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Original Article

Effects of noise and audiovisual cues on speech processing in adults with and without ADHD

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Abstract

Objective: This study examined the interplay among internal (e.g. attention, working memory abilities) and external (e.g. background noise, visual information) factors in individuals with and without ADHD. *Design*: A 2 × 2 × 6 mixed design with correlational analyses was used to compare participant results on a standardized listening in noise sentence repetition task (QuickSin; Killion et al, 2004), presented in an auditory and an audiovisual condition as signal-to-noise ratio (SNR) varied from 25–0 dB and to determine individual differences in working memory capacity and short-term recall. *Study sample:* Thirty-eight young adults without ADHD and twenty-five young adults with ADHD. *Results:* Diagnosis, modality, and signal-to-noise ratio all affected the ability to process speech in noise. The interaction between the diagnosis of ADHD, the presence of visual cues, and the level of noise had an effect on a person's ability to process speech in noise. *Conclusion:* Young adults with ADHD benefited less from visual information during noise than young adults without ADHD, an effect influenced by working memory abilities.

Key Words: Noise; signal-to-noise ratio (SNR); audiovisual cues; working memory capacity (WMC); Attention deficit/hyperactivity disorder (ADHD); adult; speech processing

The ability to process speech accurately and efficiently during daily communication is complex and reliant on ordered, internal cognitive-linguistic operations (Lagace et al, 2010; Larsby et al, 2005; Wingfield & Tun, 2007), including fundamental language abilities, and cognitive functions such as attention and working memory. These internal listening conditions are impacted by external listening conditions such that speech processing can be degraded or enhanced by factors such as background noise and visual cues.

The load and effort placed on the cognitive-linguistic system is dependent upon the integrity and quality of the auditory signal (Arlinger et al, 2009). A degraded auditory signal or competing auditory signals increases the need for internal cognitive control processes (Sorqvist & Ronnberg, 2012) and increases the required listening effort (i.e. the attention needed to understand speech) (Fraser et al, 2010; Lunner et al, 2009; Stenfelt & Ronnberg, 2009), reduces the allocation of attentional and working memory resources (Baldwin & Ash, 2011; Pichora-Fuller et al, 1995), and makes the automatic processes of decoding and lexical retrieval deliberate and effortful (Stenfelt & Ronnberg, 2009). It is the quality of the acoustic signal which determines automaticity or implicitness of speech processing (Ronnberg, 2003; Rudner & Ronnberg, 2008).

The ease of language understanding (ELU) model proposed by Ronnberg et al (2008) represents a working memory system which considers both internal and external listening conditions. It outlines a model of working memory in which there is an interaction between the implicit (i.e. automatic) capacity to recognize speech elements under adverse listening conditions and the explicit (i.e. deliberate) capacity to make sense of those elements for functional use (Ronnberg et al, 2010). The model suggests that when the acoustic signal is degraded or distorted, more deliberate processing is required to generate meaning based on previous knowledge. It is the deliberate component of the ELU model which is similar to the notions proposed by other researchers, such as the supervisory attention system outlined by Norman and Shallice (1980), the central executive outlined by Baddeley (2000), or working memory capacity/attentional control described by Engle (2002). That is, the harder it is to hear the acoustic signal, the more working memory capacity is required to accurately extract meaning.

Researchers attempt to empirically demonstrate that ELU reflects the degree to which explicit, top-down processing functions are relied upon (Stenfelt & Ronnberg, 2009). When background noise is present, explicit, top-down processing functions will be repeatedly

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Abbreviations

ADHD	Attention deficit/hyperactivity disorder
ELU	Ease of language understanding
O-span	Operation span
QuickSIN	Quick speech-in-noise
R-span	Reading span
SNR	Signal-to-noise ratio
WMC	Working memory capacity

invoked to decode, interpret, and infer the contents of connected speech (Ronnberg et al, 2010). Therefore, individuals with a high working memory capacity will experience a more reduced cognitive load when listening in the presence of background noise than individuals with a low working memory capacity. This is empirically demonstrated through research designs which measure individual working memory capacity and speech processing under mismatch conditions (e.g. background noise), and that determine what kind of statistical relationship exists between these variables. Using this outline, studies have demonstrated a strong correlation between measures of working memory capacity (e.g. reading span tasks, visual letter monitoring test) and speech recognition in noise (e.g. Hagerman sentences) (Runder et al, 2008, 2009; Sorqvist & Ronnberg, 2012). Therefore, robust internal listening conditions (e.g. working memory capacity) can mitigate the negative effects of poor external listening conditions (e.g. background noise).

