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Abstract

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by inattention, impulsivity, and hyperactivity. Symptoms of this disorder have been shown to adversely impact academic and social functioning of those with ADHD. College students with ADHD, compared to their non-ADHD peers, are at increased risk for academic and social difficulties. Given the reading-intensive and socially-driven environment of the college campus, empirical literature examining the reading comprehension and social cognition of college students are wanting. The current investigation utilized the Nelson-Denny Reading Test (NDRT) and Faux Pas Recognition test (FPRT) to assess reading comprehension and social cognition, respectively, in college students with ($n = 3$) and without ADHD ($n = 9$). The Short Story Task (SST) was administered during functional magnetic resonance imaging (fMRI) to examine neural correlates of narrative comprehension and theory of mind (ToM) while reading short fictional stories of varying prose complexity. The ADHD and control groups did not differ in IQ, GPA, or scores of NDRT, FPRT, or SST, suggesting that they had comparable academic performance, narrative comprehension, and social cognition. The fMRI analysis of SST showed that the ADHD group demonstrated increased activation in the left anterior cingulate (ACC) and parahippocampal gyrus (PHG) while reading the complex story compared to the simple story. This differential activation was not observed in the CTRL group, suggesting that the ADHD group required more neural resources to process the emotional components of the complex story to achieve the comparable performance on the SST. The ADHD group additionally exhibited lower activation in the narrative comprehension and ToM networks (medial prefrontal cortex, Broca's area, angular gyri). Collectively, these results indicate that while ADHD and CTRL groups did not differ behaviorally, they exhibit differential neural activation patterns in tasks

related to narrative comprehension and social cognition. Further investigations may inform the development of educational and psychosocial interventions to improve academic and social functioning in young adults with ADHD.

Keywords: attention-deficit/hyperactivity disorder, ADHD, reading comprehension, narrative comprehension, social cognition, theory of mind, ToM, college students, functional magnetic resonance imaging, fMRI

Exploring the Neural Correlates of Reading Comprehension and Social Cognition Deficits in

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Reading, to many, is a simple act of enjoyment. Reading *fiction*, in particular, provides a blissful means for escape, for the characters to seduce and beguile a reader into worlds she may not otherwise encounter, and for her to in turn place herself among the intimate thoughts and beliefs of her new friends and foes. The reader not only identifies and empathizes with the characters, but also transcends her *self*, as it is displaced from her usual way of being and re-contextualized in novel and unknown contexts (Djikic, Oatley, Zoeterman, & Peterson, 2009; Oatley, 2011). Ultimately, fiction can serve as an instrument for investigating ideas of self and relationships by allowing one to explore the minds of others, and for attaining ascetic and aesthetic values by facilitating the process of contextualizing the self in external, unfamiliar realms of thought (Stock, 2007).

A brief review of the scientific work aimed at better understanding the neurological mechanisms and systems underlying the reading experience reveals that it is a rather complex process. When presented with a literary story, the reader must assess the orthography (i.e., written symbols and ways in which they can be combined), phonology (i.e., sounds of language), and semantics (i.e., meanings of words) of the written text (Devlin, Matthews, & Rushworth, 2003; Pugh et al., 1996; Rumsey et al., 1997), and simultaneously maintain attention (Samuels & Edwall, 1981; Smallwood, McSpadden, & Schooler, 2008), encode information into working memory (Savage, Lavers, & Pillay, 2007; Unsworth & McMillan, 2013), and recognize and empathize with characters' emotions (Pavias, 2014). In other words, successful understanding of fiction requires a coordination of cognitive abilities across multiple domains: executive function, reading comprehension, and social cognition (Locascio, Mahone, Eason, & Cutting, 2015;

Pavias, 2014; Sesma, Mahone, Levine, Eason, & Cutting, 2009). Deficits in any of these

domains may compromise the reading experience to varying degrees.

Social Cognition and ADHD

Several clinical populations show deficits in reading comprehension and social cognition,

including Attention-Deficit/Hyperactivity Disorder (ADHD). ADHD is a neurodevelopmental

disorder characterized by inattention and hyperactivity/impulsivity (American Psychiatric

Association, 2013). Symptoms of ADHD may manifest in childhood and persist into adolescence

and adulthood (Biederman, Petty, Evans, Small, & Faraone, 2010; Biederman, Petty, O'Connor,

Hyder, & Faraone, 2012), and are associated with impairments in academic and social

functioning (Ek, Westerlund, Holmberg, & Fernell, 2011; Weyandt et al., 2013). The

convergence of these impairments are seen in lower academic and professional attainment

(Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2015; Kuriyan et al., 2013).

