Effect of Stimulant Medication on the Acceptance of Background Noise in Individuals with Attention Deficit/Hyperactivity Disorder

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Abstract
Available data indicate that, on some auditory tasks, individuals with attention deficit/hyperactivity disorder (ADHD/ADD) perform more poorly than individuals without ADHD/ADD. Research also indicates that performance may improve with the use of stimulant medication. The present study (1) examined the effect of stimulant medication on acceptance of background noise in individuals with ADHD/ADD and (2) investigated the dependence of speech presentation level on acceptance of noise in persons with ADHD/ADD. Fifteen normal hearing female college students with ADHD/ADD served as the participants. The participants were medicated in one session and unmedicated in the other session. Results showed that medication significantly increased the acceptance of background noise for individuals with ADHD/ADD. Results also indicated that acceptance of noise depends on speech presentation level, but the improvement in acceptance of noise was not dependent on medication.

Key Words: Acceptable noise level, attention deficit disorder, attention deficit/hyperactivity disorder, most comfortable level, stimulant medication

Abbreviations: ADD = attention deficit disorder; ADHD = attention deficit/hyperactivity disorder; ANL = acceptable noise level; APD = auditory processing disorder; BNL = background noise level; MCL = most comfortable listening level; SNR = signal-to-noise ratio; UCL = uncomfortable listening level

Sumario
La información disponible indica que, en algunas tareas auditivas, los individuos con trastornos de déficit de atención e hiperactividad (ADHD/ADD), tienen un desempeño más pobre que aquellos sin ADHD/ADD. La investigación también indica que el desempeño puede mejorar con el uso de medicamentos estimulantes. El presente estudio (1) examinó el efecto de una medicación estimulante sobre la aceptación del ruido de fondo en individuos con ADHD/ADD, y (2) investigó la dependencia del nivel de presentación del lenguaje sobre la aceptación del ruido en personas con ADHD/ADD. Las participantes fueron quince mujeres normo-oyentes, estudiantes universitarias, portadoras de un ADHD/ADD. Las participantes fueron medicadas en una sesión y no recibieron medicación en la otra sesión. Los resultados mostraron que la medicación incrementó significativamente la aceptación del ruido de fondo en individuos

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Attention deficit/hyperactivity disorder (ADHD) or attention deficit disorder (ADD) is a neurobiological condition affecting attention and impulse control. Deficits associated with ADHD/ADD are typically pervasive and supramodal, impacting more than one sensory modality and involving aspects of executive dysfunction (Barkley, 1990; Keller, 1992; APA, 1994; Selikowitz, 1995; Geffner et al, 1996). Recent anatomical studies of individuals with ADHD/ADD indicate that these individuals have structures in the frontal, temporal, and parietal cortices that are smaller than normal and present morphological anomalies, further supporting the notion that ADHD/ADD is a global abnormality (Rubia et al, 1999; Schweitzer et al, 2000; Sowell et al, 2003). Furthermore, comorbidity is often associated with ADHD/ADD. The most common developmental/behavior comorbid conditions include learning disabilities; speech, language, and reading difficulties; pragmatic dysfunction; and behavioral problems with no other specific diagnosis (Giddan, 1991) as well as a number of psychiatric disorders (August et al, 1996; Piszka, 2003).

One sensory modality that ADHD/ADD affects is audition. Aspects of auditory function, which have been examined in individuals with ADHD/ADD, have primarily been studied in children, and there are no comparable data for adults (Searight et al, 2000). In the absence of these data, the tentative assumption was made that information obtained on children would be similar to that of young adults. Facets of auditory function that have been examined include most comfortable listening levels (MCL), uncomfortable listening levels (UCL), word recognition scores, decision-making criteria in noise, and auditory processing skills (Gascon et al, 1986; Moss and Sheiffele, 1994; Geffner et al, 1996; Lucker et al, 1996; Chermak et al, 1999; Brier et al, 2002; Chermak et al, 2002; Gray et al, 2002).