When an individual experiences difficulty interpreting the auditory signal through a signal modality due to background noise, that individual might rely more heavily on audiovisual speech cues provided by the speaker's oral-motor movements (Buchan et al, 2008; Schneider et al, 2007). During typical face-to-face conversation, individuals are given an auditory stimulus consisting of specific phonemes and a visual stimulus consisting of dynamic facial movements. The facial movements have articulatory information which improves the individual's ability to detect (Grant & Seitz, 2000), interpret, and identify auditory input (Davis & Kim, 2004). The perception of the auditory stimulus is improved when simultaneously viewing the speaker because an appropriate phonetic representation (Bristow et al, 2008) or speech motor schema is activated (Davis & Kim, 2004) using the brain's audiovisual integration mechanism (Szycik et al, 2008, abstract). The position of the lips, jaw, and tongue yield highly accurate visual speech cues creating visemes or basic visible speech units (Jaaskelainen, 2010). Speech recognition in the presence of background noise may be enhanced by more than 40% with the provision of visual speech cues (Fraser et al, 2010; MacLeod & Summerfield, 1987, 1990). While background noise weakens the auditory signal, increasing the cognitive load, the simultaneous presentation of audiovisual speech cues may reduce the need for cognitive control (Jasskelainen, 2010; Szycik et al, 2008; Fraser et al, 2010).

Although the empirical evidence outlining the relationship between listening in noise, working memory, and visual cues is from studies with typical adults or adult hearing-aid users (Gosselin & Gagne, 2011; Lunner et al, 2009; Rudner et al, 2012; Sorqvist & Ronnberg, 2012), these concepts need to be explored in other populations with cognitive limitations. Schneider et al (2007) explained that when listeners are required to process speech in complex listening conditions (i.e. background noise, multiple speakers, etc.), one of two things must occur: the listener must switch their attention and simultaneously process multiple pieces of auditory information, or the listener must inhibit the irrelevant auditory information to focus on the target acoustic signal. This description is extremely relevant for adults with attention deficit/hyperactivity disorder (ADHD). Adults with ADHD may experience a fundamental deficit in inhibition, which includes difficulty with interference control (Barkely, 1997; Pazvantoglu et al, 2010; Woods et al, 2002; Woltering et al, 2013). Listening in noise would not only increase the demands placed on an already compromised attentional and working memory system, but would also potentially require a higher signal-to-noise ratio (SNR) for effective processing of the signal (Schneider et al, 2007). Likewise, because an auditory distractor makes it difficult to focus sustained attention on the current task (Soderlund et al, 2007), it is logical to assume that individuals with ADHD would be more susceptible to the negative effects of background noise than adults without ADHD. The purpose of this study was to examine the impact of background speech noise on speech processing in adults with ADHD as compared to young adults without ADHD.

Methods

Participants

Sixty-three young adults, age 18–35, participated in this study. The experimental group consisted of 25 young adults (9 male; 16 female) with a current or past diagnosis of ADHD. The control group consisted of 38 young adults (15 male; 23 female) without ADHD. The experimental and control groups were matched on age (ADHD $M = 23.7$ years, $SD = 4.0$; non-ADHD $M = 23.5$ years, $SD = 4.0$; $t(61) = .15$, $p = .88$), and educational level (ADHD $M = 14.6$ years, $SD = 1.32$; non-ADHD $M = 15.0$ years, $SD = 2.62$; $t(61) = .15$, $p = .37$). The participants were recruited from the university and surrounding communities. All participants spoke English as their first language and had a high school diploma with varying levels of college experience. Participants in the experimental group all were currently treated for ADHD and any participants on ADHD medication were asked to refrain from taking that medication for 12 hours prior to the study (Brams et al, 2010). Participants in the control group verbally completed a questionnaire to assure no history of ADHD or other learning disabilities. Participants in both experimental and control groups passed a hearing screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz bilaterally. All participants signed a consent form approved by Old Dominion University's Institutional Review Board in accordance with the Helsinki Declaration. Participants were given either a $10 gift card or class credit to reimburse them for their participation in the study.