Social cognition refers to the ability to understand the minds of others, and encompasses

several components: encoding, representation, and interpretation of social cues, affect

perception, emotion recognition, theory of mind (ToM), empathy, and humor processing

(Uekermann et al., 2010). Deficits in social cognition, in addition to inattention and

hyperactivity/impulsivity, have recently been identified as an independent risk factor for

interpersonal problems in ADHD (Sibley, Evans, & Serpell, 2010). For example, children with

ADHD often display social incompetence that manifests in behaviors such as abruptly shifting

and interrupting conversations, not listening to others, and initiating conversations at

inappropriate times (DuPaul, Morgan, Farkas, Hillemeier, & Maczuga, 2016). Such social rule-

breaking often leads children with ADHD to experience peer relationship difficulties and social

rejection (Hoza, 2007; Mrug et al., 2012). Social functioning impairments have likewise been

documented in adults with ADHD, such as difficulties with forming and maintaining

relationships with coworkers, supervisors, friends, or romantic partners (Lefler, Sacchetti, & Del

Carlo, 2016; Sacchetti & Lefler, 2014; Shaw-Zirt, Popali-Lehane, Chaplin, & Bergman, 2005).

Additional to these behavioral findings, deficits in sub-components of social cognition

are also found in ADHD. Children with ADHD are more likely than their peers without ADHD

to demonstrate deficits in prosody detection, affect perception, and emotion recognition (Corbett

& Glidden, 2000; Shapiro, Hughes, August, & Bloomquist, 1993; Sinzig, Morsch, & Lehmkuhl,

2008). Studies of higher social cognitive processes in children with ADHD have, however,

yielded inconsistent results, with some offering support for intact ToM and empathy (Charman,

Carroll, & Sturge, 2001; Dyck, Ferguson, & Shochet, 2001) and others against (Buitelaar, van

der Wees, Swaab-Barneveld, & van der Gaag, 1999; Caillies, Bertot, Motte, Raynaud, & Abely,

2014).

Interestingly, distinction between explicit ToM (i.e., ToM that is conceptual, operational,

and logical) and applied ToM (i.e., ability to use ToM knowledge in real-world social situations)

may help to explain ambiguity in ToM performance findings in children with ADHD (Hutchins

et al., 2016). In a study of boys between approximately 6 and 14 years of age, Hutchins et al.

(2016) utilized Theory of Mind Task Battery (ToMTB; Hutchins, Prelock, & Bonazinga, 2014;

Hutchins, Prelock, & Chace, 2008) and the Theory of Mind Inventory (TOMI; Hutchins,

Prelock, & Bonazinga, 2012; Hutchins et al., 2008) to assess explicit and applied ToM

competence, respectively. The authors reported that the ADHD subjects had comparative explicit

ToM competence but deficient applied ToM competence compared to healthy peers. Such results

led the authors to conclude that perhaps children with ADHD, who may have intact explicit

ToM, are unable to apply this knowledge in real-world situations.

Studies on social cognition in adolescents and adults with ADHD, though few, have found similar deficiencies (Uekermann et al., 2010). Sibley et al. (2010) have shown that adolescents with ADHD reported difficulties in peer relations and exhibit deficits on social cognitive tasks (e.g., comprehension of cause and effect in social situations, hostile attribution bias, social problem solving) compared to those without ADHD. Levels of ADHD symptomatology have also been found to be positively correlated with increased social impairments in college students with ADHD (Sacchetti & Lefler, 2014). With regards to specific social cognition deficits, affect recognition (Miller, Hanford, Fassbender, Duke, & Schweitzer, 2011), facial emotion processing (Ibáñez et al., 2011), and ToM (Buitelaar et al., 1999; Nydén et al., 2010) have reported to be impaired in adults with ADHD.

Prosocial interactions with friends are a major source of academic and mental support for college students with ADHD (Meaux, Green, & Broussard, 2009). Possessing social cognitive abilities and developing prosocial relationships with peer groups are therefore crucial for success during college years. Considering the importance and centrality of social life in the college setting, understanding social cognition as it pertains to academic success using objective measures in college students is valuable.

Reading Comprehension and ADHD

Children with ADHD who exhibit academic underachievement are found to perform poorly on reading assessments (Busch et al., 2002; DuPaul et al., 2016). Studies on reading comprehension proficiency in ADHD have reported reading comprehension weaknesses in children with ADHD relative to their peers. For example, they are less likely to identify the main ideas in texts (Brock & Knapp, 1996), answer fewer comprehension questions correctly (Stern & Shalev, 2013), and are more likely to show poorer word reading (Cain & Bignell, 2014),

phonological processing (Laasonen, Lehtinen, Leppämäki, Tani, & Hokkanen, 2010), and silent

reading comprehension (Ghelani, Sidhu, Jain, & Tannock, 2004).

Considering such reading comprehension deficits in children with ADHD, it is

unsurprising that adolescents with ADHD have significantly lower academic performance and

are less likely to attend or complete college than their non-ADHD peers (Breslau, Miller, Joanie

Chung, & Schweitzer, 2011; Ek et al., 2011). Those young adults with ADHD who do pursue

secondary education are also more likely to withdraw from courses, drop out, and report lower

grade point averages than their healthy peers (Advokat, Lane, & Luo, 2011; Gormley, DuPaul,

Weyandt, & Anastopoulos, 2016).

A handful of studies have found no discernible difference in reading comprehension

performance between college students with and without ADHD using standardized assessments

(e.g., Lewandowski, Gathje, Lovett, & Gordon, 2013; Miller, Lewandowski, & Antshel, 2015).