MCLs and UCLs have been shown to be lower in children with ADHD/ADD in comparison to those without ADHD/ADD (Lucker et al, 1996). These results suggest that children with ADHD/ADD are overly sensitive to sounds that are judged to be comfortable and/or tolerable by children without ADHD/ADD.

Auditory performance has also been measured using word recognition tests in quiet and in noise (Geffner et al, 1996). In quiet, word recognition ability was not different in children with and without ADHD/ADD. However, when background noise was introduced, children with ADHD/ADD performed 32% poorer on word recognition tasks than children without ADHD/ADD.

Decision-making criteria (i.e., determination if a sound was present or absent) have been examined using auditory tasks with varying degrees of noise (Brier et al, 2002; Gray et al, 2002). Specifically, children with ADHD/ADD were asked to determine if they heard a tone in the presence of various degrees of background noise, and changes in their decision-making criteria were measured on a strict-lax continuum. Results indicated that the criteria of children with and without ADHD/ADD were similar when the background noise level was not distracting. However, when the background noise was distracting, the criteria used in determining if a tone was present by individuals with ADHD/ADD became significantly more lax (i.e., a significant number of false-alarm responses were present) in comparison to criteria used by individuals without ADHD/ADD.
ADHD/ADD. The difference in decision-making strategies was interpreted as a lack of tolerance of background noise by listeners with ADHD/ADD.

Poor performance on auditory processing disorder (APD) tests has been observed in individuals with below normal intelligence, developmental disorders, dyslexia, learning disabilities, and ADHD/ADD (Piszka, 1996). For the purposes of this study, we focused on how individuals with ADHD/ADD performed on auditory tasks including APD tests. Because many children with ADHD/ADD are also classified as having APD, there has been a great deal of controversy as to whether ADHD/ADD and APD are indistinguishable or separate disorders (Gascon et al, 1986; Moss and Sheiffele, 1994; Chermak et al, 1999; Chermak et al, 2002). Two explanations have been given for the cause(s) of poor performance on APD tests by persons with ADHD/ADD: (1) the length of auditory processing tests causes a breakdown in attention, resulting in poor auditory processing scores, and (2) poor auditory processing scores are a result of poor auditory processing skills, which in turn cause deficits in attention (Burd and Fisher, 1986).

The connection between ADHD/ADD and APD was also addressed in two studies that investigated the effects of stimulant medication on auditory processing tests. Gascon et al (1986) found that children with ADHD/ADD had significant difficulties with APD tests and that their performance improved with stimulant medication. The researchers concluded, “the clinical picture of APD is indistinguishable from that of ADHD/ADD, and ... [APD tests] are sensitive measures of attention deficits” (Gascon et al, 1986, p. 31). Conversely, Tillery et al (2000) found that after children took medication for ADHD/ADD, performance improved on tests of attention but did not improve on auditory processing tasks. This suggested that sustained auditory attention, not auditory processing, is affected by stimulant medication. As with previous investigations, results with the use of stimulation medication did not resolve the controversy as to whether ADHD/ADD and APD are separate disorders.

In the studies discussed above, it was demonstrated that auditory function may be affected in individuals with normal hearing and ADHD/ADD, particularly when background noise is introduced. Nabelek et al (1991) developed a measure to determine a listener’s acceptance of background noise to differentiate listeners who would accept and reject hearing aids. The measure, which has become known as “acceptable noise level” (ANL), is a measure of an individual’s willingness to accept noise while listening to speech at MCL. ANL is computed by subtracting the maximum acceptable background noise level an individual is willing to accept from the MCL. Individuals with small ANLs (e.g., 8 dB) are willing to accept large amounts of background noise and are more likely to wear their hearing aids on a regular basis. Individuals with large ANLs (e.g., 14 dB) are, however, less willing to listen when background noise is presented and less accepting of hearing aids (Nabelek et al, 2004). ANL is not related to age, gender, hearing sensitivity, or type of noise distraction (Nabelek et al, 1991; Rogers et al, 2003). ANL does not change with the use of amplification, indicating that it is an attribute of the individual and not of the hearing aid(s) (Lytle, 1994; Nabelek et al, 2004).