Materials

QUICK SPEECH-IN-NOISE (QUICKSIN; KILLION ET AL, 2004)

Each participant's listening in noise abilities were measured using QuickSIN software run on a standard Dell computer. QuickSIN is a computer program which simultaneously presents a sentence repetition task in the presence of background noise (five talker babble). There were two presentation conditions: (1) the standard auditory-only QuickSIN, and (2) an experimental auditory + visual (face) presentation of sentences. The Killion group provided existing audiovisual recordings of all QuickSIN stimuli to the investigators. The recordings were screened to assure synchronization of the auditory and visual signals on the dedicated hardware. The examiners completed daily perceptual checks to ensure ongoing congruency between the auditory and visual signal across sessions of the experiment.

For each QuickSIN condition, the participant wore headphones in which the speech signal and background noise (i.e. speech babble) were co-located. Participants repeated target sentences with five key words. Throughout all subtests, sentences were presented at a standard, comfortable hearing level, at approximately 60 dB HL. The background noise increased by increments of five decibels from 40–60 dB HL, yielding six signal-to-noise ratios: 25, 20, 15, 10, 5, and 0 dB. In the auditory-only condition, participants listened to sentences and repeated the sentences. In the auditory + visual condition, the listener heard the sentences through headphones and saw the speaker produce the sentence on a video monitor to repeat. Eight blocks of sentences per condition were presented in counterbalanced order across participants across the two listening conditions.

The examiner scored repetition responses for QuickSIN online. The dependent measure in the task was the number of five key words correctly repeated per sentence (n = 8 sentences per SNR). We calculated the number of words correct (maximum 40) for each SNR (0, 5, 10, 15, 20, 25), in each condition, auditory and auditory-visual.

Reading span (R-span) task

Originally developed by Daneman and Carpenter (1983), the R-span is a working memory task widely used as a valid measure of working memory capacity, because it reflects a participant's ability to both store and manipulate information (Conway et al, 2005). A modified version was used in this experiment (Engle et al, 1999). Participants read aloud sentences viewed on a computer screen, determined the meaningfulness of each sentence (yes or no), and verbally recalled capital letters from the end of each sentence in the sentence set. Sentence sets varied from 2–5 sentences in length. Each participant was scored on accurate interpretation of the meaningfulness of the sentence and accurate recall of all final capital letters in the designated number of sentences. Participant's total score was reported using partial-credit load scoring, which is calculated as the number of words correctly recalled averaged across each set of sentences (Conway et al, 2005).

Operation span (O-span) task

Like the R-span task, the O-span task is a valid and reliable measure of individual differences in working memory capacity (Conway et al, 2005). Engle et al's (1999) version of the O-span task was used in this research project. During the O-span task, participants read aloud mathematical equations viewed on a computer screen, determined the accuracy of the answer provided, and verbally recalled words from the end of each equation in the mathematical equation set. Equation sets varied from 2–5 equations in length. Each participant was scored on the accurate solution to the equation and accurate recall of all words. Participant's total score was reported using partial-credit load scoring, which is calculated as the number of words correctly recalled averaged across each set of equations (Conway et al, 2005). For purposes of analyses, raw scores from both the R-span and O-span task were converted to z-scores and averaged in order to calculate a working memory capacity composite score.

