Listening effort among adults with ADHD


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Listening effort among adults with and without Attention-Deficit/Hyperactivity Disorder (ADHD)

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Running head: Listening effort among adults with ADHD

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Listening effort among adults with ADHD

Abstract

Purpose: Few studies have assessed listening effort (LE) — the cognitive resources required to perceive speech — among populations with intact hearing but reduced availability of cognitive resources. Attention Deficit Hyperactivity Disorder (ADHD) is theorized to restrict attention span, possibly making speech perception in adverse conditions more challenging. The present study examined the effect of ADHD on LE among adults using a behavioral dual task paradigm (DTP).

Method: Thirty-nine normal-hearing adults (aged 21-27 years) participated: 19 with ADHD (ADHD group) and 20 without ADHD (control group). Baseline group differences were measured in visual and auditory attention, and speech perception. Listening effort using DTP was assessed as the performance difference on a visual-motor task vs. a simultaneous auditory and visual-motor task.

Results: Group differences in attention were confirmed by differences in visual attention (larger reaction times between congruent and incongruent conditions) and auditory attention (lower accuracy in the presence of distractors) among the ADHD group, compared to the controls. LE was greater among the ADHD group than the control group. Nevertheless, no group differences were found in speech perception.

Conclusions: LE is increased among those with ADHD. As a DTP assumes limited cognitive capacity to allocate attentional resources, listening effort among those with ADHD may be increased because higher-level cognitive processes are more taxed in this population. Studies on LE using a DPT should take into consideration mechanisms of selective and divided attention. Among young adults who need to continuously process great volumes of auditory and visual information, much more effort may be expended by those with ADHD than those without it. As a result, those with ADHD may be more prone to fatigue and irritability, similar to those who are engaged in more outwardly demanding tasks.
Listening effort among adults with ADHD

Listening effort among adults with and without Attention-Deficit/Hyperactivity Disorder (ADHD)

The science of cognitive hearing deals with the role of cognition processes, such as memory and attention, in speech perception (Arlinger et al., 2009). This field explores the relation between bottom-up and top-down aspects of language processing. Recent models of speech perception have emphasized the complex interactions between working memory capacity, attention, executive functions, and episodic and semantic long-term memory, while listening (Mishra et al., 2013; Rönnberg et al., 2013; Strauss & Francis, 2017). When considering the reception of spoken language, it is important to distinguish between the terms "hearing" and "listening." While hearing is a passive act that allows access to the auditory world while perceiving sounds, listening is an active function that requires attention to information that is heard (Kiessling et al., 2003). “Listening effort” (LE) is defined as the mental exertion required to attend to, and understand, an auditory message (McGarrigle et al., 2014) or “the deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a [listening] task” (Pichora-Fuller et al., 2016). When there are conditions that negatively affect access to auditory acoustic-phonetic aspects of the speech signal, either due to hearing impairments or to external sources that degrade the auditory signal (e.g., background noise, speaker’s foreign accent), the listener expends increased effort understanding it (Van Engen & Peelle, 2014). In these conditions, the listeners must rely more on working memory, attention, or other cognitive processes to resolve this mismatch (Rönnberg, 2003; Rönnberg et al., 2013, Strauss & Francis, 2017).

The measures used to study LE can be broadly divided into three categories: self-report, psychophysiological, and behavioral (Pichora-Fuller et al., 2016, Zekveld et al., 2018; see
Listening effort among adults with ADHD