Franklin et al (forthcoming) modified the ANL procedure to determine if acceptance of noise depends on speech presentation level. Acceptance of noise was measured for a wide range of speech presentation levels on young adult females with normal hearing without ADHD/ADD. Results indicated that the mean ANLs increased systematically with speech presentation level (i.e., 10.6 dB at 20 dB HL [low stimulation level], 15.5 at MCL, and 26.4 dB at 76 dB HL [high stimulation level]).

Zentall and Zentall (1983) have proposed that individuals with ADHD/ADD may perform differently on tests requiring sustained attention (e.g., tests of vigilance, copying tasks, arithmetic tasks, etc.) when stimulation levels vary. Other investigators have shown that the auditory performance of children with ADHD/ADD is decreased in background noise (Moss and Sheiffele, 1994; Geffner et al, 1996; Brier et al, 2002; Gray et al, 2002). In the present study, the procedures of Franklin et al (forthcoming) for measuring ANLs at different speech presentation levels were used to describe the acceptance of noise in individuals with ADHD/ADD. Since individuals with ADHD/ADD use stimulant medications to control behaviors associated with this disorder, the effects of medication on the acceptance of background noise were also described. The following research
questions were addressed:

1. Does the use of stimulant medication change the acceptance of background noise in persons with ADHD/ADD?
2. Is the acceptance of background noise dependent on speech presentation level in persons with ADHD/ADD?

METHODS

Participants

Fifteen female college-aged students (mean age = 22.0 years) who were registered with the University of Tennessee Disability Services for ADHD/ADD served as the participants in this study. An attempt was made to include both male and female participants; however, because only a small number of males were willing to participate, the study was conducted using only female participants. The criteria for inclusion were as follows:

1. A reported diagnosis of ADHD/ADD by the University of Tennessee Office of Disability Services (Note: To qualify for services for ADHD/ADD at the University of Tennessee, documentation must be provided to the university to verify eligibility under the Americans with Disabilities Act of 1990 and Section 504 of the Federal Rehabilitation Act of 1973 [U.S. Department of Justice, 2004]. In addition, an appropriate professional who is both certified and licensed must provide the documentation. The documentation must include evidence of early and current impairment, a diagnostic interview, and results of accepted comprehensive tests. See University of Tennessee Office of Disability Services [2004] for complete review of the documentation guidelines for ADHD/ADD at the University of Tennessee.)
2. Regular use of stimulant medication for the treatment of ADHD/ADD
3. Normal hearing sensitivity (pure-tone hearing thresholds <20 dB HL at 0.5, 1, 2, and 4 kHz in each ear)

Descriptive information for the 15 female participants is shown in Table 1. Eight participants had a diagnosis of ADHD, and seven had a diagnosis of ADD. Ten participants were being treated with Adderall or AdderallXR; the remaining five participants were treated with other stimulant medicines. The duration of drug therapy ranged from 0.75–11 years with a median duration of treatment of 2.5 years.

Materials and Procedures

Pure-tone auditory thresholds were screened with an audiometer (GSI 16, model 680

