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Impaired linguistic processing and atypical brain laterality in adults with ADHD☆

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Abstract

Introduction: cognitive/behavioral testing, structural imaging, and functional imaging, has demonstrated atypical cerebral asymmetries in patients with attention-deficit/hyperactivity disorder (ADHD). However, few studies directly examined the nature of hemispheric specialization and interaction in this population. Methods: the present experiment applied techniques from behavioral laterality research to assess directly left/right brain dynamics in unmedicated adults with ADHD ($n=21$) and controls ($n=22$). We used a lateralized lexical decision task to assess hemispheric differences in word recognition and cross-callosal interhemispheric transfer of linguistic information. Results: analysis of variance indicated that ADHD subjects were impaired relative to controls in identifying words in both hemispheres ($P=0.001$). Furthermore, ADHD subjects exhibited decreased effects for ‘word regularity’ ($P=004$), enhanced effects of ‘word frequency’ ($P=007$), and an increased bias for ‘nonword’ responses overall ($P=03$), as well as during left visual field trials in particular ($P=01$). Conclusions: adult subjects with ADHD demonstrated poor linguistic processing. Group differences in sensitivity to semantic and phonological linguistic variables, along with differences in response biases, suggested that ADHD subjects had reduced left hemisphere and enhanced right hemisphere involvement during our task. These findings are relevant to current research investigating ‘endophenotypes’ in ADHD, as laterality indices may prove useful in etiological research, particularly molecular genetic investigations, and highlights the relevance of brain laterality research in clinical psychiatry.

Keywords: Laterality; ADHD; Language; Hemisphere; Linguistic; Attention

1. Introduction

The validity of the diagnosis of attention-deficit/hyperactivity (ADHD) in adults has gained considerable strength with recent reports [1–9]. However, relative to studies of children with ADHD, few have compared basic cognitive processes between adults with ADHD and controls, and what core deficits in cognitive processing exist, if any, remains unclear. Therefore, more studies of adult ADHD are needed to clarify the basic processes which underlie the disorder and a focus on adults with ADHD may actually have an advantage of being less confounded by developmental effects.

A variety of cognitive studies have suggested that childhood ADHD is associated with differences in brain lateralization [10–14]. However, few have been designed explicitly to address this issue. The covert orienting of spatial attention paradigm adapted from Posner et al. [15] has been used to study brain laterality with respect to the neural processes used for shifting attention. Work with this paradigm in children with ADHD has generated interesting but conflicting results [10,13,14], and has not consistently incorporated controls relevant to brain laterality research.

Sheppard et al. [12], using a line bisection task, showed that children with ADHD bisect lines with a rightward bias

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indicating a ‘neglect’ of the left half of space. They inferred that ADHD might involve abnormal right hemisphere processing. A similar deficit was observed in patients with right-sided parietal lesions [16]. In this vein, Heilman and colleagues have highlighted numerous findings showing that ADHD symptoms are, in many ways, reminiscent of those associated with right sided brain damage [17]. Furthermore, Garcia-Sanchez et al. [11] found ADHD teenagers to be impaired on a battery of ‘right hemisphere’ tasks.

In contrast to the above studies, some recent findings have implicated left hemisphere dysfunction in child and adolescent ADHD samples showing that linguistic impairments, including difficulty with semantic processing, are contributing factors [8,18–24].

Manassis and colleagues [25,26] conducted two studies utilizing versions of Bryden and MacRae’s Dichotic listening for emotions and words [27] to investigate brain laterality differences between children with ADHD, anxious children, and normal controls. They reported no group differences in measures of laterality. However, these experiments utilized verbal responses which might have confounded the results given that speech is left lateralized. Also, these experiments utilized the signal detection measure ‘d prime’ as a primary dependant measure in spite of the inability to assess laterality of false alarms with this paradigm.

In summary, neurocognitive testing in ADHD, primarily with child samples, has yielded conflicting results in relation to lateralized differences. Not all studies have incorporated important controls for laterality and no consensus exists as to the exact nature of associated cognitive impairments.