Gagné, Besser, & Lemke, 2017, for additional review). Behavioral measures of two kinds are mainly used: the recall paradigm and the dual task paradigm (DTP). In the recall paradigm, as the auditory presentation of items increases in number, fewer items are recalled as a result of increased LE (Pichora-Fuller et al., 1995; Rabbitt, 1991; Rudner, 2016). The DPT is based on the concept that when several processes compete for the same resources, performance will deteriorate (Navon & Gopher, 1979; Norman & Bobrow, 1975). Consequently, DPT measures LE by measuring participant performance on two tasks performed simultaneously. One task is defined as a primary task, and the participant is required to attend to it while performing an additional secondary task. Performance on the secondary task is compared to the condition in which it is performed alone with no additional competing task. When measuring listening effort in a DPT, the primary task is typically an auditory one, involving word or sentence recognition. The secondary task may involve visual, motor, linguistic, or tactile activities that produce a relatively high accuracy rate when performed alone (Gosselin & Gagné, 2011; Hughes & Galvin, 2013; Picou & Ricketts, 2014). Indeed, DTP studies have used a variety of secondary activities using vibrotactile stimuli (Gosselin & Gagné, 2011); visual tasks, such as visual matching (Hughes & Galvin, 2013) and tracking visual objects (Tun, McCoy, & Wingfield, 2009); linguistic tasks, such as making semantic or rhyme judgments (Pals et al., 2013; Picou & Ricketts, 2014); and combinations of motor and visual tasks, such as car driving simulations (Wu et al., 2014). An increase in cognitive effort, or load, related to performing the primary task leads accordingly to lower performance on the secondary task (Gosselin & Gagné, 2010). The difference between the secondary task performance when performed alone, versus performed together with the primary auditory task, is interpreted as listening effort (Fraser et al., 2010). Broadbent (1958) was the first researcher who showed that when a primary speech perception
Listening effort among adults with ADHD

task was difficult, listeners performed poorly on a secondary visual task, despite achieving the same accuracy on the primary task as when performed alone. This suggests that the same speech perception scores do not always reflect similar effort.

Studies of listening effort have mainly focused on conditions of degraded auditory stimuli, such as background noise, or on individuals with hearing impairments (Downs & Crum, 1978; Hughes et al., 2018; Rudner, Lunner, Behrens, Thorén, & Rönnberg, 2012). Studies of participants with hearing impairments have shown that, in some situations, they demonstrate the same speech recognition accuracy in good and degraded listening conditions, but evidence an increased LE in the latter one; such were also the findings among hearing aided participants when their aides’ noise reduction algorithms were either turned on or off (Desjardins & Doherty, 2014; Downs, 1982; Hornsby, 2013; Sarampalis, Kalluri, Edwards, & Hafter, 2009).

Studies of participants with normal hearing have shown different amounts of LE corresponding to different stimuli parameters. For example, when auditory stimuli are accompanied by competing speech, more effort is required than when accompanied by stationary noise (Ng, Rudner, Lunner, Pedersen, & Rönnberg, 2013). When the stimulus location is not clear, more effort is allocated than when its location is perceptually well-defined (Koelewijn, de Kluiver, Shinn-Cunningham, Zekveld, & Kramer, 2015). Additionally, when speech is delivered dichotically, more LE is spent than when delivered diotically (Seeman & Sims, 2015). In all of these instances, the participants were presented with degraded auditory signals. These degraded signals required allocation of greater resources, resulting in increased LE.

Moreover, according to the taxonomic model of attention in effortful listening, LE depends on external or internal sources, such as when the stimuli is accompanied by noise (external) or when it is spoken in foreign language (internal) (Strauss & Francis, 2017). LE is also affected by
individual differences among listeners, in such areas as motivation, memory capacity, attentional resources, and arousal level (Pichora-Fuller et al., 2016, Rönnberg et al., 2013). Indeed, the Framework for Understanding Effortful Listening (FUEL), a model that emphasizes the role of motivation in LE, suggests that low effort is expended when task demands are too difficult, and motivation is low (Pichora-Fuller et al., 2016; Wendt et al., 2018). The role of motivation is also demonstrated by studies that show providing rewards to participants increases the effort they expend during listening tasks (Koelewijn et al., 2018). Taking a different perspective, the Ease of Language Understanding (ELU) model focuses on the role of auditory, linguistic, and cognitive processes in speech perception (Rönnberg et al., 2013; Blomberg, Danielsson, Rudner, Söderlund, & Rönnberg, 2019). According to this model, when the auditory signal is degraded, it is difficult to match the auditory input with its long-term stored representations. In these conditions, listeners make larger use of working memory to retain the input and resolve this mismatch. Therefore, individuals with larger working memory capacities may expend less LE in difficult listening conditions (Rönnberg et al., 2013; Blomberg et al., 2019). This idea is supported by studies that show a relationship between working memory and LE (Mishra et al., 2013; Ng et al., 2013), although not all of them do so (Brown & Strand, 2019). Other researchers point to attentional resources (i.e., capacities related to attention allocation) as an important factor in LE (Pichora-Fuller et al., 2016; Strauss & Francis, 2017), suggesting that if attentional resources are limited, listening effort will increase. Indeed, attentional resources might limited be due to occupation with difficulties in attention switching (switching focus from one source to another; Kieffer, Vukovic, & Berry, 2013), selective attention (requiring focus on one source while consciously ignoring distractors; Jaśkowski, 1993), or sustained attention (maintaining long-term focus on repetitive stimuli; Lam & Beale, 1991). Accordingly, individual differences
Listening effort among adults with ADHD

in the ability to allocate attention, such as among adults with Attention deficit/hyperactivity disorder (ADHD) may account for some differences in LE.

