moderate, and severe. Children with an ADHD

diagnosis fell into the severe class, with a few falling in the moderate category (Lubke et

al., 2009). This suggests that attention problems fall onto a severity continuum, and those

who do not meet the DSM-5 criteria for ADHD may still have moderate attention

problems.

Other factors besides attention will hinder the benefit of auditory training, and

these must be considered when developing software to aid populations with comorbid

conditions. Those who do not meet the criteria for ADHD may indeed have inattentive,

impulsive, and nervous behavior that may mitigate the effectiveness of an auditory

training regimen. Conversely, those who have moderate trouble with attention and

focusing may benefit from auditory training paradigm similar to this study's methods.

Although none of the adult subjects had an ADHD diagnosis, many had surprisingly high

false alarm rates at the onset of training. Over the course of two days, however, these

subjects could be trained to lower their false alarm rate while maintaining a similar

threshold. Auditory training aimed at reducing false alarm rates may benefit many

individuals, no matter what age and regardless of diagnosis.

Appendix B: Reaction Times

a. Introduction

Performance in auditory tasks is influenced by a number of factors including attention, motivation, and IQ. These factors will not only affect hits, misses, and false alarm rate, but will also influence reaction time. First described by Donders in 1868, reaction time can be measured in a number of ways (Abel, Rajan, & Giguere, 1990). When a single response is required from a stimulus, a simple reaction time (RTa) is a useful measure. RTb is measured when there is a choice paradigm, in which one of two possible stimuli are presented and a choice must be made. RTc is measured when a subject must respond to one stimulus and suppress a response to the second stimulus. While RTa will measure the time for cortical registration and response execution, RTb and RTc measure the time it takes for cortical registration, stimulus categorization, and response selection (Abel, et al., 1990). In the present study, participants must first listen, register the auditory input, categorize the information, and make a choice of whether the stimulus is present or not.

Reaction time has been used in a number of studies to measure effort employed during an auditory task. In particular, reaction time as a measure of cognitive effort has been used to evaluate the effectiveness of noise reduction technologies in hearing aids (Sarampalis, Kalluri, Edwards and Hafter, 2009). Reaction times increase (become slower) with decreasing signal to noise ratios and will decrease (become faster) with the introduction of noise reduction. Reaction speed, therefore, is thought to be a reflection of cognitive effort, and as the task becomes more difficult and requires more cognitive

effort, reaction time will increase. The literature indicates that reaction times are an effective measure of cognitive load in dual-task paradigms (Sarampalis et al, 2009).

Previous studies have shown that in signal detection tasks, the introduction of background noise will increase false alarms as well as reaction time (Abel, 2009). Effective maskers, such as the ones used in this study, will result in higher false alarms due to increased task difficulty, and reaction time will increase presumably for the same reason. Longer reaction times, which signify longer decision times, indicate greater caution in and uncertainty of response (Abel, 2009). Fast reaction times, therefore, may also demonstrate certainty, or confidence, in the response. In the present study, reaction times are used as a measure of cognitive effort and level of certainty or uncertainty of response.