However, a qualitative study of college students with ADHD reported that reading difficulty is

part of a myriad of multifaceted academic challenges (Lefler et al., 2016). Subjects in this study

made statements such as "I would just read a book, but it's like you're not even comprehending

it. It's like you see the words and you know what the word is, but you don't know what's going

on in the book," and "My comprehension is what gets me. … I'll read an entire page and then …

I'll have to go back and start all over again." Since the genres of the reading materials described

by these subjects are not explicitly stated in the study, it is unclear whether to attribute their

reported difficulty in comprehension to nonfiction (e.g., textbooks or peer-reviewed articles) or

fiction (e.g. short stories or novels) reading. It is clear, however, that college students with

ADHD do suffer from difficulties with reading. While this can be partially due to deficits in

executive functioning, especially with regards to attention and working memory (Georgiou &

Das, 2016), the role of social cognition in text comprehension has not yet been investigated in individuals with ADHD.

Neural Correlates of Social Cognition and Narrative Comprehension

Reading comprehension and social cognition, or more specifically, narrative comprehension and ToM, are elements that contribute to a holistic reading experience (see above). Narrative comprehension is the process by which one understands stories presented as a thematically-ordered sequence of actual or fiction events through discourse-level language (written or spoken text) (Mar, 2011). ToM is a higher-order social cognitive process that enables one to make first-order mental state inferences (i.e., assessing another person's emotions, beliefs, and intentions) and second-order mental state inferences (i.e., assessing another person's thoughts on others' emotions, beliefs, and intentions) (Premack & Woodruff, 1978). Functional magnetic resonance imaging (fMRI) studies on the neural basis of ToM have identified a "mentalizing network" comprised of brain regions that support mental state inferences. This network includes the medial prefrontal cortex (mPFC), posterior cingulate cortex (pCC), precuneus, and bilateral temporoparietal junction (TPJ) (Frith & Frith, 2003; Kanske, Böckler, Trautwein, & Singer, 2015; Vogeley et al., 2001).

Mar recently reported a quantitative meta-analysis of ToM and narrative comprehension neuroimaging studies using the activation-likelihood estimation (ALE) approach to better identify these two networks and their overlapping neural regions (2011). This analysis broadened the mentalizing network to include mPFC, bilateral posterior superior temporal sulci (pSTS; including bilateral angular and supramarginal gyri), bilateral TPJ, bilateral middle temporal gyri (MTG), bilateral superior temporal sulci (STS), pCC, precuneus, left inferior frontal gyrus (IFG), and bilateral parahippocampal gyri (PHG). This meta-analysis also identified a narrative

comprehension network including the mPFC, bilateral IFG, MTG, STS, and superior temporal

gyri (STG), TPJ, left PHG, and cerebellum. Finally, a conjunction analysis of the ToM and

narrative comprehension networks revealed that they overlapped in the mPFC, bilateral

pSTS/TPJ, bilateral anterior MTG, and left IFG. Overall, these meta-analytic findings confirm a

shared neural processing pathway for both ToM and narrative comprehension (Mar, 2011). This

commonality is further supported by behavioral findings that reading literary fiction is helpful in

improving affective and cognitive ToM (Kidd & Castano, 2013). Such convergence suggests that

fiction may be a framework within which the relationship between narrative comprehension and

ToM may be assessed.

The Current Study

Given the reading-intensive nature of university coursework and the socially active

environment of the college campus, there exists a need to address the gap in empirical literature

examining the relationship between general reading comprehension and social cognition, and

more specifically, that between narrative comprehension and ToM in college students with

ADHD. To date, no such study has been published. Fiction may serve as a simulation of social

experiences (Mar & Oatley, 2008) and necessitates intact narrative comprehension and ToM (see

above), The current investigation thus utilized fiction as an instrument to examine the neural

correlates of and relationship between the two processes in young adults with and without

ADHD. To this end, tasks were administered to characterize differences in reading

comprehension (NDRT; Brown, Fishco, & Hanna, 1993) and social cognition (Faux Pas

Recognition Test, FPRT; Baron-Cohen, Riordan, Stone, Jones, & Plaisted, 1999; Gregory et al.,

2002; Stone, Baron-Cohen, & Knight, 1998) between college students with and without ADHD.

Then, a modified Short Story Task (SST; Dodell-Feder, Lincoln, Coulson, & Hooker, 2013),

which incorporated an additional short literary fiction with high prose complexity, was administered during functional magnetic resonance imaging (fMRI) to measure neural activity involved in narrative comprehension and ToM processing.

This study was designed to test the following hypotheses: 1) Both reading comprehension and social cognition would be deficient in ADHD compared to the control (CTRL) group using standardized tests (NDRT and FPRT); 2) group-difference in narrative comprehension and ToM performance, assessed by the SST, would be observed for the story with high prose complexity, but not for that with low prose complexity; 3) no group-difference in narrative comprehension and ToM networks would been seen while reading a text with more simplistic prose, and 4) the ADHD group would exhibit reduced activation in both the narrative comprehension and ToM networks while reading a text with higher prose complexity.

Materials and Methods

The current investigation was a between-subject, cross-sectional study which examined narrative comprehension and ToM and compared cortical activation patterns during performance on a modified Short Story Task in college students with ADHD compared to healthy controls. The Institutional Review Board of the University of Vermont (UVM) approved the study procedures. All participants provided written informed consent.