Digit span

During experimental tasks, participants were asked to verbally recall digit lists presented orally by a female, English speaking experimenter. The digits forward and digits backward subtest of the clinical evaluation of language fundamentals (CELF-4) (Semel et al, 2003) was used to calculate a digit span score for each participant.

Procedure

The testing session took approximately 60 minutes to complete for participants without ADHD and 75 minutes for those with ADHD. Testing took place in a quiet lab space. Participants signed consent, provided demographic information, and completed the hearing screening. They then completed the reading span, operation span, digit recall, and QuickSIN tasks. The order of those tasks was counterbalanced across participants according to the testing group as randomly determined at entry to the experiment. For all experimental tasks, participants were given practice trials.

Data analysis

SPSS was used to calculate descriptive statistics and within- and between-group differences on each variable (i.e. listening conditions, SNR, working memory capacity, short-term memory) through a multivariate analysis of variance (MANOVA). Independent t-tests and correlational analyses were completed to assess relationships between the covariates and percent correct performance at each SNR level on the experimental QuickSIN tasks.

Results

A 2 × 2 × 6 mixed design was used in which the modality of presentation (auditory-only vs. auditory + visual) and SNR level (25, 20, 15, 10, 5, 0) were the within subject manipulations, and the between group variable was ADHD vs. Non-ADHD. Data were also collected on two covariates (working memory capacity, short-term memory) which measured individual differences that were expected to relate to performance on the QuickSIN or the grouping variable (Maxwell & Delaney, 2004).

QuickSin results

Figure 1 shows means and standard errors for the ADHD and control groups on the two versions of QuickSIN, auditory, and auditory + visual. There was a significant main effect of group, $F(1, 61) = 5.41$, $p < .05$, $\eta^2 = .081$, modality, $F(1, 61) = 347.14$, $p < .000$, $\eta^2 = .85$, and a main effect of SNR, $F(5, 57) = 306.46$, $p < .000$, $\eta^2 = .96$. There were two way interaction effects of SNR and group, $F(5, 57) = 4.80$, $p < .001$, $\eta^2 = .296$, and modality and SNR, $F(5, 57) = 63.77$, $p < .001$, $\eta^2 = .848$. There was no two way interaction effect of group and modality, $F(1, 61) = 3.40$, $p > .05$, $\eta^2 = .053$. All of these significant main effects and interaction effects were subsumed under a significant three-way interaction effect of modality, SNR, and group, $F(5, 57) = 2.38$, $p < .05$, $\eta^2 = .173$.

The nature of this three-way interaction effect was further investigated in follow-up analyses. A 2 (group) × 6 (SNR) MANOVA was conducted for each modality. For the auditory condition alone, there was a main effect of SNR, $F(5, 57) = 572.27$, $p < .000$, $\eta^2 = .98$, but there was no interaction between SNR and group, $F(5, 57) = 1.19$, $p > .05$, $\eta^2 = .094$, suggesting no difference for young adults with and without ADHD in their ability to process speech in noise as the noise level increased. For the audiovisual condition, there was a main effect of SNR, $F(5, 57) = 90.70$, $p < .000$. Unlike the auditory condition, there was also an interaction effect between the SNR and