b. Results

Due to the high rate of false alarms in the first three undergraduate participants (see Appendix A), the undergraduate cohort is separated into two groups for reaction time analysis. Out of 28,800 reaction times measured from the 16 subjects over two days of training, 27,644 reaction times were 2 seconds or less. Therefore, all 1156 reaction times greater than 2 seconds were considered extremes, and thus none were excluded. The number of times the reaction time was greater than 2 seconds (referred to here as a "long delay") is very different between groups. Mean long delay is the percent of time the RT was >2s for each group, and the percentage of long delays by group is plotted in Figure 10. A chi-square of the counts shows that Graduate Group 1 has far less occurrences of a "long delay" (>2 s) than the other groups (χ^2_3= 136; p<.001). Graduate Group 1 has a far smaller percentage of long delays (2.5%) compared to Graduate Group 2 (5.5%), the first three subjects in the Undergraduate group (3.5%), and the second half of the Undergraduate group (5%).
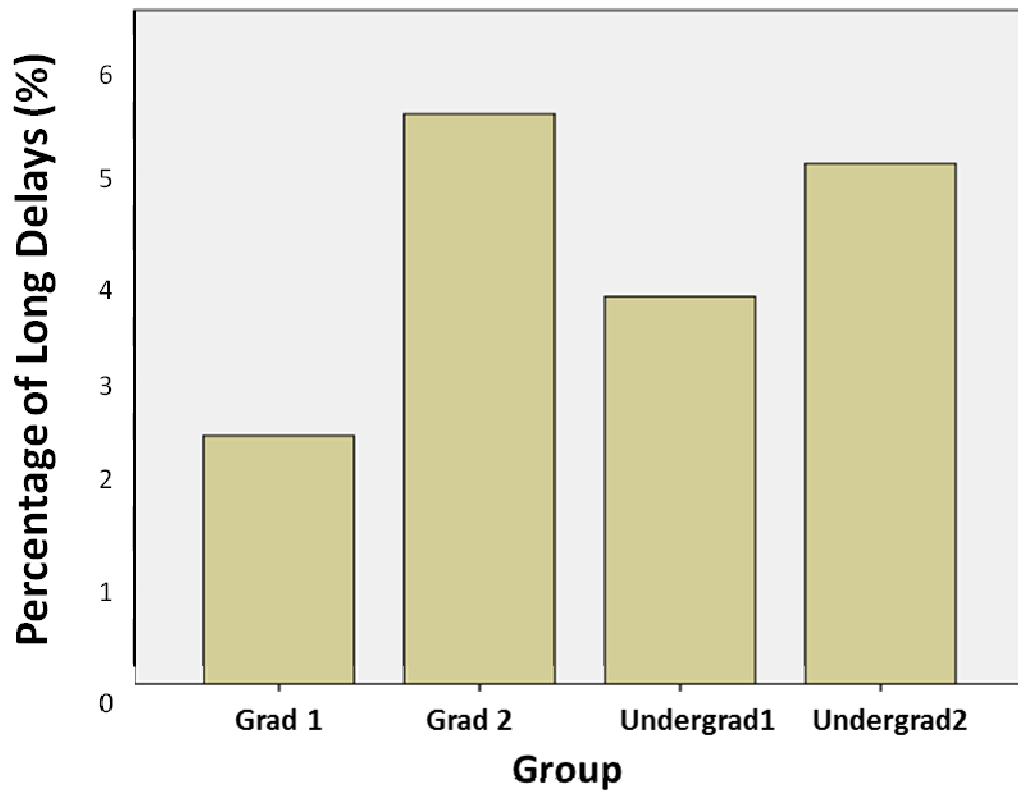
Figure 10