Imaging studies, both structural and functional, have reported possible lateralized differences in both adult and child ADHD samples (for review see: 28,29). For instance, structural studies in ADHD children and adolescents have found reduced caudate volumes and reversed asymmetry as well as decreased right-sided globus pallidus and anterior grey and white matter compared with controls [3,5]. Furthermore, although inconsistent with regard to the exact location, several reports suggest that ADHD children have smaller regions of the corpus callosum compared with controls [30–32]. A number of resting-state functional activation studies indicate abnormal R>L asymmetries in adults and children with ADHD [33–36], while others looking at activation during cognitive challenges have indicated decreased right-sided activation [7,37,38].

Importantly, lateralized differences in brain structure and function do not clearly inform us about the functional impact on interhemispheric interaction. ADHD-associated grey and white matter volume changes are inconclusive as to their impact on cognition and behavior while functional imaging differences in a single hemisphere are difficult to wholly attribute to a specific lateralized deficit given the complexity and diffuse networking of the cerebral cortex. Nonetheless, taken together, there is a broad range of imaging studies suggesting that ADHD involves atypical cerebral asymmetries of both structure and function.

In the current experiment, we used a well-studied lateralized lexical decision paradigm to directly investigate the nature of hemispheric specialization and interaction in adults with ADHD. This paradigm has been studied in normal control, split brain, dyslexic, and schizophrenic subjects [39–43]. The lateralized lexical decision task measures a subject’s ability to process words and orthographically regular (pronounceable) nonwords presented in either the left visual field (LVF), targeting the right hemisphere (RH), or in the right visual field (RVF) targeting the left hemisphere (LH).

During this task, right-handed subjects typically show an overall RVF advantage in accuracy and latency, which is taken to reflect left hemisphere (LH) specialization for word recognition. Also, it is common to find that words are processed better in the LH while nonwords are processed equally well in either hemisphere. Considering each hemisphere independently, words are processed more accurately than nonwords in the LH, while nonwords are often processed better than words in the RH. However, the size of the latter difference is variable across studies.

A previous study by Iacoboni and Zaidel [41] sought to determine to what extent each hemisphere can process words and nonwords independently. They reasoned that if task processing took place in a single hemisphere there should be no difference between unilateral and bilateral presentations where a distracter ‘word’ or ‘nonword’ adds ‘noise’ to the non-targeted hemisphere. Alternatively, if task processing required interhemispheric interaction then the addition of ‘distracter noise’ to the non-targeted, but ultimately contributing hemisphere, should impair performance. They found that bilateral presentations only significantly impaired performance for word targets projecting to the RH. This suggests that RH word processing is dependent upon some form of LH involvement during this task.

With lateralized lexical decisions, interhemispheric interaction is assessed by measuring lexicality priming. This measures how distracters projected to one hemisphere affect the subject’s ability to resolve targets in the opposite hemisphere. Normal right-handed subjects typically perform better when the distracter is the same category as the target (i.e. target and distracter are either both words or both nonwords). If interhemispheric processing is impaired this effect should be attenuated or absent [44].

Lateralized lexical decision also informs about the degree to which left or right hemisphere ‘stimulus processing’ and/or ‘response’ strategies are expressed. Stimulus processing strategies are explored within the framework of the hemispheric version of the dual route model of word recognition [45]. This model distinguishes two types of reading: sounding words out (phonological), or recognizing them as visual patterns (lexical). When using a sounding out strategy, subjects typically process words that sound like they are spelled (regular words) better than words with irregular spellings. When using the 'visual word' strategy, subjects typically process common or 'high frequency' words better than uncommon or 'low frequency' words. Results from acquired dyslexia [46,47] and from split brain patients [48] suggest that both hemispheres use the 'visual word' strategy but only the LH uses a sounding out strategy. Also, some data suggests that the RH may be especially sensitive to word frequency [49]. Thus, group's sensitivity to 'word' frequency and regularity can potentially inform us about the degree to which left and/or right hemisphere 'stimulus processing' strategies are emphasized.

Response strategies can be explored with the signal detection measure 'beta' or 'bias'. Beta measures response strategies knowingly or unknowingly adopted by subjects during a task [50]. In lateralized lexical decisions, normal right handed subjects typically show a bias to respond 'word' during RVF-LH trials and 'nonword' during LVF-RH trials [41,51]. Also, subjects typically show a 'word' bias overall which likely indicates LH dominance for this task. Thus, by assessing bias we can potentially gain insight about the relative use of left or right hemisphere based 'response strategies'.