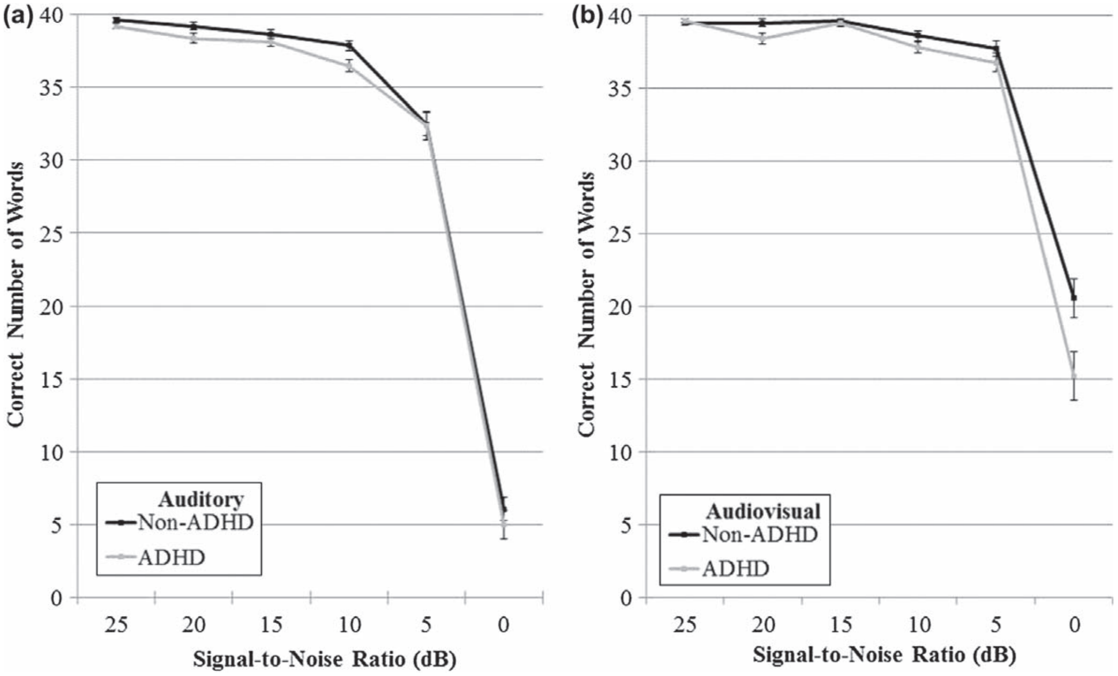

Figure 1. Mean accuracy on QuickSIN as a function of ADHD, SNR, and modality.

group, $F(5, 57) = 4.38$, $p < .05$, $\eta^2 = .28$, indicating that the ADHD group performed significantly poorer than the control group in the audiovisual condition. A series of pairwise comparisons of ADHD to Non-ADHD groups at each of the SNR levels in the auditory-visual condition revealed significantly lower performance of the ADHD group at SNR20, $t(61) = 2.40$, $p < .02$, Cohen's $d = .02$, and SNR0, $t(61) = 2.51$, $p < .015$, Cohen's $d = .67$.

Working memory relationships

To investigate how working memory capacity and short-term recall impacted performance, we compared the ADHD and non-ADHD groups performance on the reading span task, operation span task, digit recall forward, digit recall backward, and the working memory capacity composite score through a series of independent *t* tests. Means and standard deviations for each group across tasks are reported in Table 1. Results revealed significant group differences only for the operation span task, $t(61) = -2.24$, $p < .05$, Cohen's $d = .58$, and working memory capacity composite scores, $t(61) = -2.13$, $p < .05$, Cohen's $d = .55$. Young adults without ADHD performed better on each of these measures than individuals with ADHD. Although young adults without ADHD also performed better on the additional tasks, their scores were not significantly different from participants with ADHD on the reading span task, $t(61) = -1.61$, $p > .05$, Cohen's $d = .38$; recalling digits forward, $t(61) = -1.061$, $p > .05$, Cohen's $d = .28$, and recalling digits backward, $t(61) = -1.70$, $p > .05$, Cohen's $d = .43$).

Table 1. Means and standard deviations for each group across covariate tasks.

	Group			
	Non-ADHD		*ADHD*	
	Mean	*SD*	*Mean*	*SD*
Digits forward	11.18	1.71	10.60	2.40
Digits backward	7.13	2.42	6.12	2.24
O-Span	.66	.11	.59	.130
R-Span	.72	.14	.67	.123
WM composite	.21	.86	−.28	.909

In order to understand the relationship between working memory capacity and performance on speech processing in noise, correlational analyses were completed for both the ADHD and non-ADHD groups for the auditory and audiovisual conditions at each SNR level. The correlational analyses were run using the total working memory composite scores. Correlation results are provided in Table 2.