Volunteers were recruited through UVM's Accommodations, Consultations, Collaboration, and Educational Support Services (ACCESS); advertisements on public bulletin boards on UVM campus and UVM e-newsletters ("UVM Announcements and Events" and "This Week in the Honors College"), and a review of past participants in previous studies conducted by Dr. Potter's laboratory who had given written consent to be contacted for additional research opportunities.

Twenty-six telephone screenings were conducted and 13 subjects were enrolled in the study. Volunteers were excluded due to any of the following conditions: presence of non-removable metals in or on the body; history of traumatic brain injury or other surgery or injury involving metals, or non-right-handedness. All participants reported English as their first language. The ADHD group was recruited by self-report of ADHD diagnosis and further characterized with an ADHD rating scale (see screening procedures).

Enrolled participants comprised 4 young adults with ADHD (0 male:4 females) and 9 controls (3 males:6 females), all of whom were full-time UVM students between the ages of 18 and 25 years (refer to Table 1 for a summary of sample characteristics).

Screening Procedures

Screening procedures were conducted after obtaining informed consent at the UVM Medical Center's Clinical Research Center (CRC). Subjects underwent further psychological assessments including the Vocabulary and Matrix Reasoning subscales of the Wechsler Abbreviated Intelligence Scale (WASI; Wechsler, 1999) to obtain an estimated full-scale intelligence quotient (a score of <70 was exclusionary). The Conners' Adult ADHD Rating Scale–Self-Report: Long Version (CAARS-S:L; Conners, Erhardt, & Sparrow, 1998) was administered to measure ADHD symptoms. A T-score of >65 on the "DSM-IV Total ADHD Symptom" subscale was considered inclusionary in the ADHD group. Subjects were then administered tasks of reading comprehension (Nelson-Denny Reading Test) and social cognition (Faux Pas Recognition Test; see below). Finally, a brief confirmatory screening for MRI safety, including a written medical screen and urine pregnancy test (for females; a positive result was exclusionary), was conducted. If a subject's participation was split into two visits, medical screening procedures were conducted the day of and prior to the fMRI scan.

Nelson-Denny Reading Test (NDRT; Brown, Fishco, & Hanna, 1993). Subjects'

reading comprehension was assessed by the NDRT, which is a standardized measure of reading

ability and rate among high school and college students. It includes two subtests, Vocabulary and

Comprehension, only the latter subtest was used in the current study. The Comprehension subtest

requires examinees to read 7 short passages drawn from high school and college textbooks and to

respond to 38 multiple-choice questions about these passages within 20 minutes. Some questions

require understanding of factual contents, others require the ability to make logical inferences

based on information explicitly stated in the passages. Reading rate is assessed in the first minute

of reading the first passage. Raw scores of reading comprehension and reading rate were

translated to T-scores normalized against peers at the national level. The NDRT was

administered outside the fMRI scanner.

Faux Pas Recognition Test (FPRT; Baron-Cohen, Riordan, Stone, Jones, & Plaisted,

1999; Gregory et al., 2002; Stone, Baron-Cohen, & Knight, 1998). Subjects' social cognition

was assessed using the FPRT, which includes 5 subscales (Faux Pas Detection,

Inappropriateness, Intentions, Beliefs, and Empathy). This test includes 20 short vignettes, 10 of

which contain incidents of faux pas (someone mistakenly saying something offensive or

awkward). Each vignette is accompanied by 2 control questions about general story

comprehension and 6 social questions pertaining to the faux pas. Scoring was performed

according to protocol developed by Baron-Cohen et al.

Study Procedures

After the screening procedures were completed, the subjects underwent a training session

using a MRI simulator located in the CRC that was similar to the real MRI machine in size and

shape. This portion of the study visit was implemented with goals to reduce subjects' risk of

anxiety and potential for unanticipated reactions, such as claustrophobia, by allowing them to become familiarized with the MRI procedures and equipment. Subjects were then screened again for safety concerns by a MRI technologist prior to entering the scanner located in UVM Functional Brain Imaging Facility for the 60-minute imaging session, during which anatomical and functional scans were obtained.

Short Story Task (SST; Dodell-Feder, Lincoln, Coulson, & Hooker, 2013). An adapted Short Story Task (SST) was used to assess the relationship between narrative comprehension and ToM deficits while reading literary fiction during the fMRI procedure. Two stories of varying prose complexity (see below) were programmed in E-Prime 2.0 (Psychology SoftwareTools, Inc., Pittsburgh, PA, USA). Text was presented in 30-point Garamond font with double spacing on 10-inch by 7.5-inch PowerPoint slides converted into JPEG files. The stimuli were back-projected onto a screen that the subjects viewed via a mirror mounted onto the MRI head coil. Subjects were given 10 minutes to read each given story at their own pace. The order of the stories (simple vs. complex) was randomly assigned to each subject.