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 (Diagnostic and Statistics Manual of Mental Disorders 5th ed.; *DSM-5*; American Psychiatric Association [APA], 2013; 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 release of the *DSM-5* in 2013 brought official recognition to the fact that, at least for some people, ADHD can continue through adulthood. However, most studies of the effect of ADHD on perceptual and cognitive performance are still carried out with children, and studies on adults with ADHD are scarce.

Accordingly, only few studies have assessed auditory perception in adults with ADHD (Fostick, 2017; Freyaldenhoven, Thelin, Plyler, Nabelek, & Burchfield, 2005; Michalek et al., 2014). These studies found that, in some auditory tasks, adults with ADHD perform significantly poorer compared to adults without ADHD. For example, Fostick (2017) found that temporal order judgment (TOJ) thresholds were significantly higher among adults with ADHD, as compared to those without ADHD. In an auditory Stroop task, Mourik, Sergeant, Heslenfeld, König, and Oosterlaan (2011) found different excitation patterns to conflicting information, and different use of various neuronal pathways, in an ADHD group versus a control group, although
Listening effort among adults with ADHD

their behavioral results were similar. Other studies that tested auditory processing among adult participants with ADHD focused on background noise as a potential detractor or booster of performance. For instance, two studies showed that participants with ADHD had difficulties in speech perception when speech was accompanied by noise, especially in multi-talker babble noise (Freyaldenhoven et al., 2005, Blomberg et al., 2019). Conversely, a different study showed that when speech was accompanied by white noise, participants with ADHD performed better on complex memory and verbal tasks than when speech was presented with no background noise (Söderlund, Sikström, & Smart, 2007). This discrepancy might be explained by a difference in the effect of the accompanying noise: multi-talker babble noise may serve as larger distractor for participants with ADHD than white noise since it is an informational masker. Moreover, some researchers suggest that stationary stochastic noise, such as white noise, may elicit low dopamine levels that characterize participants with ADHD, thus improving their performance (Söderlund, Sikström, & Smart, 2007).

The conflicting evidence in studies testing speech perception in the presence of ADHD raise the question: Is there a difficulty in speech perception for those with ADHD? The answer may be found in the mechanisms related to speech perception, such as attention span or working memory capacity. Michalek et al. (2014) tested auditory speech perception in different noise conditions with and without visual cues among participants with and without ADHD. When lip reading information was added, the accuracy rate for control participants improved to a greater extent than for participants with ADHD. The addition of visual information that usually facilitates speech perception in noise did not assist participants with ADHD. These researchers suggested that participants with ADHD either had a smaller amount of visual attention span or had less working memory capacity than the controls; they posit that the additional information
Listening effort among adults with ADHD

(visual lip-reading information) that entered the stream of processed data stretched the ADHD participants’ smaller cognitive load. Studies of speech perception, therefore, should take into account underlying mechanisms that can affect the cognitive processing of participants with ADHD: possessing a lower attention span, for instance, may result in more expended effort for speech perception in adverse conditions, even if their performance is comparable to participants without ADHD.

The purpose of this study was to evaluate the effect of ADHD on listening effort, taking into consideration group differences in visual and auditory attention and speech recognition performance. First, baseline group differences in visual and auditory attention, and speech perception, were assessed, followed by measurement of potential group differences in LE. LE was measured using a behavioral DTP, with speech perception in noise as the primary task and a visual–motor secondary task (see the detailed description in the Method section). It was hypothesized that the groups would differ in performance on baseline attention tasks, and, due to more limited attentional resources, the ADHD group would show increased LE when required to perform a simultaneous secondary task, as compared to the control group.