In the current study, we assess lateralized word and nonword processing along with interhemsipheric interaction in adults with ADHD. We also explored the degree to which ADHD subjects emphasize left or right hemisphere 'stimulus processing' and/or 'response' strategies.

2. Methods and materials

2.1. Subjects

After receiving a full verbal explanation of all study requirements and procedures, subjects provided written informed consent approved by the UCLA Institutional Review Board. Subjects were paid $15.00 per hour for participation.

ADHD subjects were recruited through community advertisements and outpatient clinic outreach efforts. ADHD subjects met full DSM-IV diagnostic criteria for both current and childhood ADHD (inattentive or combined subtype) as assessed by a board-certified research psychiatrist using the behavioral disorders section of the schedule for affective disorders and schizophrenia for school-age children—present and lifetime version (K-SADS-PL) [52], following procedures outlined by Biederman and colleagues [1]. Other current psychopathology was assessed with the structured clinical interview for DSM-IV Axis I disorders (SCID) [53].

Non-ADHD control subjects were recruited from posted community advertisements and word-of-mouth referrals. Control subjects demonstrated an absence of ADHD currently and in childhood. This was established by having three or fewer inattention and three or fewer hyperactive-impulsive symptoms both currently and in childhood as assessed by a board-certified research psychiatrist using the K-SADS-PL interview. As with ADHD subjects, the SCID was used to assess other concurrent psychopathology.

All subjects underwent a shortened version of the Edinburgh handedness inventory [54]. This version involved a seven item scale with potential scores ranging from −14, indicating maximum left handedness, to 14, indicating maximum right handedness (0 indicates ambidextrous status). Estimated full scale IQs were obtained using the block design and vocabulary subtests of the Wechsler adult intelligence scale-revised (WAIS-R) or the Kaufman brief intelligence test (KBIT). Subjects were excluded if any of the following conditions were present: significant neurological or medical disorders; drug and/or alcohol abuse within the past 6 months; use of psychotropic medication within the last 2 weeks (within the last month for neuroleptics and long half life agents); a known diagnosis of a learning disorder; estimated full scale IQ < 80; non-right handedness (as indicated by scoring less than 11 on the handedness inventory); impaired vision. All subjects learned english as first language. Control subjects were required to be free of any current or past Axis I psychiatric disorder.

Subjects comprised 21 adults with ADHD and 22 adult controls. One additional male ADHD subject was excluded as outlier analysis revealed that he did not follow instructions and only responded to targets presented in one visual field. Demographic and diagnostic information is summarized in Table 1. ADHD subjects were significantly older than control subjects, but did not statistically differ on mean IQ or education level (i.e. attending at least 1 year of college). All subjects were free of psychotropic medication, including stimulants, a minimum of 2 weeks prior to testing. Five of 21 ADHD subjects were previously treated with psychostimulants. Numerical average of clinical global impression severity rating (CGI-S) were available for all but two ADHD subjects. All ADHD subjects received severity ratings of four or five. The group mean was 4.26 indicating moderate or greater severity in our ADHD sample. All subjects were right handed.

2.2. Task

Subjects were seated at a distance of 57.3 cm from a computer screen, with their chins in a chinrest, and index and middle finger poised on a vertically aligned pair of microswitch response buttons.

Stimuli were 240 letter strings, three, four, and five letters long—half were words and half were orthographically regular (pronounceable) nonwords matched for length. Word frequency (high: greater than 100 per million, low: less than 50 per million) and regularity were counterbalanced across all three, four, and five letter word types [55] with each target category appearing an equal number of times in the left and right visual field.

Table 1
Subject information

	ADHD group		Control group	
	Mean	SD	Mean	SD
Age[a]	34.67	(7.13)	26.50	(5.23)
I.Q.	108.00	(10.24)	111.45	(7.04)
Gender	5F/16M		6F/16M	
ADHD subtype	Current	Childhood[b]	Current	Childhood
	(15:I)(6:C)(0:H/I)	(13:I)(5:C)(1:H/I)	N/A	N/A
CGI-S	Mean 4.26			
College education	14 of 21		19 of 22	
Current psychiatric comorbidities	3-Social phobia 1-Panic disorder 1-MDD, GAD, trichotillomania 2-GAD		None	

[a] Significant group difference (Age: $P<0.0001$); F/M, females/males; CGI-S, clinical global impression severity rating; Education, attended at least 1 year college; MDD, major depressive disorder; GAD, generalized anxiety disorder; ADHD subtypes: I: inattentive; H/I, hyperactive/impulsive; C, combined type.
[b] Two subject's previous ADHD subtypes could not be ascertained.