In the auditory condition for non-ADHD participants, there was no significant relationship between working memory capacity and SNR0, $r = .190$, $p > .05$, suggesting that working memory capacity is not related to speech processing under the noisiest listening condition. For individuals with ADHD in the auditory condition, however, there was a significant relationship between working memory capacity and SNR0, $r = .400$, $p < .05$, suggesting that working memory capacity is related to speech processing under the noisiest condition. These results suggest that young adults with ADHD rely on working memory capacity more heavily than young adults without ADHD under the noisiest listening condition in order to maintain a commensurate level of listening performance.

In the audiovisual condition for non-ADHD participants, there was a significant relationship between working memory capacity and SNR0, $r = .371$, $p < .05$, suggesting that working memory capacity is related to speech processing under the noisiest listening condition when a visual cue is provided. For individuals with ADHD in the audiovisual condition, there was not a significant relationship between working memory capacity and SNR0, $r = .253$, $p > .05$, suggesting that working memory capacity is not related to speech

Table 2. Correlation results: ADHD and Non-ADHD groups.

	Non-ADHD			*ADHD*		
	WMC	*DF*	*DB*	*WMC*	*DF*	*DB*
WMC	1	.048	.175	1	.181	.319
DF	.048	1	.616**	.181	1	.532**
DB	.175	.616**	1	.319	.532**	1
A25	−.071	.134	.016	.225	.359	.150
A20	.074	.184	−.054	.452*	.290	.196
A15	.390*	.236	.301	.099	.258	.187
A10	.088	.180	.099	−.194	.103	.004
A5	.139	.136	.163	.304	.043	.047
A0	.190	−.139	.059	.400*	.031	.165
AV25	.226	.325*	.120	.314	.435*	.283
AV20	.234	.105	.074	.160	.476*	.104
AV15	−.076	.195	−.061	−.013	.068	−.114
AV10	.054	.144	.000	.503*	.206	.163
AV5	.251	.023	.036	.056	.063	−.071
AV0	.371*	.139	.214	.253	.150	.100

Note: Pearson's product moment coefficients for: WMC = working memory capacity composite; DF = digits forward; DB = digits backward; A25-A0 = auditory subset only; AV25-AV0 = audiovisual subtest only.
*Results are significant at $p < .05$.
**Results are significant at $p < .01$.

processing under the noisiest listening condition when a visual cue is provided. These results suggest that it is the difference in working memory capacity which may have facilitated a reduction in listening performance for individuals with ADHD. Finally, for individuals with ADHD in the audiovisual condition, there was a significant relationship between working memory capacity and SNR10, $r = .503$, $p < .05$.

Discussion

This experiment investigated the influence of background noise and visual cues on speech processing for individuals with and without a diagnosis of ADHD, while also considering the impact of working memory capacity. Individuals with ADHD had more difficulty in the primary listening task in background noise than the control group in the auditory + visual condition. These results were related to performance in working memory capacity tasks as well. These findings are considered with respect to models of working memory and speech processing.

The working memory model for ease of language understanding (ELU)

Results from this research are consistent with findings of previous empirical studies (Lunner & Sundewall-Thoren, 2007; Rudner & Ronnberg, 2008; Rudner et al, 2009) supporting the relationship between working memory capacity and the ability to recognize speech in noise. When background noise is present, speech processing becomes more deliberate or explicit, requiring higher levels of attentional control (i.e. working memory capacity) to maintain the incoming signal while simultaneously activating representations in long-term memory, and ignoring irrelevant acoustic and visual information (Rudner & Ronnberg, 2008; Ronnberg et al, 2010, 2013). For individuals with ADHD, correlations between working memory composite scores and speech processing at two noise levels in the auditory condition (i.e. SNR 20, 0) empirically support a relationship between the presence of background noise and cognitive load, making the processing of the acoustic signal more reliant upon higher level control processes (i.e. working memory capacity).