Method

Participants

The ADHD group included 19 participants (13 women) aged 21 to 26 years (M = 24.15, SD = 1.70). All the participants were diagnosed with ADHD according to DSM-5 criteria (APA, 2013), by a senior psychiatrist. The control group included 20 participants (13 women) aged 21
Listening effort among adults with ADHD
to 27 years ($M = 24.04, SD = 1.88$). The participants in both groups had hearing levels $\leq 20$ dB in frequencies of 500 to 4000 Hz. 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 provided signed informed consent. The participants completed all tasks in one session lasting one hour and received the equivalent of $25$ in New Israeli Shekels in compensation for their time.

**Tasks and apparatus**

In order to confirm that the ADHD group indeed differed from the control group in measures of attention, auditory and visual attention tests were performed at baseline.

**Auditory Attention.**

For testing auditory attention, participants were asked to repeat sets of digits that were heard. In an undistracted condition, a recording of sets of digits read aloud only in a female voice is presented. In a condition with distractors, a recording of sets of digits read aloud in a female voice is presented with interruptions of digits read aloud in a male voice. The participants were asked to repeat only the digits heard in the female voice. The difference between the undistracted and distractors conditions was taken as a measure of interference. The digits were presented at a rate of one digit per second, with increased sets from 2 to 9 digits. The digits from WAIS-III (Wechsler Adults Intelligence Scale version III; Wechsler, 1997) are used. Participants received two trials at each set size until they fail on both trials at a particular level (set size). The score represents the number of sets reported correctly. Its split-half reliability is $r = 0.87$ (Wechsler, 1997). This task was presented bilaterally at 65dB SPL via laptop using a supra-aural headphone (Sennheiser HD 215). The intensity was calibrated using 1 kHz pure tone with similar energy as
Listening effort among adults with ADHD

the speech signal. Calibration was done using B&K 2250 sound level meter with GRAS artificial ear.

**Visual Attention.**

For testing visual attention, the visual Stroop task was used. The Stroop task measures the ease with which a person can shift one’s perceptual set to changing demands, and, critically, to suppress a habitual response in favor of an unusual one. In this study, we used the classical Stroop task developed by Stroop (1935). In the neutral condition, the examinee is asked to read aloud a list of color name words. The conflict condition is provided by having color words written in an incongruous font color (e.g. the word *green* is written in a red color font). The examinee is asked to name the incongruent font color in which the word is written (e.g., red), which requires inhibition of the dominant, automatic tendency to read the word itself. The difference between the neutral and conflict condition is often taken as a measure of interference. This task was conducted on a laptop (Dell Latitude D505) using Direct RT software.

**Speech perception.**

In order to assess possible group differences in speech perception, tests of meaningful words and of nonsense one-syllable Consonant-Vowel-Consonant (CVC) words were used. The test for meaningful words was the Hebrew version of the AB words test (Boothroyd, 1968), and the test for nonsense words was equivalent in structure (Taitelbaum-Sweed & Fostick, 2016). Both were composed of lists of ten one-syllable Consonant-Vowel-Consonant words that were phonetically balanced (i.e., in each list every consonant appeared once, and every vowel appeared twice).
Listening effort among adults with ADHD

The words were presented in three conditions: (1) without background noise; (2) accompanied by background white noise evenly distributed over the entire range of frequencies (0.25 – 8 kHz) and presented in a signal-to-noise ratio (SNR) of -5 dB; and (3) accompanied by background four-talker babble noise (two men and two women) with a frequency range of 0.5 – 5 kHz, also presented in an SNR of -5 dB. All conditions were presented at 65 dB SPL. Each of the three conditions was analyzed for both word and phoneme accuracy.

Listening Effort

Dual Task.

Listening effort was measured via a dual task paradigm. The primary task was an auditory speech perception task of listening to meaningful CVC words accompanied by four-talker babble noise (two men, two women) in a signal to noise ratio of -5 dB, presented at 65 dB SPL, as described above. The secondary task was a visual-motor task (described in detail below). The secondary task was performed independently first, and then the two tasks (primary and secondary) were performed together with synchronized presentation of probe lights and words. In line with previous studies using a dual task paradigm, the decrease in reaction time (RT) for the secondary task during the performance of both tasks together represents the listening effort (Gosselin & Gagné, 2011; Picou & Ricketts, 2014).