After the stories were read in the MRI scanner, the subjects were brought back to the CRC where they were asked 14 free-response questions regarding each story in a structured format. Subjects were given a copy of the stories and questions and allowed to refer back to them as needed in order to eliminate memory or attention demands. While administering the questions, the subjects were not provided any feedback regarding their responses, and they were free to respond at any length. Responses were recorded with a digital voice recorder. Scoring was completed by this author (IJS) and a Research Specialist in the Potter Lab (SLD) according to a scoring rubric that assigned greater points for accurate comprehension and mental state

attributions that included multiple characters' mental states. All stories were independently scored by the two raters; any rating disagreement was resolved through discussion.

Adaptation of SST. The original SST developed by Dodell-Feder, Lincoln, Coulson, and Hooker (2013) requires the subjects to read a literary, fictional short story called "The End of Something" by Ernest Hemingway and answer 9 free-response questions which assess spontaneous mental state inference and explicit mental state reasoning ability. To assess the level of story comprehension, 5 questions related to non-mental story content are also included. The adapted version used in the current study retains this original framework modified for reading in a scanner, and includes another short story, "Revenge" by Vladimir Nabokov, per recommendation made by the same Boston-based novelist with a PhD in English and expertise in 20th Century American Literature with whom Dodell-Feder et al. (2013) consulted in developing the original SST. This story was chosen due to its similarity in subject matter and ToM content with "The End of Something."

Stories used in the adapted SST. "The End of Something" by Ernest Hemingway and "Revenge" by Vladimir Nabokov are similar in that they both portray a nuanced interaction between a romantic couple who engages in a conflict and subsequently parts ways (see Supplemental Materials, Appendices A and B). Through the course of the stories, the characters display sarcasm, non-verbal and indirect communication, higher-order emotions (e.g., guilt), and attempt to hide their intentions and feelings from one another. The mental states of the characters are not explicitly stated, requiring the readers to make a series of first-order (i.e., inferring thoughts, feelings, and intentions of a single character) and second-order (i.e., inferring what one character believes about another character's thoughts, feelings, and intentions) mental state inferences in order to understand the social interactions between the characters and the "Why?"

questions of the stories. The prose of Hemingway's short story is simplistic, direct, and easily

understood, minimizing the possibility of verbal interference on ToM reasoning. Nabokov's

prose, however, is more complex and difficult than that of Hemingway, which allowed the

current study to assess the relationship between narrative comprehension skills and ToM

abilities.

   Questions and scoring rubric of the SST. Questions were designed to assess three

factors: (1) *Spontaneous mental state inference* (1 question, scored as 0 or 1); (2) *explicit mental*

state reasoning regarding characters' beliefs, emotions, intentions, and desires (8 questions,

scored as 0, 1, or 2), and (3) *comprehension* of the prose and story events without any mental

state content (5 questions, scored as 0, 1, or 2).

   The subjects were asked a single question to assess *spontaneous mental state inference*

("In just a few sentences, how would you summarize the story?"). Subjects' responses to this

question were coded as 0 or 1 depending on absence or presence of a mental state inference,

respectively.

   The scores for the explicit mental state reasoning questions were dependent upon the

accuracy of the mental state inference, number of character perspectives or emotions considered,

and understanding of non-verbal or indirect communications. Generally, second-order inferences

received more points than first-order inferences. A score of 2 was granted when second-order

inferences were made when applicable to the question; a score of 1 reflected first-order or only

partial inferences of the characters' mental states, and a score of 0 was given when an inaccurate

or accurate but irrelevant response was provided. An overall *mental state reasoning score* was

calculated as the sum of points from the eight mental state reasoning questions; the scores can

range of 0 (little to no understanding of story characters' mental states) to 16 (full understanding of story characters' mental states).

The scores for the comprehension questions were dependent upon the accuracy of the subject's response to questions probing non-mental state story comprehension. A score of 0 was assigned for responses that were obviously inaccurate; 1 for those that demonstrated partial comprehension, and 2 for those that demonstrated full comprehension. The *comprehension score*, which is the sum of scores from the five comprehension questions, can range from 0 (demonstrating no understanding of the story's non-mental state content) to 10 (demonstrating full understanding of the story's non-mental state content). This score was used to assess whether ToM was associated with general comprehension of the non-social aspects of the story.

Questions and scoring rubric for "Revenge". Questions for "Revenge" were devised in comparable construction and difficulty with those for "The End of Something." There were 1 spontaneous mental state inference question, 8 explicit mental state reasoning questions assessing subjects' understanding of the story characters' emotions, beliefs, and intentions, and 5 comprehension questions examining subjects' understanding of the non-social aspects of the story. These questions were distributed to 23 volunteers who provided responses via Google Forms. Responses were compiled and sorted into scores of 0, 1, and 2 according to original rubric guidelines outlined by Dodell-Feder et al. (2013). Complete administration materials and scoring instructions are included in Supplemental Materials, Appendix C.

MRI Scanner and Image Acquisition

All structural and functional MRI scans were acquired using a Philips Achieva high field 3-Tesla dStream MRI scanner at the UVM Functional Brain Imaging Facility. Subject used a handheld MR-compatible response grip with two buttons (ResponseGrip, NordicNeuroLab AS,

Bergen, Norway) placed in their right hand to "flip the page" with their right thumb while reading the two short stories in the SST. The duration of time that subjects spent on each page was recorded electronically in E-Prime via the ResponseGrip Interface Unit.

