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The effect of ADHD and methylphenidate treatment on the adult auditory temporal order judgment threshold

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Abstract

Purpose: The DSM-5 recognizes that ADHD diagnosed in childhood will persist into adulthood among at least some individuals. There is a paucity of evidence, however, regarding whether other difficulties that often accompany childhood ADHD will also continue into adulthood, specifically auditory processing deficits. The aim of this study was to examine the effect of ADHD and the stimulant medication methylphenidate on auditory perception performance among adults.

Method: Thirty-three adults diagnosed with ADHD according to DSM-5 criteria (ADHD group) and 48 adults without ADHD (non-ADHD group) performed an auditory temporal order judgment (TOJ) task. Participants with ADHD performed the task twice: with and without taking methylphenidate (Ritalin), in random order.

Results: TOJ thresholds of the ADHD group were significantly higher than that of the non-ADHD group. Methylphenidate significantly decreased TOJ thresholds within the ADHD group, making their performance similar to the non-ADHD participants.

Conclusions: Auditory processing difficulties of those diagnosed with ADHD seem to persist into adulthood. Similar to findings with children, methylphenidate treatment improves performance on tasks requiring this ability among adults. Therefore, given the association between auditory temporal processing and linguistic skills, the beneficial effect of methylphenidate on adults’ academic achievement may be accomplished by positively affecting auditory temporal processing. Further studies in this line of research are needed.
Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a developmental disorder showing a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with the individual’s development or daily functioning. Its symptoms manifest in behaviors like failure to pay close attention to details, difficulty organizing tasks and activities, excessive talking, fidgeting, or an inability to remain seated in appropriate situations (DSM-5, American Psychiatric Association; Goodman, Mitchell, Rhodewalt, & Surman, 2016). The prevalence of ADHD ranges between 5.29% and 7.1% in children and adolescents, and between 1.2% and 7.3% in adults (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007; Tarver, Daley, & Sayal, 2014; Thomas, Sanders, Doust, Beller, & Glasziou, 2015). The treatment of ADHD is focused on its core symptoms. The main treatment is stimulant medication (e.g., Faraone & Buitelaar, 2010; Faraone & Glatt, 2010; Reimherr, Marchant, Gift, Steans, & Wender, 2015; Tarver et al, 2014), which increases the level of neurotransmitters in the synaptic cleft, especially dopamine (Yanofski, 2010).

The literature points out similarities between diagnosis of ADHD and Auditory Processing Disorder (APD) and shows that children with ADHD are inferior to their age-matched counterparts in various auditory perception tasks (Bellis, Billiet, & Ross 2011; Breier, Gray, Fletcher, Foorman, & Klaas, 2002; Breier, Fletcher, Foorman, Klaas, & Gray, 2003). Moreover, some studies that tested the effect of stimulant medications on performance of various cognitive tasks have shown their beneficial effect on auditory perception as well (Jerome, 2000; Ozdag, Yorbik, Ulas, Hmamcioglu, & Vural, 2004; Tillery, Katz, & Keller, 2000).

The release of DSM-5 in 2013 brought official recognition to the fact that, at least for some people, ADHD can continue through adulthood. Recently, several studies examined issues relating to diagnosis and treatment of adults with ADHD (Goodman et al., 2016; Mörstedt,
Corbisiero, Bitto, & Stieglitz, 2015; Reimherr et al., 2015; Williamson & Johnston, 2015). However, most studies on the effect of ADHD, and its treatment, on perceptual and cognitive performance are still carried out on children. The aim of this study was to examine the effect of ADHD and the stimulant medication methylphenidate on auditory perception among adults. Auditory perception was measured using a well-known auditory temporal processing task: the temporal order judgment (TOJ) task, which is also widely used in studying temporal processing deficits in children and adults with learning disabilities (e.g., Ben-Artzi, Fostick, & Babkoff, 2005; Fostick, Bar-El, Ram-Tsur, 2012a,b; Fostick, Babkoff, & Zukerman, 2014a; Fostick, Eshcoli, Shtibelman, Nechemya, & Levi, 2014b; Hood, & Conlon, 2004; Liddle, Jackson, Rorden, & Jackson, 2009; Perez, Garcia, Lage, Leh, & Valdes-Sosa, 2008; Tallal, 1980). We hypothesized that, similar to previous studies of children, adults with ADHD would have higher TOJ thresholds, compared to adults without ADHD. We also hypothesized that methylphenidate intake would improve TOJ task performance of participants with ADHD.
Method