When Graduate Group 1 is graphed next to all other participants (see Figure 11), the difference is clear. A chi-square of the counts (percentage of times RT >2s) shows a big difference between Graduate Group 1 and all other groups combined. Graduate Group 1 had much fewer incidences of long delays in their reaction times than the other groups (χ^2_1= 109; p<.001).
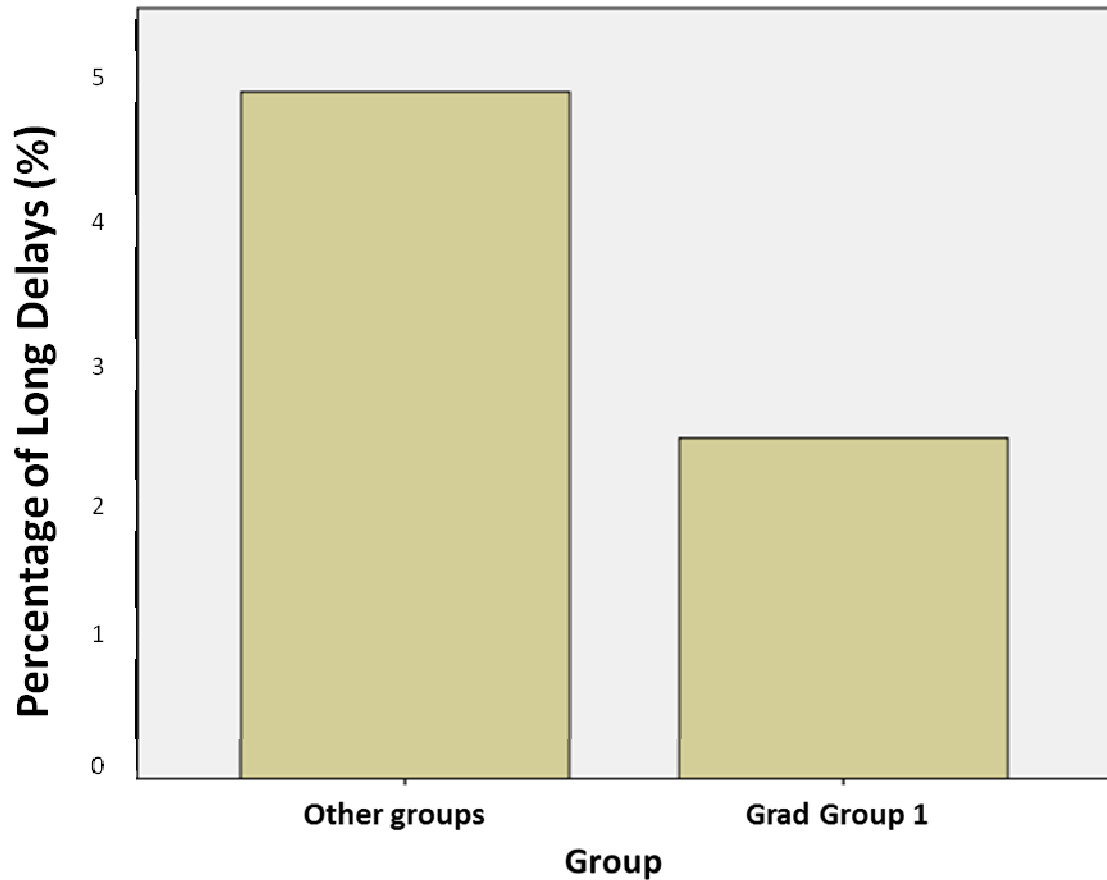
Figure 11