<table>
<thead>
<tr>
<th>Subject</th>
<th>Diagnosis (Dx)</th>
<th>Medicine</th>
<th>Daily Dosage (mg)</th>
<th>Years of Dx</th>
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<tbody>
<tr>
<td>1</td>
<td>ADHD/ADD</td>
<td>Adderall</td>
<td>40</td>
<td>1.5</td>
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<tr>
<td>2</td>
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<td>Adderall</td>
<td>20</td>
<td>1.25</td>
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<tr>
<td>3</td>
<td>ADD</td>
<td>Dexedrine</td>
<td>10</td>
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<td>4</td>
<td>ADD</td>
<td>AdderallXR</td>
<td>30</td>
<td>1.5</td>
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<tr>
<td>5</td>
<td>ADD</td>
<td>Adderall</td>
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<td>6</td>
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</tr>
<tr>
<td>9</td>
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<td>Adderall</td>
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<td>AdderallXR</td>
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#1716) using supra-aural headphones (Telephonics, TDH-50P). The audiometer was calibrated to the American National Standards Institute (ANSI, S3.6-1996) standards. The participant was seated in a sound-treated booth (IAC, model #404A) with acceptable ambient noise levels (ANSI, S3.1-1991). Three prospective participants who did not have normal hearing sensitivity ceased their participation after the hearing screening.

ANLs were then measured in the sound field in a sound-treated booth with the participant seated 1.5 m from a loudspeaker located at 0º azimuth. Test materials was delivered by a Dell (OptiPlex GX 400) personal computer disc player, which was routed through an audiometer to an ear level loudspeaker. ANLs were measured using a Cosmos recording of male running speech (i.e., Arizona Travelogue1) as the speech stimulus, and multitalker babble as the competing stimulus. Three speech presentation levels (20 dB HL, MCL, and 76 dB HL) were presented in random order.

To obtain ANLs, MCLs and maximum acceptable background noise levels (BNLs) were measured using procedures described by Nabelek et al (1991). First, listeners adjusted the level of the story to their MCL. Multitalker babble was then added, and the listeners adjusted the babble noise to the maximum level of the background noise they were willing to accept or “put up with” without becoming tense or tired while listening to and following the words of the story (called BNL). The acceptable noise level (ANL) was then calculated by subtracting the BNL from the MCL (see Appendix A for ANL instructions).

For the fixed speech presentation level conditions (20 dB HL and 76 dB HL), procedures described by Franklin et al (forthcoming) were used. These procedures were employed so that the data obtained from the present study could be compared to similar data taken from young adult females without ADHD/ADD. For these procedures, the speech presentation level was fixed, and only the BNL was measured. These ANLs were calculated by subtracting the BNL from the fixed speech presentation level condition (20 dB HL, MCL, and 76 dB HL). For each condition, if the difference between the ANLs was more than 4 dB, a third ANL was obtained, and the median ANL was selected. A third trial was necessary on 3 out of 90 occasions. The time required to determine one ANL ranged from 45 seconds to two minutes.

The participants were evaluated at the ANL Laboratory at the University of Tennessee. There were two separate experimental testing sessions—one with and one without medication. The order of the sessions was counterbalanced: eight participants were unmedicated for their first session and medicated for their second session, and seven participants were medicated during the first session and unmedicated for their second session. For the unmedicated session, participants were required to take their medication at least 12 hours prior to the testing session. [Note: The effects of stimulant medications can be seen within 30 minutes, peak approximately three to six hours from administration, and diminish between 12 and 15 hours after administration (Santosh and Taylor, 2000; Medical Economics, 2003)]. In this study, the mean time between last administration of medication and the unmedicated experimental session was 28.7 hours (range: 19–72 hours). Therefore, the effects of the stimulant medication should have subsided between 13.7 and 16.7 hours prior to experimental testing.

In the first session, each participant (1) completed informed consent procedures, (2) received a hearing screening, and (3) performed the experimental tasks. The second session was typically conducted five days after the first session (range: 2–20 days). In the second session, only the experimental tasks were performed. The first session was completed in approximately 30 minutes, and the second session was completed in approximately 15 minutes.

**RESULTS**

**Most Comfortable Level**

MCLs for each condition were averaged across the 15 subjects. The mean MCL was 42.3 dB HL (SD = 7.7 dB) for the unmedicated condition and 42.1 dB HL (SD = 7.2 dB) for the medicated condition. Results of a paired sample t-test revealed that MCLs for the
unmedicated and medicated conditions were not significantly different (t[14] = 0.08, p = .94). These results indicated that MCLs were unaffected by the use of stimulant medication in individuals with ADHD/ADD.