Visual-motor task.
A task involving a motor response to visual input was conducted using six “units” configured in an approximated half circle shape along the length of a table. Each unit included a small 8 X 5 X 6 cm metal box attached in a modular configuration to the table top, containing a red-light emitting diode (LED), a buzzer, and a push button. In the present study, the buzzers of the units were switched off and only the lighting (visual) element was activated. Each participant was sitting facing the concave side of the unit arrangement, and their dominant hand was placed at the starting point in the middle of the long edge of the table, about 50 cm from each unit. When a unit was activated, the light was turned on and the participant was asked to reach and press the push button of the active unit as soon as possible, in order to deactivate it. To control for the semi-circular nature of the configuration, the lights were presented randomly eight times in each unit. The mean response time reflected the overall performance on the task and counterbalanced possible differences in reaching time. Evaluation of the response duration was conducted by a custom-made movement-time monitoring system attached to the top of a drawing table measuring 110 X 75 cm.

The system was programmed by a LabVIEW algorithm which provided various setting options for the number of activations, sequences, durations, and intervals. The LabVIEW algorithm, loaded on a Dell laptop, was programmed for a random mode of 46 activations at durations and intervals of 1 second each.

Procedure

The study took place in our lab. All participants were screened for their hearing level prior to participation in the study. The tests were performed in the morning and participants did not take their daily medication before the experiment. Since the longest effect of ADHD
Listening effort among adults with ADHD

medication last eight hours, this delayed medicating ensured that participants were not affected by the previous day’s medication (Childress, 2016). When performing the tasks, participants seated directly in front of the computer. Participant responded verbally to the attention tasks, speech perception task, and DTP and research associate scored their responses. The participants completed all the study tasks (Stroop, Digit Span, speech perception, DTP) in a random order.

Statistical analysis

Multivariate analyses of variance (MANOVA) were used to analyze group effects for visual attention tasks [Stroop, reaction time (RT)], auditory working memory tasks (Digit Span, standardized scores), and DPT tasks (visual-motor and visual-motor + speech perception, accuracy and response time). A repeated measures ANOVA was used to analyze word and phoneme recognition scores in speech perception tasks, with noise condition and word meaning condition (meaningful vs. nonsense) as within-subjects variables, and group as a between subjects variable.

Results

Figure 1 presents the results for the Stroop (Figure 1a) and Digit Span (Figure 1b) tasks and Table 1 presents their means and standard deviations. Significant group effects were found for both tasks ($F(2,36) = 3.914, p = .045, \eta^2 = .215$ and $F(2,36) = 3.611, p = .037, \eta^2 = .217$, respectively). The difference in performance between congruent and incongruent conditions on the Stroop task, and between conditions with and without distractors on the Digit Span, were larger for the ADHD group than for the control group ($F(1,38) = 3.826, p = .022, \eta^2 = .218$ and $F(1,38) = 5.048, p = .031, \eta^2 = .212$, respectively). Interestingly, there was marginal to no
Listening effort among adults with ADHD

difference between the groups in the baseline conditions of the Stroop and Digit Span test (congruent and no distractions conditions, $F(1,38) = 3.983, p = .053, \eta^2 = .097$ and $F(1,38) = .064, p = .802, \eta^2 = .002$, respectively), while significant differences were found for both tests in the more challenging conditions (incongruent and with distractors, $F(1,38) = 6.263, p = .017, \eta^2 = .214$ and $F(1,38) = 5.823, p = .021, \eta^2 = .214$, respectively).

Table 1 presents means and standard deviations for word recognition scores among the two speech perception tasks. No group effect was found ($F(1,38) = 3.028, p = .181, \eta^2 = .080$). Significant effects were found for both noise (no noise, white noise, multi-talker babble noise) and meaning conditions (nonsense vs. meaningful word recognition scores) ($F(1,38) = 1588.597, p < .001, \eta^2 = .989$ and $F(1,38) = 34.505, p < .001, \eta^2 = .483$, respectively). Figure 2 presents word recognition scores in noise and meaning conditions. Word recognition scores with no background noise were higher than with babble noise ($LSD = .596, p < .001$) and white noise ($LSD = .294, p < .001$). Word recognition scores with babble noise were higher than with white noise ($LSD = .596, p < .001$).