Because reactions times have a positive skew, a log transform was used for the subsequent analyses to normalize the distributions. By analyzing the meanLogRT (see Figure 12 and 13), Graduate Group 1 again had significantly shorter reaction times than each group individually and combined. Considering the literature that indicates reaction time may vary with cognitive effort, Graduate Group 1 experienced far less difficulty with the task than the other groups.
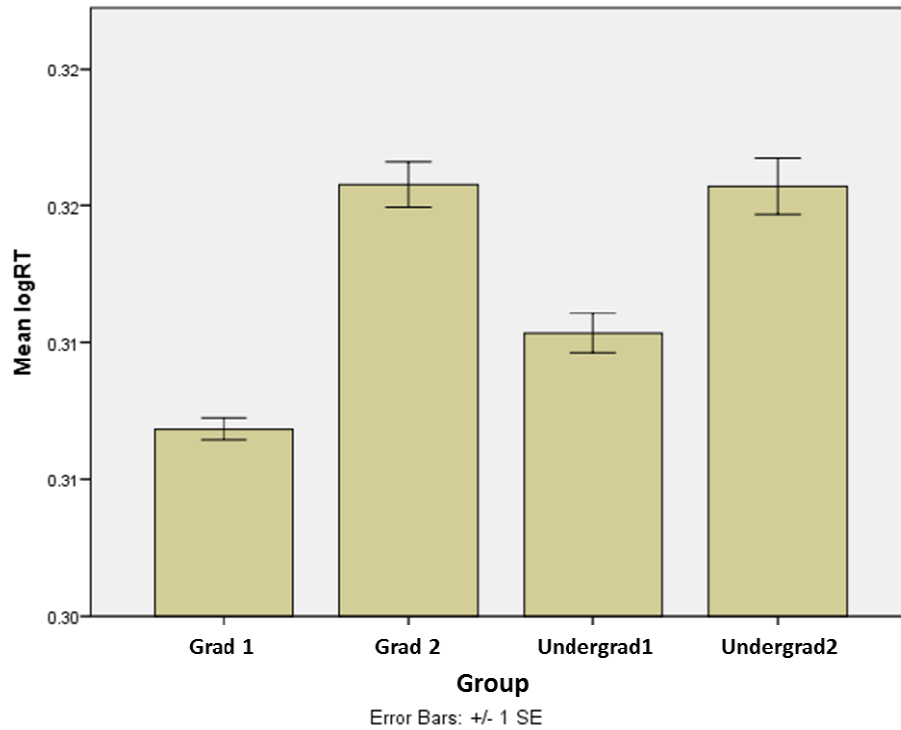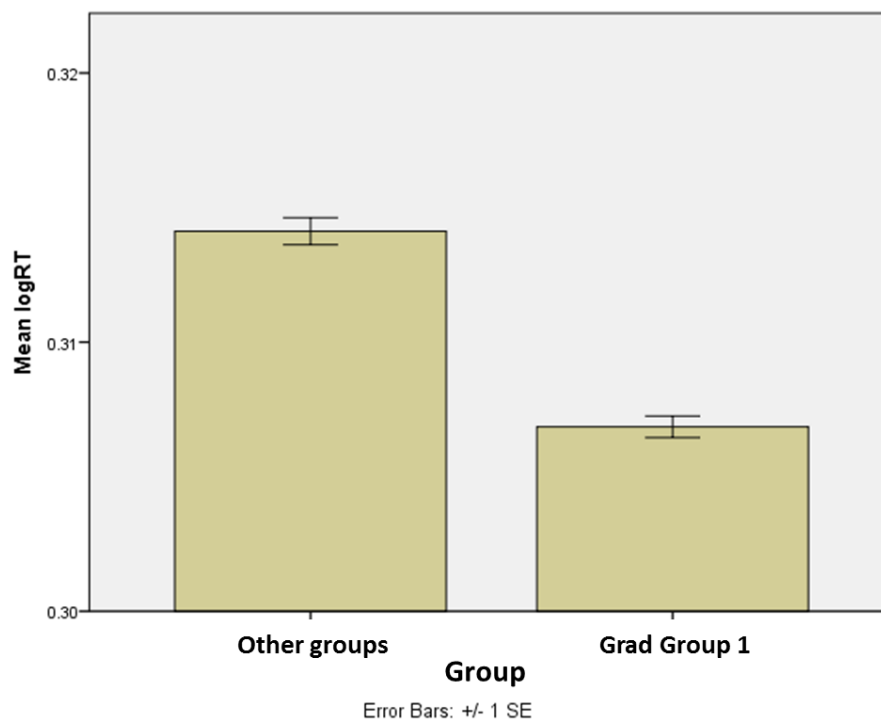
Figure 12