A fixation cross was displayed throughout the experiment. A warning tone sounded 1050 ms before stimulus presentations. Horizontal lower case letter strings of the same length were presented bilaterally for 150 ms with their innermost edge at 2° to the right and left of fixation. New trials began 1050 ms after responses on previous trials. Targets were indicated by an underline. Subjects responded with their index finger for words and middle finger for nonwords. Prior to testing, all subjects underwent a practice session. Subjects were instructed to respond with the left or right hand and performed the experiment once with each hand. The order of response hands was counterbalanced between subjects. The experiment consisted two blocks of 120 trials (alternating respond hand between blocks) and lasted approximately 15 min.

2.3. Data analysis

Analyses of variance (ANOVA) with repeated measures were performed with the following dependent variables: percentage of correct trials (accuracy); median reaction times for correct responses (latency); and the signal detection measure of bias (beta), using SAS v8.2. Within-subject factors were: target visual field (left or right); target wordness (word or nonword); distracter wordness (word or nonword); and, for word targets, target frequency (high or low); and target regularity (irregular or regular). Diagnosis was the only between-subject factor. Since groups differed in mean age, age was included as a covariate in all group comparisons (the effect of age did not approach significance in any analysis). Since current psychiatric comorbidity was present in 30% of the sample, ADHD subjects with comorbidity ($n=7$) and without comorbidity ($n=14$) were compared ad hoc using ANOVA for effects where ADHD subjects differed from controls. Subjects were excluded if overall performance was more than two standard deviation away from the mean for their group.

Data analysis comprises four components: [1] We examined (in accuracy and latency) the ability of ADHD and control subjects to process words and nonwords when presented either in the RVF, targeting the LH, or in LVF, targeting the RH (target wordness *x* visual field *x* diagnosis); [2] We assessed the effect that distracters, presented simultaneously in the opposite visual field, have on target decisions and interpret this as an index of interhemispheric interaction (distracter wordness *x* target wordness); [3] We investigated whether word frequency and regularity influences ADHD and control subjects' ability to process word targets in either the left or right visual fields (target frequency *x* visual field *x* diagnosis; target regularity *x* visual field *x* diagnosis); [4] We examined the signal detection measure beta (visual field *x* diagnosis). Beta measures whether subjects are biased to choose a particular response due to inherent tendencies or strategies that have been knowingly or unknowingly adopted [50]. The final section reports on the effects of comorbidity.

3. Results

3.1. Hemispheric specialization: word and nonword processing

All subjects were more accurate and faster during RVF (86%:712 ms) than LVF (79%:735 ms) trials [visual field: in accuracy $F(1,41)=36.96$, $P<0001$; in latency $F(1,41)=7.38$, $P=01$]. Subjects responded faster to words (700 ms) than to nonwords (748 ms) [target wordness: $F(1,41)=32.23$, $P<0001$]. Words were detected more accurately ($P<0001$) (but not faster) in the right compared to the left visual field, while nonwords were detected equally well in either. In the RVF, words were detected more accurately ($P=0.02$) and faster ($P=0.006$) than nonwords. In the LVF, nonwords were detected more accurately ($P<0.0001$) but not faster than words [target wordness *x* visual field: in accuracy: $F(1,41)=59.6$, $P<0.0001$; in latency $F(1,41)=15.62$, $P=0.0003$].

ADHD subjects were less accurate and slower overall than controls (ADHD:77%:770 ms; controls:87%:677 ms) [diagnosis: in accuracy $F(1,41)=20.73$, $P<0.0001$; in latency $F(1,41)=4.26$, $P=0.04$]. In accuracy, ADHD subjects showed a larger difference in performance between left and right visual field trials (i.e. a greater RVF advantage) than controls [diagnosis *x* visual field: $F(1,41)=9.27$, $P=0.004$]. Controls detected words and nonwords equally well, while ADHD subjects were more accurate for detecting nonwords than words ($P=0.01$) [diagnosis x target wordness: $F(1,41)=4.84$, $P=0.03$]. ADHD subjects were significantly less accurate for words in both visual fields, however, the LVF impairment was more pronounced (Fig. 1). ADHD subjects were not significantly impaired for nonwords in either visual field [diagnosis *x* target wordness *x* visual field: $F(1,41)=12.22$, $P=0.001$].