Subjects were equipped with earplugs and sound-attenuating headphones to mitigate the noise levels associated with MRI scanning. Each subject with corrected vision was provided with goggles with vision-correcting lenses suitable for his/her prescription prior to scanning.

Structural Imaging Acquisition Parameters. All subjects received the following two anatomical scans: (1) A sagittal T1-weighted spoiled gradient volumetric sequence oriented perpendicular to the long axis of the temporal lobes and anterior commissure-posterior commissure line (AC-PC line) using an echo time (TE) of 4.5ms, repetition time (TR) of 9.8ms, flip angle of 8 degrees, number signal averages (NSA) of 1.0, a field of view (FOV) of 256 × 256 mm^2, 320 × 320 matrix, and 0.8mm slice thickness with 0.8 × 0.8 resolution and no gap for 320 slices. The acquisition time for this sequence was 4:59 minutes. (2) A sagittal T2-weight Fluid-Attenuated Inversion Recovery (T2-FLAIR) was used to acquire 256 contiguous slices of 1.0mm thickness (TE = 302ms, TR = 4800ms, NSA = 1.0, and FOV = 256 × 256 mm^2, 256 × 256 matrix). The acquisition time for this sequence was 7:16 minutes. T2-FLAIR anatomical images were reviewed by a board-certified neuroradiologist to exclude intracranial pathology.

Functional Imaging Acquisition Parameters. T2*-weighted blood oxygen level-dependent (BOLD_ functional images were collected using a single-shot, Gradient-Echo, echoplanar pulse sequence in the axial plane (TE = 35mm, TR = 2000mm, flip angle = 90 degrees, 33 contiguous slices, slice thickness = 4.0mm, FOV = 240 × 240 mm^2, 64 × 64 matrix, 3.75 × 3.75 resolution). The reference scan for future slice selection within Talairach space was obtained along an axial oblique plane (parallel to the AC-PC line) using a spoiled gradient, T1-

weighted volumetric sequence (no gap, TR = 4ms, TE = 0.78ms, flip angle = 90°, 1 NSA, slice

thickness = 2.5mm). Field map correction for magnetic inhomogeneitites was accomplished by

acquiring images with offset TE at the end of the functional series.

Statistical Analysis

      Analysis of cognitive measures. A series of between-group analyses using independent-

sample *t*-tests compared the performance on NDRT, FPRT, and SST between ADHD and control

subjects. A 2x2 repeated measures ANOVA was conducted to examine the effects of group

(ADHD vs CTRL) and prose complexity (simple vs. complex) in the SST.

      Analysis of functional MRI. Images were analyzed using BrainVoyager (Formisano et

al., 2006). After volume realignment, further pre-processing comprised a correction for slice ×

time errors, as well as spatial (8-mm full-width half-maximum isotropic Gaussian kernel) and

temporal (high pass filter: 5 cycles/run) smoothing. Anatomical and functional images were co-

registered and normalized to Talairach space. Statistical analysis was performed by multiple

linear regression of the signal time course at each voxel. The expected BOLD signal change for

each story type was modeled by a canonical hemodynamic response function. Data was

individually analyzed for each subject using a pair-wise comparison of the mean BOLD signal

for each story (simple vs. complex). To examine between-group effects, the images from each

subject were fit to a second-level random effects analysis of group (ADHD vs. CTRL). In the

first step, voxel-wise statistical maps were generated, and predictor estimates and β-weights were

generated for each subject. In the second step, group analyses of these individual contrasts were

performed with *t*-tests. We adjusted for multiple corrections by first setting a $p < 0.005$ false

discovery rate (FDR)-corrected, and then applying a voxel-size cluster correction. This

correction was generated using 1000 Monte-Carlo simulations to estimate the cluster size with an alpha level set at $p < 0.05$.

Results

Of the 13 subjects enrolled, data obtained from one subject in the ADHD group were discarded due to excessive head movements during anatomical image acquisition, making functional neuroimaging data non-interpretable. ADHD and CTRL groups did not differ by age, GPA, or IQ; as expected, the ADHD group scored significantly higher on the DSM-IV Total ADHD Symptom subscale of the CAARS-S:L (Table 1).

Performance on Cognitive Measures

A series of independent sample *t*-tests showed that the ADHD and CTRL groups did not differ in reading comprehension score or reading rate as assessed by the NDRT (Table 2). There were no between-group differences on the FPRT, including the Faux Pax Detection, Inappropriateness, Intentions, Beliefs, or Empathy scores (Table 2).

Performance on the SST was analyzed using a repeated measures ANOVA with a within-subject factor of prose complexity (simple vs. complex) and between-subject factor of group (ADHD vs. CTRL). There was no main effect of group or prose complexity on spontaneous mental state inference or comprehension scores. No effect of group was observed for mental state reasoning. There was a trend for a main effect of prose complexity on mental state reasoning, with higher scores associated with the simple story (Table 3).