**Acceptable Noise Level**

ANLs for each medication condition and speech presentation level were averaged across the 15 subjects. Figure 1 shows a systematic increase in ANLs as speech presentation level increased for individuals with ADHD/ADD while medicated and unmedicated. Figure 1 also shows a decrease in ANL (i.e., the listener accepted more noise) when medication was utilized in individuals with ADHD/ADD. (Note: For comparison purposes, Figure 1 also includes mean ANLs across speech presentation levels obtained by Franklin et al [forthcoming] for young adult females without ADHD/ADD).

A two-way analysis of variance (ANOVA) was performed to evaluate the effects of stimulant medication and speech presentation level on acceptance of background noise. The dependent variable was ANL value. The within-subject factors were medication with two levels (with or without) and speech presentation level with three levels (20 dB HL, MCL, and 76 dB HL). The analysis revealed significant main effects for medication (F[1,14] = 10.9, p = .005) and speech presentation level (F[2,13] = 52.7, p < .001). Speech presentation levels were further assessed using pairwise comparisons; all comparisons were significant at the 0.05 significance level. The medication by speech presentation level interaction was not significant (F[2,13] = 0.17, p = 0.846). These results demonstrated that ANL increased significantly with presentation level and were significantly improved when medication was used. Results further indicated that the improved ANL, which resulted from using stimulant medication, was not dependent on the presentation level of the speech stimuli.

**DISCUSSION**

MCL results indicate that MCL was unaffected by the use of medication for those with ADHD/ADD. Furthermore, MCL results obtained in the present study were comparable to the MCLs obtained by Franklin et al (forthcoming) for ten college-age female listeners who did not have ADHD/ADD (mean MCL = 41.6 dB HL [SD = 4.9 dB]). These results for young adult females differ from those of Lucker et al (1996) who found that children with ADHD/ADD prefer lower MCLs than children without ADHD/ADD. The differences in these findings may be due to differences in how ADHD/ADD is manifested in young adults (Copeland, 1991; Wender,
These findings may also indicate that individuals with ADHD/ADD may be overly sensitive to sounds as children but that they are able to outgrow this over sensitivity as adults.

The most significant findings of the present study were that (1) ANLs decreased significantly at all presentation levels with the use of stimulant medication, and (2) the amount of ANL decrease was similar for all speech presentation levels. First, ANLs decreased by an average amount of 2.6 dB across all presentation levels when the participant was medicated. This suggests that when individuals with ADHD/ADD are medicated, the signal-to-noise ratio (SNR) in the environment can be decreased by about 2–3 dB without reducing the willingness to attend and listen to the signal.

Second, the improvements in ANL were the same (average 2.6 dB) at all speech presentation levels: when the speech was barely audible, at MCL, and when the speech was loud. This finding was unexpected based on a theory by Zentall and Zentall (1983) that children with ADHD/ADD perform differently when understimulated or overstimulated as compared to optimal stimulation. If the results had been in accordance with this theory, ANLs should have been significantly poorer at the low and high speech presentation levels. Thus, for both MCL and ANL, the auditory findings for individuals with ADHD/ADD are different in children and adult females.

It was hypothesized that individuals with ADHD/ADD may be less accepting of background noise than individuals without ADHD/ADD. Therefore, ANL results from the present study were compared to ANLs obtained by Franklin et al (forthcoming) on individuals without ADHD/ADD. The comparison of the present ANL results to those of Franklin et al (forthcoming) showed that individuals with and without ADHD/ADD are equally accepting of background noise at all speech presentation levels (see Figure 1). These results demonstrated that ANLs were similar for those with and without ADHD/ADD, independent of medication state. It should be noted that the ANLs obtained in this study were obtained on college-aged females who had not taken stimulant medication for 19–72 hours prior to testing the unmedicated condition. Different effects on acceptance of noise may have been expected if males were tested, nonstimulant medications were investigated, or medication was withdrawn for longer periods of time. Furthermore, the long-term effects of stimulant medication on audition should be investigated.