3.2. Hemispheric interaction: analysis of lexicality priming

All subjects showed a normal lexicality priming effect in both accuracy and latency [distracter wordness *x* target wordness: In accuracy, $F(1,41)=5.32$, $P=0.03$: in latency $F(1,41)=5.20$, $P=0.03$]. Simple effects for these interactions were not significant. There were no group differences.

3.3. Word processing strategies: analysis of word frequency and regularity

All subjects were more accurate and faster at detecting high (84%:684 ms) than low (76%:727) frequency words [target frequency: in accuracy $F(1,41)=53.77$, $P<0.001$; in latency $F(1,41)=24.04$, $P<0.001$]. In accuracy, this effect

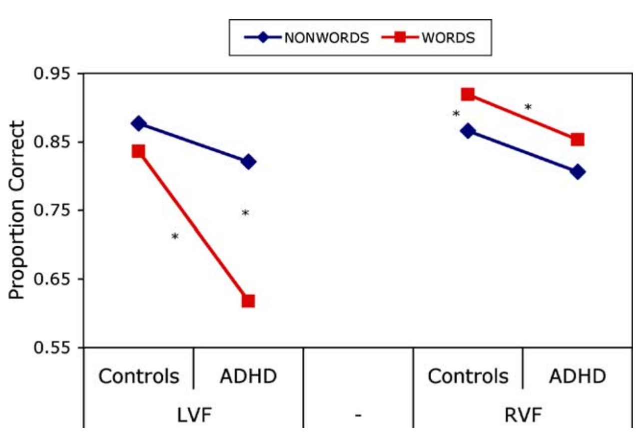

Fig. 1. Bilateral word processing deficit in adult ADHD: significant interaction of target wordness *x* visual field *x* diagnosis [$F(1,41)=12.22$, $P=0.001$]; '*' indicates a significant difference of means ($P<0.05$). RVF, right visual field; LVF, means left visual field; figure compares control and adult ADHD subjects in their ability to detect word and nonword targets in the left and right visual field's. Note: deficit for word targets in ADHD.

was more pronounced during LVF trials [target frequency *x* visual field: $F(1,41)=4.11$, $P=0.05$]. A nonsignificant trend ($P=0.08$) suggested that subjects were faster at detecting regular than irregular words.

In accuracy, ADHD subjects were more sensitive to word frequency than controls [diagnosis x target frequency: $F(1,41)=8.04$, $P=0.007$]. In accuracy, controls exhibited normal sensitivity to word regularity, while ADHD subjects showed none [diagnosis *x* target regularity: $F(1,41)=9.29$, $P=0.004$]. There were no group interactions for latency.

3.4. Response strategies: analysis of beta

In this analysis, negative values indicate a 'word' bias and positive values indicate a 'nonword' bias. All subjects were biased to respond 'word' (−0.3) during RVF trials and 'nonword' (0.29) during LVF trials [visual field: $F(1,41)=29.36$, $P<0.0001$].

Overall, controls were biased to respond 'word' (−0.22) while subjects with ADHD were biased to respond 'nonword' (0.21) [diagnosis: $F(1,41)=5.09$, $P=0.03$]. Because ADHD subjects showed both enhanced 'nonword' bias and a deficit for 'word' targets, we further assessed group differences in bias in each visual field independently to explore whether bias might help explain lateralized word deficits in ADHD. Adults with ADHD were strongly biased to respond 'nonword' (0.52) during LVF trials compared to controls (0.045) [diagnosis for LVF trials: $F(1,41)=6.44$, $P=0.01$]. In the RVF, groups did not significantly differ.

3.5. Analysis of current comorbidity

ADHD subjects with comorbidity had significantly greater 'nonword' bias (0.91) than ADHD subjects without comorbidity (0.34) during LVF trials [$F(1,19)=5.6$, $P=0.03$]. With comorbid subjects removed from the analysis: increased nonword bias in noncomorbid subjects no longer reached significance [overall bias: $F(1,34)=2.6$, $P=0.11$] [LVF bias: $F(1,34)=2.4$, $P=0.13$], and noncomorbid ADHD subjects showed a nonword deficit compared to controls during LVF trials [$F(1,34)=7.77$, $P=0.009$]. Otherwise, the general pattern of results did not change. In this study, all comorbidity was anxiety related except for one subject who had depressive symptoms in addition to anxiety.