There was also a significant interaction of Noise X Meaning ($F(2,36) = 32.009, p < .001, \eta^2 = .640$). There was no difference between meaningful and nonsense words presented with no background noise ($LSD = .733, p = .468$) and with babble noise ($LSD = .025, p = .980$). Higher recognition scores were found for meaningful than nonsense words when they were presented with white noise ($LSD = 8.112, p = .000$). No interactions were found for Noise X Group
Listening effort among adults with ADHD

\((F(2,36) = 1.210, p = .310, \eta^2 = .063)\), Meaning X Group \((F(2,36) = .004, p = .948, \eta^2 = .000)\), and Noise X Meaning X Group \((F(2,36) = .136, p = .873, \eta^2 = .008)\).

**Table 1** presents means and standard deviations for the DPT. There was no group effect found for accuracy scores in DTP tasks \((F(2,36) = 1.539, p = .227, \eta^2 = .060, \text{Figure 3a})\). However, a significant group effect was found for response time \((F(2,36) = 3.624, p = .029, \eta^2 = .331, \text{Figure 3b})\). Listening effort (the difference between response time in the visual only condition and the visual + auditory condition) was found to be greater in the ADHD group than in the control group \((F(1,39) = 3.481, p = .044, \eta^2 = .227)\). The ADHD group also demonstrated a longer response time in the visual + auditory condition than the control group \((F(1,39) = 7.164, p = .013, \eta^2 = .230)\), but no effect was found for the response time in the visual only condition \((F(1,39) = 2.179, p = .153, \eta^2 = .083)\).

**Discussion**

In the present study, a dual task paradigm (DTP) showed a decrease in response time for a secondary visual-motor task for all participants (with and without ADHD) when performed simultaneously with a primary auditory task. However, participants with ADHD showed greater LE, reflected in much longer reaction times when the secondary task was performed simultaneously with the primary task, than when performed alone. Interestingly, in spite of the
greater effort showed by participants with ADHD, their accuracy rate in the speech perception task was comparable to the non-ADHD group. These results suggest that when evaluating the abilities of participants with ADHD, focusing on the performance “bottom line” is not enough. One should also consider the effort underlying performance.

Studies testing speech perception among those with ADHD have been mainly conducted on children. In most of them, children with ADHD demonstrated poorer performance than those without ADHD, showing poorer speech comprehension of sentences and instructions, higher speech reception thresholds, and lower accuracy when repeating spoken words accompanied by background noise (Geffner et al., 1996; Lucker et al. 1996; McInnes et al., 2003; Söderlund & Jobs, 2016; Tillman & Carhart, 1966; Wassenberg et al., 2010). However, when asked to point at the picture of a word that was heard, with four response options (the Goldman–Fristoe–Woodcock Test of Auditory Discrimination, GFW; Goldman et al., 1970), or when asked to repeat spoken words with no background noise, no difference was observed between participants with and without ADHD (Corbett & Stanczak, 1999; Geffner et al., 1996). It seems that when the task is rather easy (no background noise, perception in a closed set), the attention deficit does not affect performance. However, when the sophistication of the task increases (e.g., comprehending inferences and instructions) or when the listening conditions are difficult (e.g., background noise), the difficulty in allocating the required attention emerges.

In the present study, there was no difference in speech perception accuracy between participants with and without ADHD, even in the more challenging conditions in which speech was presented with background noise. This is not in line with most of the literature. However, it should be taken into account that most of the literature did not test adults. Adults’ years of experience with spoken language enrich their lexicon and make it easier to identify spoken
Listening effort among adults with ADHD

words. Therefore, it is possible that either compensatory mechanisms develop over a longer period of living or a larger lexicon may aid adults with ADHD to achieve better results in speech perception than children. Nevertheless, although the speech perception accuracy did not differ between the groups in our study, it was evident from the subsequent DTP testing that the participants with ADHD did put in more effort to achieve the same level of accuracy, revealing a heretofore concealed difference between the groups.