With regard to the auditory condition, it may be that the processing of speech becomes less automatic and more deliberate or dependent on working memory capacity when the increase in the signal-to-noise ratio exceeds the system's innate threshold and ability to automatically compensate. Working memory capacity highly correlated with speech processing (QuickSIN scores) when the signal-to-noise ratio increased to 20 dB and 0dB in the ADHD group and 15 dB in the control group. This pattern suggests that a person's processing system may adapt to a noise level and process the acoustic signal automatically, but once that noise level increases processing beyond a certain capacity, then the processing system must compensate again, making the processing of the acoustic signal deliberate and reliant upon working memory capacity. It may not be that a young adult relies on working memory capacity or deliberate processing consistently under all noisy conditions, but that young adults go back and forth between implicit and explicit processing depending on the noise level. Further, listening demands were greater for young adults with ADHD, as suggested by a reliance on working memory capacity in the loudest listening condition, because their innate working memory capacity was somewhat lower than controls.

Audiovisual cues

Results from this research project are consistent with other work showing that visual cues strengthen the auditory message by reducing listening effort and improving speech recognition (MacCleod & Summerfield, 1987, 1990), including speech recognition in noise (Bristow et al, 2008; Fraser et al, 2010; Larsby et al, 2005). Mean speech processing scores for all young adults were significantly improved in the audiovisual condition. The provision of congruent visual cues allowed participants to accurately interpret the auditory stimulus as background noise systematically increased, possibly by allowing lipreading as the auditory signal was reduced.

The overall pattern of performance for young adults with and without ADHD in the auditory condition essentially demonstrates a commensurate ability to process speech in the presence of fluctuating levels of background noise without the presence of visual cues. This result aligns with a study finding that children with ADHD were able to control auditory interference as well as children without ADHD (van Mourik et al, 2011).

However, differences between the groups with and without ADHD were evident in the audio-visual condition. Audiovisual cues had a more positive impact on speech processing for young adults without a diagnosis of ADHD than those with ADHD when background noise was at the highest level (AV SNR0 dB). The inclusion of visual cues did not facilitate speech processing for adults with ADHD to the same extent as for adults without ADHD at SNR 0 dB. When it would seem adults with ADHD would need audiovisual cues the most, they benefited the least from their presence.

There are a few potential reasons why the presence of audiovisual cues did not improve speech processing performance for the ADHD group as much as normal at the most difficult SNR level. Working memory capacity scores were significantly lower for the ADHD group when compared to young adults without ADHD. One possibility is that a young adult's cognitive load increases as the SNR level increases, necessitating the processing system to initiate the transfer from automatic speech processing, facilitated by short-term recall, to deliberate speech processing, facilitated by working memory capacity. It appears that, although numerically reduced when compared to their matched peers, working memory capacity or attentional control in the ADHD group was sufficient to process speech as efficiently and accurately as their matched peers without ADHD in the auditory condition. It is when another piece of information (i.e. interference) enters the stream of processing data in the form of visual information, as in the auditory + visual condition, that the cognitive load is stretched. The reduction in working memory capacity for young adults with ADHD becomes detrimental. This theory is supported by the strong relationship between working memory capacity and speech processing at AV SNR 0 dB for non-ADHD participants only, and by studies suggesting that ADHD demonstrate as a core cognitive deficit decreased interference control (Barkley, 1997; Pazvantoglu et al, 2010; Woltering et al, 2013; Woods et al, 2002). This theory is further confirmed by the recent findings that the inclusion of visual information during listening tasks interferes with attentional control processes (i.e. executive control/working memory capacity) (Mishra et al, 2013). Young adults with ADHD do not have sufficient executive control processes necessary to simultaneously maintain phonological input, ignore irrelevant acoustic information, and integrate visual speech cues in order to retrieve accurate linguistic representations from long term memory. We propose that a reduction in working memory capacity limits the ability to effectively handle multiple streams of information in young adults with ADHD.

Another potential reason for the discrepancy in the impact of audiovisual cues on speech processing in noise for young adults with ADHD is visual attention. It is not known whether or not young adults with ADHD were able to sustain visual focus on the visual cue. If the young adults with ADHD shifted eye gaze frequently during the task, then the provided visual information was not salient enough to positively influence speech processing. In order for visual speech cues to be effective, they must be held in sight long enough to generate accurate sensory traces which can then be mapped onto stored phonetic representations. This possibility needs to be explored in other studies, possibly with the use of eye-tracking.