Figure 13

Finally, the regression of the percent of trials with a long delay went up significantly over training trials in the other three groups combined ($F_{1, 17998}=7$, p=.007, $R^2 < .001$ with a slope of 8.4 E-6). See Figure 14 for a plot of Graduate Group 1 and all others over training blocks of 180 trials. In other words, the regression line went up by 1.5% over two days of training. There was no linear trend with Graduate Group 1.
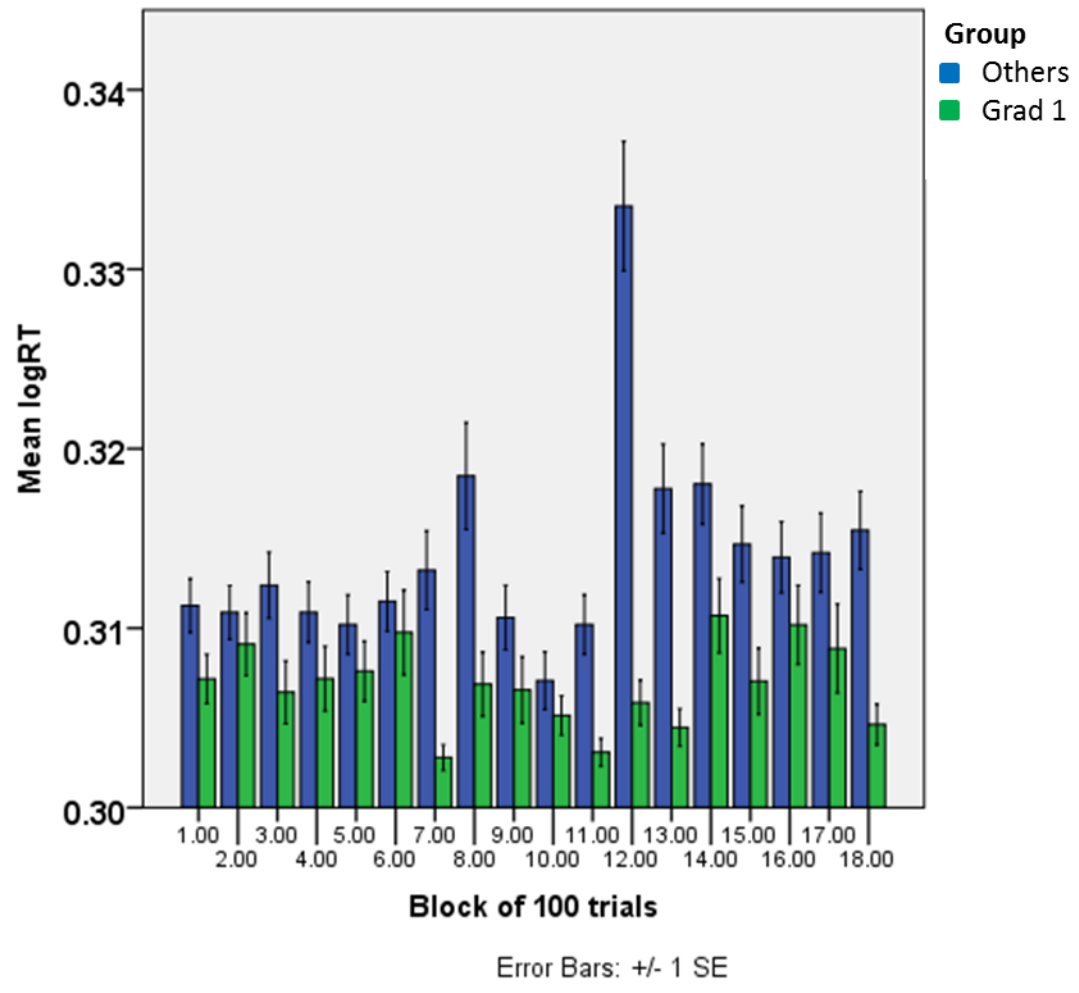

Figure 14

c. Discussion

Participants in Graduate Group 1 had lower false alarm rates, discussed in Appendix A, and also exhibited faster reaction times and less variable reaction times. This supports the idea that this group did not find the task as difficult, did not use as much effort, and has less uncertainty as the other groups studied.