**CONCLUSIONS**

In the general population, ANL values vary greatly among individuals (Nabelek et al, 2004). Likewise, in the sample population (i.e., female college students with ADHD/ADD) ANLs varied among individuals. The use of stimulant medication, however, resulted in a significant, systematic improvement in the acceptance of noise. More specifically, ANLs decreased with the introduction of medication, indicating that the individuals were more willing to accept background noise when medicated. With these improvements, it would be expected that a medicated individual would be more accepting of noise in daily listening situations such as the classroom, work environment, shopping centers, etc.

The reduction of ANL with medication may result in improved speech understanding in adverse listening situations. While ANL does not measure speech understanding ability, if individuals are more accepting of background noise given the same auditory environment, understanding may be enhanced. Killion (1997) states that for every 1 dB improvement in SNR, an individual’s speech understanding ability may increase by 10%. In noisy environments, an increase in speech understanding could result in increased ability to cope with background noise.

The present results also provide the first objective evidence that ANL can be manipulated with pharmacological intervention. It appears these ANL reductions are most likely not a result of peripheral auditory phenomenon but occur as a result of behavioral changes associated with executive function (Barkley, 1990). The reason for these effects may be due, in part, to changes in auditory processing, or more likely to changes in auditory processing as a result of central, nonauditory processes (i.e., suppression of cortical activity, enhanced inhibitory processes, etc.).

Furthermore, MCL was unaffected by the introduction of stimulant medication.
Several hypotheses can be made about the absence of change in MCL results. First, when MCLs are established, judgment is not required in the presence of distraction. Second, whereas responses obtained for ANL are probably the result of complex cortical function, the responses for MCL may not require such complex cortical function. Therefore, stimulant medication may not have an affect on simple cortical activity.

In previous research on the effects of ADHD on audition, investigators have shown that MCLs, UCLs, decision-making criteria, and auditory processing can be altered. The majority of these studies have been conducted on children. In the present study, (1) MCL was not different in adult females with and without ADHD, and (2) changes in ANL with medication were not dependent on speech presentation level, both of which might have been expected in children (Zentall and Zentall, 1983; Lucker et al, 1996). There are two possible explanations for these differences: (1) the differences may be related to the differences in the way ADHD/ADD is manifested in children versus adults, or (2) by adulthood, individuals with ADHD/ADD may have learned compensation strategies for this disorder. Further research on ADHD/ADD is needed to investigate the auditory effects of ADHD/ADD in adulthood and the direct comparison of behaviors associated with ADHD/ADD in children and adults.

NOTES

1. Cosmos, Inc. is owned and operated by Robert McClocklin. A copy of the ANL CD can be obtained from him by contacting Robert McClocklin at rmcclock@shaw.ca or 1-866-764-7673, or by mailing a request to Robert McClocklin, 4744 West Ridge Dr., Kelowna, British Columbia, Canada VIW3B5. In addition, a copy of the ANL materials can be found at http://web.utk.edu/~aspweb/faculty/nabelek/anl.shtml.

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REFERENCES


Appendix A. ANL Instructions

Instructions for establishing MCL:

You will listen to a story through a loudspeaker. After a few moments, select the loudness of the story that is most comfortable for you, as if listening to a radio. Handheld buttons will allow you to make adjustments. First, turn the loudness up until it is too loud and then down until it is too soft. Finally, select the loudness level that is most comfortable for you.

Instructions for establishing BNL:

You will listen to the same story with background noise of several people talking at the same time. After you have listened to this for a few moments select the level of background noise that is the MOST you would be willing to accept or “put up with” without becoming tense or tired while following the story. First, turn the noise up until it is too loud and then down until the story becomes very clear. Finally, adjust the noise (up and down) to the MAXIMUM noise level that you would be willing to “put up with” for a long time while following the story.