Participants

The ADHD group included 16 females and 18 males aged 18-35 (mean=25.22, SD=5.02). All were diagnosed with ADHD according to DSM-5 criteria by a senior psychiatrist. One participant was excluded due to inability to distinguish between right and left (needed for TOJ) leaving a total of 33 participants in this group. All participants use methylphenidate (short-acting Ritalin) 20 – 30 mg on a regular basis. The participants did not receive any other concomitant medications or psychological / educational treatments. An additional 48 participants (20 females, 28 males; aged 20-31, mean=24.02, SD=2.6) comprised the non-ADHD group. Participants in both groups had hearing levels ≤ 20 dB in frequencies 500-4,000 Hz.

Stimuli, apparatus, and procedure

In order to measure auditory TOJ, participants were presented with pairs of 15 msec duration 1.8 kHz tones presented dichotically (first tone to one ear, second tone to other ear), and were requested to reproduce the order in which they heard the tones (left first then right; or right first then left). Tone combinations were presented in a random order with an inter-stimulus interval (ISI) of 5, 10, 15, 30, 60, 90, 120 or 240 msec also presented randomly. Each ISI value was repeated 16 times, resulting in a total of 256 trials, with a short recess after every 32 trials. The percentage of correct responses was recorded for each participant for each ISI, and the threshold was obtained as the ISI for which 75% correct responses were maintained. A four-stage training phase preceded the experiment and is detailed in Fostick, Bar-El and Ram-Tsur (2012a). The TOJ task was computed using MatLab software which generated the sounds and recorded the responses. Sounds were delivered using TDH-49 headphones.
The study was approved by the institutional ethics committee. Before initiating the first session, participants received a verbal and written explanation of the experiment and signed an informed consent document. Each participant was tested in two sessions, one session in which they had used their stimulant medication and one session in which they had not, in a random order. Each session was performed in the morning, between 8:00 to 10:00. Two to three weeks separated the sessions. For the session without medication, participants did not take their daily dose in the morning until they completed the experiment.
Results

Figure 1 presents TOJ threshold means and standard errors for ADHD participants with and without treatment, and for non-ADHD participants. Kolmogorov-Smirnov and Shapiro-Wilk tests were found to be non-significant for the ADHD group with treatment (K-S$_{(33)}$= .123, p=.132; S-W$_{(33)}$=.960, p=.169), the ADHD group without treatment (K-S$_{(33)}$= .111, p=.200; S-W$_{(33)}$=.963, p=.220), and the non-ADHD group (K-S$_{(48)}$= .121, p=.190; S-W$_{(48)}$=.960, p=.206), thus supporting the null hypothesis that the distributions of these groups were normal. A within-subjects comparison for ADHD participants (with versus without methylphenidate) was performed using a paired samples t-test. Two between-subjects comparisons for ADHD participants (one with methylphenidate and one without methylphenidate) versus non-ADHD participants were performed using independent samples t-tests. Bonferroni correction for multiple comparisons was used.

TOJ thresholds for participants with ADHD receiving no methylphenidate treatment (Mean=153.19, SD=79.92) were significantly higher than both ADHD participants using methylphenidate (Mean=75.43, SD=45.97, t(32)=5.74, p<0.001, Partial Eta Squared=.315) and non-ADHD participants (Mean=68.26, SD=42.86, t(79)=6.11, p<0.001, Partial Eta Squared=.320). No significant difference was found between TOJ thresholds of ADHD participants using methylphenidate and non-ADHD participants (t(79)=1.83, p=.145, Partial Eta Squared=.077).
Discussion

In the current study, we tested the effects of ADHD and the use of methylphenidate on TOJ thresholds of adult participants. The results showed that TOJ thresholds were significantly higher among adults with ADHD, as compared to those without ADHD. Moreover, we found that methylphenidate reduced TOJ thresholds to the extent that they were not different from those of the non-ADHD group. These results are in line with studies conducted on children that showed poor performance of ADHD groups in auditory processing (Abdo, Murphy, & Shochat, 2010; Bellis et al., 2011; Chermak, Hall, & Musiek, 1999; Iliadoua & Bamiou, 2012; Jerger & Museik, 2000), and beneficial effects of methylphenidate (Keith & Engineer, 1991; Ozdag et al., 2004; Schochat, Scheuer, & Andrade, 2002; Sawada et al., 2010).