Functional Neuroanatomy Data

Between-group differences were observed while reading the simple story (Table 4). Compared to the CTRL group, the ADHD group showed increased activation in the right IFG

(Brodmann area 47; Figure 1) and right anterior cingulate gyrus (Brodmann area 32), and decreased activation in the left precuneus (Brodmann area 7), right cingulate gyrus (Brodmann area 32), and left declive in the cerebellum.

While reading the complex story (Table 5), the ADHD group exhibited increased activation in left PHG (Brodmann area 35) and left tuber in the cerebellum, and decreased activation in bilateral IFG (pars opercularis and pars triangularis; Brodmann areas 44 and 45; Figure 2), bilateral MFG (Brodmann areas 6, 8, and 9), bilateral superior frontal gyri (SFG, Brodmann areas 8 and 10), right medial frontal gyrus (Brodmann area 9) , right anterior cingulate gyrus (Brodmann area 24), left angular gyrus (Brodmann area 39) and MTG (Brodmann area 21), right middle occipital gyrus (Brodmann area 18) and lingual gyrus (Brodmann area 17), right insula (Brodmann area 13), left thalamus, and the cerebellum compared to the CTRL group.

In addition, the ADHD group, while reading the complex story compared to the simple story (Table 6), showed decreased activation in bilateral IFG (pars triangularis, Brodmann area 45; Figure 3), bilateral MFG (Brodmann areas 8 and 9), right superior temporal gyrus (Brodmann area 22), right insula (Brodmann area 13), right posterior cingulate gyrus (Brodmann area 31), right precuneus (Brodmann area 7), left MTG (Brodmann area 21) and angular gyrus (Brodmann area 39), as well as increased activation in the left PHG and anterior cingulate gyrus (Brodmann area 24), right caudate, left culmen, uvula, and tuber. The CTRL group did not exhibit any difference in neural activation while reading the complex story to the simple story.

Discussion

The current study examined reading comprehension and social cognition, and the relationship between the more specific domains of narrative comprehension and ToM in college

students with and without ADHD using fMRI. We found that the ADHD and CTRL groups did

not differ in reading comprehension or social cognition performance. The ADHD group

demonstrated similar narrative comprehension and ToM performance with the CTRL group. The

ADHD group exhibited differential neural activation patterns in the narrative comprehension and

ToM networks compared to the CTRL group while reading short stories with lower and high

prose complexities. Due to the limited sample size, especially in the ADHD group ($n = 3$), the

following discussion and interpretation of results should be considered with great caution.

No Group Differences on Standardized Tests of Reading Comprehension or Social

Cognition

The ADHD and CTRL groups, contrary to our first hypothesis, did not differ on reading

comprehension or social cognition. There was no group difference in reading comprehension or

reading rate as assessed by the NDRT. The current finding is consistent with results of a study

that utilized a modified NDRT and found that college students with and without ADHD had

comparable reading comprehension performance (Miller, Lewandowski, & Antshel, 2015).

Another study on test-taking performance in college students with and without ADHD also

found that the ADHD subjects did not differ from their peers in reading comprehension or

reading speed as examined by a reading abilities battery adapted from the SAT, ACT, and GRE.

(Lewandowski, Gathje, Lovett, & Gordon, 2013).

However, the current finding of comparable reading comprehension could be masked by

the limited sample size. Reading comprehension scores of the 3 ADHD subjects included in the

current study were placed in the 26th, 54th, and 77th percentile, while the CTRL subjects' ranged

from 20th to 88th percentile. There was a large variability in ADHD subjects' reading rates due to

one subjects' reading rate being in the 99th percentile. With the limited sample size, the analysis

may have been unduly sensitive to individual differences and variability in the data, and thus

leading to an uncertain estimate of reading comprehension abilities of our desired population.

Further efforts should be paid to increase the sample size and power of the statistical analyses in

order to ascertain the true nature of reading comprehension performance in college students with

ADHD.

In addition to increasing the sample size, future studies should also consider utilizing

other standardized assessments for reading comprehension. Though the NDRT's reliability and

validity have been established on a national level (Brown et al., 1993), it has been found that its

reading comprehension questions may be answered correctly with overall accuracy rates that are

well-above chance for university students with and without at-risk status for learning disabilities,

suggesting that the NDRT may not possess adequate sensitivity to detect reading disabilities

(Coleman, Lindstrom, Nelson, Lindstrom, & Gregg, 2010; Ready, Chaudhry, Schatz, &

Strazzullo, 2013). In the context of current investigation, the NDRT may not be sensitive to

reading comprehension deficits in the ADHD subjects, who were college students and without

any other learning or reading disability.

Prior to conducting the study, other standardized tests which probe reading abilities in

adults, such as the SAT, GRE, and Medical College Admission Test (MCAT) were deemed

inapplicable. The SAT is designed to assess reading comprehension level of students prior to

college admission, which was thought to be inadequate in assessing reading abilities in

matriculated students. The GRE and MCAT, on the other hand, are devised for students who

have completed most of their undergraduate curricula prior to pursuing graduate-level education,

rendering them too difficult for average undergraduate students and inapplicable for use in the

desired study population. Such standardized tests would be applicable if the study purposes

include identifying high-achieving performers; however, within the context of the current study, the aim of which was to determine whether reading comprehension deficits could be observed in college students with ADHD, use of a standardized assessment of reading abilities specific for the college population (i.e., NDRT) was more applicable.