4. Discussion

We found three important clinical features of adults with ADHD compared to controls: (1) They were specifically impaired for detecting word targets in both hemispheres; (2) They exhibited a reduced effect of word regularity along with an enhanced effect of word frequency; (3) They had greater 'nonword' bias overall and specifically during RH trials. These data suggest that a linguistic deficit may be present in ADHD that is associated with abnormal stimulus processing and response strategies. We suggest that these abnormal strategies involve reduced LH and enhanced RH processing during our task.

The LH hemisphere deficit for word targets in ADHD is straightforward and implies some form of linguistic dysfunction. However, the RH deficit is more difficult to interpret. Recall that the study by Iacoboni and Zaidel [41] suggested that during lateralized lexical decisions, RH word processing depended upon LH involvement. This implies that a RH deficit for words could be partially due to either poor LH function and/or impaired access to LH resources. Our data did not support the presence of impaired interhemispheric transfer but did indicate poor LH word processing. Considering that ADHD subjects exhibit poor LH word process and that, during RH trials, LH resources are additionally taxed by a distracter, it is conceivable that their pronounced RH deficit for word targets could be partially due to poor quality of LH assistance during these trials.

Group differences in word frequency and regularity effects suggested that ADHD subjects processed stimuli differently than controls. An enhanced effect of word frequency along with a reduced effect of word regularity indicated that they relied more on a 'visual word' strategy and less on a phonological strategy to perform our task [39,44,45]. Since, word regularity effects are thought to be selectively associated with LH processing (46-48)—but see [39,41], it would appear that ADHD subjects had a reduced expression of LH functions. Regardless of this interpretation, it is clear that a limited capacity to access and/or utilize phonological processing could disrupt performance for word targets in both hemispheres and may partially explain the observed deficits in ADHD. Furthermore, in addition to the proposal of reduced expression of LH functions, a 'RH emphasis' may also be indicated by their enhanced sensitivity to word frequency [49].

Group differences in beta or 'response bias' indicated that adults with ADHD used different response strategies than controls. Recall that bias in lateralized lexical decisions is differentially expressed dependent upon which hemisphere first processes the target stimuli. Normal right handed subjects typically demonstrate a 'word' bias during LH trials and a 'nonword' bias during RH trials. Thus, in this task, 'bias' can inform us about the relative expression of left or right hemisphere response strategies. An exaggerated 'nonword' bias overall and during RH trials, in particular, suggested that ADHD subjects emphasized a RH based response strategy during our task. This notion is consonant with the view that ADHD subjects under-express LH and over-express RH processing. Furthermore, it implies that their deficit for word targets may partly stem from the greater use of a RH based response strategy that favors nonword responses. However, the strength of this effect may be affected by comorbidity status.

The current study was not designed to evaluate the effects of comorbidity on laterality performance. Hence, this analysis is limited by small sample sizes. Nonetheless, within the small sample of comorbid ($n=7$) versus noncomorbid ($n=14$) ADHD subjects, the comorbid group shows a more striking nonword bias during RH trials than the noncomorbid group. These data suggested that the presence of comorbidity (in this case, largely current anxiety disorders) might influence group effects on the lexical decision task. Specifically, the data support a greater RH bias among ADHD individuals with anxiety than those without, and a possibly greater RH deficit for nonwords among ADHD without anxiety. These data require follow-up in a larger sample. If replicated, it may be that subjects with anxiety utilize a more conservative response strategy, such that, they are less likely to respond 'word' on a given trial.