The lack of difference in speech perception performance between groups with and without ADHD was mirrored in the baseline results of the visual and auditory attention tasks. On the visual Stroop task, there was no performance difference, or only a marginal one, between those with and without ADHD, when words and colors were congruent, and similarly, for the Digit Span task when digits were presented with no distractors. These results again show that, when adults are concerned, baseline conditions that require a relatively small amount of attentional resources do not reflect the attentional deficit. However, when the difficulty of the task increases, such as when the word-color condition is incongruent, or when distractors are presented during the auditory task, differences between the groups emerge. The current study’s Stroop test results are in line with some studies carried out on adults with ADHD that showed group effects only in the incongruent condition, when RT data was analyzed (Mor et al., 2015; Silva et al., 2013; Soutschek et al., 2013; Vakil et al., 2016), but not when accuracy data was analyzed (Silva et al., 2013; see Vakil et al., 2016, for accuracy data), suggesting that RT is more sensitive to group differences among adults with and without ADHD (Vakil et al., 2016). In the Digit Span task, the condition without distractors did not reveal group differences in the present study, nor a previous one (Biehl et al., 2015). The present study is the first, however, to test Digit
Listening effort among adults with ADHD

Span with distractors among participants with ADHD, so no comparison to previous findings is available.

In the present study, a behavioral DTP was utilized to evaluate listening effort. The prolonged reaction times for the secondary task, when performed simultaneously with the primary task, were interpreted as representative of listening effort during speech perception. This interpretation is in line with previous studies on listening effort using a DTP (Gosselin & Gagné, 2011; Hughes & Galvin, 2013; Picou & Ricketts, 2014). What causes the increase in effort and RT in the secondary visual-motor task? It is likely the transition from a single to a dual task that causes performance on each task to decrease as a result of competition for the same attentional resources (Gallun, Mason, & Kidd, 2007; Navon & Gopher, 1979; Norman & Bobrow, 1975). Also, possibly contributing to the performance difference may be working memory capacity. The ELU model proposes that the smaller the available resources are, the greater the effort that is needed (Rönnberg, 2003; Rönnberg et al., 2013). Given that attending to two tasks likely occupies more available working memory resources than a single task, greater effort and RT are likely to result. Moreover, individual variability in both of these areas – attention and working memory – may also explain some additional differences in LE.

Although the findings of the present study show more LE among participants with ADHD than participants without ADHD, the current design does not pinpoint any specific explanatory mechanisms. The greater effort expended by those with ADHD on the DTP might be due to difficulties in attention switching between listening and responding motorically, selectively attending to the auditory stimuli (words) while responding to the visual stimuli (lights), or sustained attention required by the task demands. Future studies that utilize a DTP in order to test LE should consider the mechanisms involved in the task, the resources necessarily
Listening effort among adults with ADHD

required by those mechanisms, and the potential resource inequities between participants with different conditions, in order to better determine whether LE may alternatively represent capacity limitation or task-switching difficulty. Doing so would contribute to a better understanding of the nature and extent of listening effort among various groups.

The results of the current study revealed a larger reduction in performance on the visual-motor secondary task for the ADHD group compared the non-ADHD group. One theory about the difficulties of those with ADHD in these kinds of tasks suggests that they derive from reduced working memory capacity (Michalek et al., 2014). Some studies used memory tasks to measure LE, with the rationale that as LE increases, there will be fewer resources available to encode speech material into memory. Therefore, it may be important for future studies to test participants with ADHD with tasks that directly assess working memory, such as repeating and then recalling the final words of a series of sentences (Ng et al., 2013). Also, the use of psychophysiological objective measures in future studies such as pupillometry would strengthen the findings of the present one. Lastly, testing the same participants twice, with and without stimulant medication in effect (similar to the design of Fostick, 2017), may answer the additional question of whether such medication can reduce LE among the ADHD group; a positive finding would provide evidence that students with ADHD may be at risk of fatigue.

This is the first study to directly assess LE in adult participants with ADHD. The findings have both methodological and clinical implications. Methodologically, when testing adults, it should be taken into account that their longevity and life experience has provided a large knowledge base and compensation strategies that are generally not available to children. As a result, tests that show group differences for children with ADHD might be insensitive to adults with ADHD. More importantly, adults with ADHD might be engaging in different performance
Listening effort among adults with ADHD

exertion, investing much more effort than adults without ADHD, in order to obtain the same results. Therefore, when testing adults with ADHD, one should consider the sophistication of the task, not simply being satisfied with end results but also considering the performance effort involved. This latter point should also be considered clinically. Among students and workers of all ages who need to continuously process great volumes of auditory and visual information, much more effort and energy may be expended by those with ADHD than those without it. As a result, those with ADHD may be at increased risk of fatigue.