Reaction time has been used as a measure of listening effort in recent research. A globally-accepted standardized test of listening effort has not been developed, but a variety of measures have been used in the past to examine auditory effort, such as pupillary dilation, heart rate, cortisol levels, and EMG responses (Houben, van Doorn-Bierman, & Deschler, 2013). The relationship between these measures and listening effort are not definitive, however, and the equipment and expertise required to measure these effects are not readily available in most audiology clinics. Reaction time measures are a proposed solution to effectively measuring listening effort in hearing-impaired subjects. Results show that reaction time increases with more difficult tasks, such as lower signal-to-noise ratios in speech intelligibility tests (Houben et al, 2013). Another obstacle, however, is the uncertainty of what is influencing listening effort. Possibilities of what is actually being measured include tiredness due to attention and/or other factors and cognitive load (Houben et al., 2013).
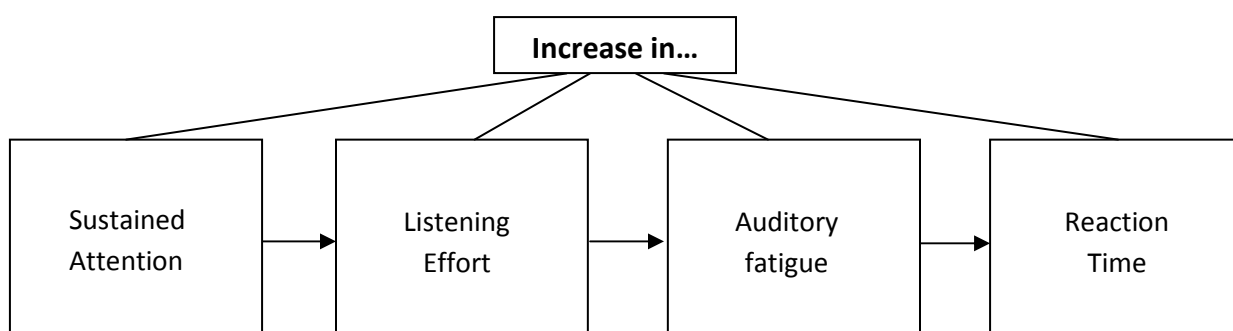
Graduate Group 2 and the Undergraduate Group had significantly more incidents of prolonged reaction time (>2 seconds), providing evidence of increased listening effort and possible fatigue.

Increased listening effort could be an effect of fatigue due to sustained attention. Reaction time has been a measure of listening effort, and could possibly be used as a measure of attention. In a recent study by Zhang, Barry, Moore, and Amitay (2012), a behavioral test of attention was developed to predict auditory performance and to quantify the impact of attention on an auditory task. The primary measure of the Test of Attention in Listening (TAIL) test was reaction time. Although reaction time is not a direct measure of attention, as shown by the lack of correlation between baseline reaction time and derived attention measures, it is useful in this context to separate contributions of attention from information processing efficiency (Zhang et al., 2012).

Appendix C: Overall Conclusions

This study provides evidence of generalization across two different non-sensory masking tasks. Training in contralateral masking improved thresholds in an informational masking task. Informational masking-like listening tasks frequently occur in real-world listening situations whenever there is a signal of interest within random masking components of differing frequencies (a teacher speaking in a noisy classroom, for example). Contralateral masking-like listening tasks would also occur whenever there is a signal spatially separated from similar-frequency background noise (a cocktail party, for example).

The training data show that all but our initially best group of listeners can markedly improve their performance in a contralateral masking task with considerable effort; in this study, two consecutive days of 900 signal-detection trials per day for a total of about 3 hours of effort was sufficient to improve performance. It appears that after two days of training, performance in this task approaches asymptote for all control listeners (adults without a diagnosis of ADHD).

There is a continuum of impulsivity at the start of training to avoid false alarms in a contralateral masking task. The groups studied here had significantly different false alarm rates at the beginning of training. A group of graduate students who knew they would need to study their data showed significantly better initial performance than a collection of other supposedly control groups. The variance in this group of motivated listeners was low. This provides evidence that a spectrum of impulsivity exists among these groups initially; however, after a period of training, all groups were able to limit distractibility and reduce impulsivity.

It appears that many adults, except for the most engaged graduate students with previous training in threshold-level listening tasks and motivation to attain optimal performance, can be made to behave as if they have ADHD for the first few hundred trials of prolonged training. This might set up a possible opportunity to study ADHD-like behaviors in a group (college students) that are likely easier to attract to such studies of psychoacoustics. One speculation about this rapid induction of 'attention deficit' is that the maximum likelihood method approaches threshold quickly (in maybe as few as 10 trials) so the task becomes difficult and subjects start getting feedback of incorrect responses, yet they face the knowledge of hours of similar work ahead, and might momentarily become more impulsive in frustration before they settle down to a more optimal long-term listening and responding strategy.

Reactions times appear to be a useful measure of cognitive effort in such a training task. The graduate group that attained optimal performance quickly and sustained that performance throughout training had significantly less incidences of prolonged response times. According to the literature, this suggests that the motivated, high performing graduate group was also expelling less effort and were more certain in the responses. These results are consistent with the idea that this group found the task less difficult, and were able to surpass all other groups in performance.

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