Dyslexia is a common comorbid condition in ADHD [1,56,57], however, poor reading ability, if present, is not expected to generate the specific pattern of abnormal laterality we observed [43]. Although no direct evaluation of reading ability was done in the current study, we did exclude subjects who had a self-reported learning disability. Also, ADHD and control groups did not differ in IQ or in the proportion who attended at least 1 year of college. However, in order to exclude the possibility that an undiagnosed reading disability may have generated the specific pattern of abnormal laterality we observed, we performed additional analyses. It is known that LH performance in lateralized lexical decisions (among right handed subjects) provides a general measure of reading ability [58]. Thus, we assessed whether overall LH performance in ADHD subjects was significantly correlated with any of the findings that reflected unusual laterality in our study (i.e. impaired RH word processing, enhanced 'nonword' bias, increased sensitivity to target word frequency, and decreased sensitivity to target word regularity in ADHD). We found no significant correlations. In fact, the direction of these 'non-significant' correlations actually suggested that ADHD subjects with 'better' rather than 'worse' LH performance had a more pronounced expression of atypical laterality results. This strongly suggests that our laterality results are not attributable to poor reading ability per se.

On the whole, a clear deficit for word targets in adults with ADHD is evident. Whether this deficit is mainly the result of abnormal use of lateralized cognitive resources or a more fundamental impairment for linguistic processing cannot be definitively assessed. For instance, reduced LH and enhanced RH processing could be primary to, or a result of, a general linguistic impairment. Either way, this study indicates that abnormal brain laterality and impaired linguistic function may be associated in adults with ADHD.

Interestingly, a number of studies measuring brain activations at rest have reported R>L asymmetries in ADHD [33–36], while others have shown linguistic impairments [18–20,22–24]. The implications of poor LH-based linguistic function, and perhaps, an exaggerated RH function in ADHD are far reaching. Such right/left asymmetry differences may reflect specific genetic underpinnings in ADHD [59].

The ability to efficiently process and 'mentally' manipulate symbol-bound information is clearly important for many cognitive operations—namely, executive functions. Barkley [60] has suggested that executive functions are generally dependent upon the proper use of internalized speech. Furthermore, he has suggested that organizing goal-directed behaviors requires generating and holding in working memory mentally represented actions and/or rules that help to guide behavior and focus attention [60]. It seems possible that a decreased capacity to efficiently process and/or utilize linguistic information could negatively affect both processes. Additionally, working memory capacity has been directly associated with language function in numerous studies (for review see: 61,62). An important future research goal may be to try and determine whether a language deficit in ADHD directly contributes to impairments for executive functions.

McCracken [63] has suggested that ADHD may be associated with a 'dis-regulation' of the brain stem nucleus 'locus ceruleus' which is thought to produce 80 percent of the largely right-lateralized norepinephrine projections to the cerebral cortex [64]. This system has been shown to play a key role in regulating arousal, vigilance, sleep, autonomic function, and emotion [65]. It is interesting to consider that successful goal-directed action might require some form of regulation over these and other 'non-language' based RH mechanisms. Essentially, 'staying on task' could require that RH functions be brought into line, or coordinated with, 'goals' organized via LH language and frontal lobe executive functions. In support of this, it is understood that frontal brain mechanisms associated with executive functions play a key role in the 'top–down' regulation of the locus ceruleus [65]. Also, Barkley's [60] notion of unregulated prepotent responses in ADHD may fit with the view that RH processes are not being properly regulated in ADHD. Future research should seek to address whether RH disregulation, either stemming from or leading to, LH language impairment is a factor in ADHD.

In summary, our primary result is that ADHD subjects are impaired in their ability to rapidly identify word targets during lateralized lexical decisions. This impairment is associated with abnormal processing and response strategies suggestive of reduced LH and perhaps increased RH involvement during the task. Ours, and other studies showing poor language function in ADHD bring to the forefront two important hypotheses that should be explored in future studies: (1) poor linguistic function in ADHD negatively impacts executive processes necessary for effective goal-directed behaviors; and (2) a language deficit in ADHD is associated with poor regulation of RH processes.

Future studies of lateralized lexical decision should better explore potential effects of ADHD subtype and gender, include more extensive assessment of language abilities (particularly reading), assess functional brain activation during task performance, and determine whether the current findings generalize to younger populations. Our ADHD population consisted mainly of the inattentive subtype which is not unusual among adult samples; however, it is possible that our results apply selectively to the inattentive subtype of ADHD. Also, processing during our task occurs rapidly and may represent cognition during relatively early or basic stages of linguistic process. Further work investigating laterality in ADHD across subtypes and psychiatric comorbid disorders (especially dyslexia and anxiety), as well as during childhood and adolescence, are needed. Lastly, we were not able assess for possible caffeine-related effects on performance. However, we did assess the effects of nicotine and found none.

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