Acknowledgements

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Listening effort among adults with ADHD

References


Listening effort among adults with ADHD


Listening effort among adults with ADHD


Listening effort among adults with ADHD


Listening effort among adults with ADHD


Listening effort among adults with ADHD


Listening effort among adults with ADHD


Listening effort among adults with ADHD

Listening effort among adults with ADHD

Table 1. Mean (standard deviation) for visual (Stroop) and auditory (Digit Span) attention tests, speech perception tests, and Dual task paradigm

<table>
<thead>
<tr>
<th></th>
<th>ADHD group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stroop task reaction time</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent condition</td>
<td>1044.21 (590.37)</td>
<td>775.02 (122.44)</td>
</tr>
<tr>
<td>Incongruent condition</td>
<td>1271.78 (731.48)</td>
<td>854.21 (146.15)</td>
</tr>
<tr>
<td>Incongruent - Congruent</td>
<td>227.57 (351.17)</td>
<td>79.19 (71.42)</td>
</tr>
<tr>
<td><strong>Digit Span reaction time</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undistracted condition</td>
<td>9.84 (2.32)</td>
<td>10.00 (1.52)</td>
</tr>
<tr>
<td>Distracted condition</td>
<td>7.21 (2.25)</td>
<td>8.70 (1.56)</td>
</tr>
<tr>
<td>Distracted - Undistracted</td>
<td>2.63 (2.31)</td>
<td>1.30 (1.26)</td>
</tr>
<tr>
<td><strong>Word accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meaningful words, no background noise</td>
<td>0.99 (0.02)</td>
<td>0.99 (0.02)</td>
</tr>
<tr>
<td>Meaningful words, white noise</td>
<td>0.48 (0.11)</td>
<td>0.52 (0.10)</td>
</tr>
<tr>
<td>Meaningful words, babble noise</td>
<td>0.69 (0.11)</td>
<td>0.71 (0.09)</td>
</tr>
<tr>
<td>Nonsense words, no background noise</td>
<td>0.99 (0.02)</td>
<td>1.00 (0.01)</td>
</tr>
<tr>
<td>Nonsense words, white noise</td>
<td>0.26 (0.12)</td>
<td>0.31 (0.11)</td>
</tr>
<tr>
<td>Nonsense words, babble noise</td>
<td>0.69 (0.10)</td>
<td>0.70 (0.10)</td>
</tr>
<tr>
<td><strong>Phoneme accuracy</strong></td>
<td></td>
<td></td>
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<tr>
<td>Meaningful words, no background noise</td>
<td>1.00 (0.01)</td>
<td>1.00 (0.01)</td>
</tr>
<tr>
<td>Meaningful words, white noise</td>
<td>0.76 (0.08)</td>
<td>0.79 (0.08)</td>
</tr>
<tr>
<td>Meaningful words, babble noise</td>
<td>0.85 (0.04)</td>
<td>0.84 (0.05)</td>
</tr>
<tr>
<td>Nonsense words, no background noise</td>
<td>1.00 (0.01)</td>
<td>1.00 (0.00)</td>
</tr>
<tr>
<td>Nonsense words, white noise</td>
<td>0.69 (0.06)</td>
<td>0.72 (0.05)</td>
</tr>
<tr>
<td>Nonsense words, babble noise</td>
<td>0.88 (0.04)</td>
<td>0.88 (0.04)</td>
</tr>
<tr>
<td><strong>Dual task paradigm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>9.78 (13.38)</td>
<td>5.12 (12.98)</td>
</tr>
<tr>
<td>Reaction time</td>
<td>55.29 (54.79)</td>
<td>25.37 (22.97)</td>
</tr>
</tbody>
</table>
Figure 1. Boxplots represent minimum and maximum, interquartile range, and median of visual and auditory attention tasks for ADHD and Control groups: (a) Stroop test and (b) Digit Span test.
Listening effort among adults with ADHD

Figure 2. Results of speech perception tasks in Noise and Meaning conditions for ADHD and Control groups.
Listening effort among adults with ADHD

Figure 3. Results of DPT Single task (visual–motor), Dual task (visual-motor + auditory), and Listening Effort (LE) (differences in visual-motor performance between single and dual conditions) for ADHD and Control groups: (a) accuracy and (b) response time (RT).