The present study is the first to show a deficit in auditory temporal processing among adults diagnosed with ADHD, and the effect of a stimulant medication on auditory processing performance. This finding has a twofold significance: (1) an auditory temporal deficit that is reported among children with ADHD appears to extend into adulthood; (2) the stimulant medication methylphenidate has a profoundly positive effect on auditory processing performance among adults with ADHD, equalizing it to the performance level of individuals without ADHD.

Auditory temporal processing, and specifically TOJ threshold, has been previously shown to be associated with linguistic skills, such as reading, phonological awareness, and speech perception (Fostick et al., 2012, 2013, 2014a,b). High TOJ thresholds have been found among dyslexic readers (e.g., Ben-Artzi et al., 2005; Fostick et al., 2012; Fostick et al., 2014a), aging adults (Ben-Artzi, Babkoff, & Fostick, 2011; Fostick & Babkoff, 2013; Fostick et al., 2013), aphasic patients (e.g., von Steinbuchel, Wittmann, Strasburger, & Szelag, 1999; Fink, Churan, & Wittmann, 2006), and sleep deprived adults (Babkoff, Zukerman, Fostick, & Ben-Artzi, 2005;
Fostick et al., 2014b); the common feature among these populations is difficulty in linguistic skills. This association between auditory temporal processing and linguistic skills suggests that the positive effect of methylphenidate on academic achievement (e.g., Katzman & Sternat, 2004; Prasad et al., 2013) may be accomplished by positively affecting auditory temporal processing. Additional studies to test the effect of methylphenidate on TOJ performance among adults with dyslexia (without ADHD) may shed further light on this theory, and show whether methylphenidate affects temporal processing and linguistic skills even with no ADHD.

Whether the improvement shown after methylphenidate intake is the result of its effect on ADHD or on auditory temporal processing is still under debate in the literature. Tillery et al. (2000) showed that when controlling for learning, fatigue, and maturation, stimulant medications did not affect performance related to auditory processing, rather only to sustained attention. Others, however, suggest that ADHD and APD share common neurological basis that is affected by methylphenidate (Jerome, 2000; Riccio, Hynd, Cohen, Hall, Molt, 1994; Wasserman, Pine, Workman, & Bruder, 1999). As the first study to test the effect of methylphenidate on auditory temporal processing among adults with ADHD, our finding provides preliminary evidence that methylphenidate might be a beneficial treatment for this group. However, there is a need for further studies to clarify methylphenidate’s mechanism of action among adults with ADHD while controlling for tasks requiring sustained attention; such studies would shed light on whether the stimulant medication is actually affecting attention or auditory temporal processing. Further, implementing the current study design in other modalities, or cross-modally, could provide evidence as to whether adults with ADHD suffer from a general difficulty in temporal processing, and, if so, to what extent does methylphenidate affect it.
Although the results of the current study were robust, using additional measures of auditory temporal processing would allow more extensive evaluation of auditory processing under both medicated and un-medicated conditions and bolster the strength of our conclusions. While the present study suffers from being small and preliminary, it is pioneering in its measurement of auditory temporal processing among adults with ADHD, and points to the importance of this line of research. Further studies are needed to shed more light on this topic and its theoretical implications.
References


Reimherr, F. W., Marchant, B. K., Gift, T. E., Steans, T. A., Wender, P. H. (2015). Types of adult attention-deficit hyperactivity disorder (ADHD): baseline characteristics, initial


Figure 1. TOJ threshold means and standard errors for ADHD participants with and without treatment, and for non-ADHD participants.