Finally, for young adults with ADHD short-term recall correlated with SNRAV25 and AV20, SNR levels which did not correlate with working memory capacity. These results suggest that the neurological system can compensate for low levels of background noise maintaining implicit processing. Because of this relationship between basic short-term recall and speech processing in low noise levels with accompanying visual cues, it could be inferred that automatic decoding of the acoustic signal, under low noise conditions, is facilitated by temporary storage of phonological information (Ronnberg et al, 2013).

Implications

Although this research project is rooted in conceptual theory, our results can be translated into practical and functional treatment implications for practitioners who work with adults with ADHD. First, these results support the importance of selecting reliable and valid evaluation tools so that measured behaviors accurately reflect underlying cognitive constructs and linguistic skills. A good assessment will include a variety of empirically based standardized and nonstandardized tests, the results of which can generate a unified and comprehensive representation of the client's language skills in relation to cognitive processes.

Second, results of this study indicate that background noise can be detrimental to auditory processing, particularly for individuals with ADHD. This suggests the need for practitioners to carefully monitor the educational and therapeutic environments for students with ADHD, and provide quiet working conditions for these individuals as needed, particularly avoiding background speech noise.

Finally, these results support the importance of facilitating an appropriate balance between verbal input and visual cues which is relative to the activity. It is clear that for individuals with reduced working memory capacity, a point of saturation may be reached whereby visual cues increase cognitive load and reduce performance. Practitioners should complete observations of clients with ADHD in order to determine how best to use visual cues as environmental supports. It will be important to monitor the balance between the provided visual cues and associated verbal instructions, explanations, and/or background noise.

Limitations

There are limitations which could have influenced the results of this study. The small sample size influences the power of generated statistical results. More participants could yield larger between group differences. By having a larger representation of young adults with ADHD, an interaction effect between modality and group may have been generated. In addition, there may have been more conclusive results regarding the relationship between working memory capacity and speech processing at all noise levels for both groups of young adults.

Another issue is related to recruiting participants with a true and pure ADHD diagnosis. Although efforts were made to ensure young adults in the ADHD group had an accurate diagnosis, there was no way to ensure that the nature and severity of that diagnosis was identical or consistent across group members. Many of the ADHD participants had co-morbid diagnoses (i.e. anxiety disorder, executive function disorder, or a learning disability), making the connection between reported results and the diagnosis of ADHD more difficult.

The work of Shinn-Cunningham & Best (2008) suggests that auditory spatial cues facilitate selective attention during listening tasks which are comprised of multiple streams of auditory information. In this study, the listening task was presented bilaterally through headphones eliminating otherwise available spatial cues. Therefore, one element of functional listening is omitted, making the listening task even more challenging by further limiting selective attention in young adults diagnosed with ADHD. This detail makes it difficult to generalize the results of this study to everyday listening situations.

A final consideration is highlighted by Freyaldenhoven et al (2005) study showing that stimulant medication increased the level of background noise young adult women with ADHD were able to accept. The young adults in this research project were asked to be medication free for 12 hours prior to completing evaluation tasks. Results of this project may have been different if the young adults with ADHD were tested while medicated. Despite this limitation, the reported results are viewed to be representative and valid reflections of cognitive performance absent of any pharmaceutical assistance and therefore valuable.

Conclusion

Of course, background speech noise negatively impacted speech processing for young adults with and without ADHD. Although the inclusion of audiovisual cues improved performance for all young adults, young adults with ADHD did not benefit as much from the presence of visual cues at the most difficult listening level. It appeared that as the level of background noise increased, so did the young adults', with and without ADHD, reliance on working memory capacity to accurately decode the auditory signal. Because the provision of visual cues increased the cognitive load and because individuals with ADHD may have a reduced working memory capacity, visual cues actually may have reduced speech processing performance at the highest, most difficult noise levels.

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