The ADHD and CTRL groups demonstrated comparable performance on the FPRT, whose subscales assessed different subcomponents of social cognition. This is consistent with findings that ToM and empathy are intact in individuals with ADHD (Charman et al., 2001; Dyck et al., 2001), and does not support there being deficits in these subcomponents of social cognition for adults with ADHD (Buitelaar et al., 1999; Caillies et al., 2014; Gonzalez-Gadea et al., 2013). However, intact social cognition is unlikely considering that social functioning impairments are documented in adults with ADHD (Lefler et al., 2016; Sacchetti & Lefler, 2014; Shaw-Zirt et al., 2005). It could be that while adults with ADHD have intact ToM knowledge, they experience difficulty in applying it in real-world social situations. Perhaps a distinction between explicit and applied ToM, as Hutchins et al., 2016 had made in examining ToM in children with ADHD, can also be investigated in adults with ADHD. Again, the small sample size limits the ability to draw any firm conclusion regarding social cognition ability in college students with ADHD.

There are several possible limitations with the FPRT as an assessment tool. The questions following each vignette, designed to probe subcomponents of social cognition in the FPRT, are repetitive, and potentially overly explicit and leading. In a socially nuanced situation in the real-world, one is required to assess and react spontaneously to the situation after analyzing and determining the nature of the faux pas. The FPRT's questions are thus somewhat prompting as the subject, upon being asked "Did anyone say something they shouldn't have said or something

awkward?", would be prompted in the direction of thinking that there may be a faux pas in the vignette.

Moreover, FPRT employed in the current study is "roughly based on the children's version of the test" (Baron-Cohen et al., 1999), therefore the vignettes containing the faux pas and questions probing social cognition in the adult FPRT may be too explicit and simplistic in nature. For instance, consider Story 12 in which Joe pokes fun at a new classmate Mike in a bathroom where Mike is in a stall, unseen by Joe and his friend Pete. The faux pas presented in this story is rather clear and straight-forward: Joe says something he should not have said because Mike is actually in a stall and overhears the hurtful remark. Although the vignettes' short length and simple language are useful in reducing attention and working memory demands, the nuance of the situations depicted in the stories are rather rudimentary, and therefore may not be adequately sensitive to detect social cognition deficits in young adults with ADHD.

Other assessments of social cognition, such as the false belief task (Wimmer & Perner, 1983) and Happé Strange Stories test (Happé, 1994) were considered prior to conducting the study. The former examines the contrast between the reality and an individual's belief about the world; the latter is an advanced test of ToM that includes vignettes involving lie, white lie, joke, pretend, misunderstanding, persuade, appearance/reality, figure of speech, sarcasm, forget, double bluff, and contrary emotions. However, considering that the false belief task is designed for children, and Happé Strange Stories test for probing ToM only, such measures were deemed incongruent with the study's goals of assessing social cognition as a global measure in young adults. Reading the Mind in the Eyes test (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) was also considered. In keeping consistent with the study's goal, which was to examine the relationship between narrative comprehension and social cognition, and therefore required a

narrative-based measure of social cognition, using the Reading the Mind in the Eyes test would be more suitable for studies aiming to assess ToM from a visual processing approach.

There appears to be a need for a standardized reading comprehension test for adults, especially one that is solely specific to the college level. Other tests probing social cognition described above could also be used in further investigations either as alternatives to or in conjunction with FPRT.

Narrative Comprehension and ToM

To the best of our knowledge, this is the first study using fiction to examine narrative comprehension and ToM simultaneously in ADHD. We found no group differences in narrative comprehension and ToM performance assessed by the SST. Given that the two groups did not differ by IQ or GPA, or in reading comprehension and social cognition, it is likely that the ADHD subjects are high-functioning and have developed academic and social strategies to achieve similar narrative comprehension and ToM performance as the CTRL subjects. However, our sample may be biased as it is likely that only high-functioning ADHD individuals were recruited (i.e., ADHD individuals who perform well academically may actively seek out research opportunities more than those who do not perform well). However, the small sample size does not allow for a conclusion to be reached regarding narrative comprehension or ToM differences in college students with ADHD.

While there was not an effect of prose complexity on narrative comprehension, there was a near-significant trend on mental state reasoning, with higher scores associated with the story with simple prose. This suggests that across all subjects, making first- and second-order inferences for the story with higher prose complexity was more difficult than doing so for the story with lower prose complexity. With a larger sample size, one may potentially see a

significant difference in mental state reasoning scores between the stories. In addition, further testing such as that done by (Dodell-Feder et al., 2013) could be beneficial in improving the reliability and construct validity of the modified SST.

Group Differences in Functional Neuroanatomy

Contrary to our hypothesis, the ADHD subjects, compared to the controls, demonstrated hyperactivity in the right IFG and hypoactivity in the right ACC and left precuneus while reading the text with lower prose complexity. It has been reported that the ACC plays a critical role in emotional awareness (Lane et al., 1998). It has also been found that the ACC and precuneus are consistently involved in the ToM but not the narrative comprehension network, and the opposite is suggested for the right IFG (Mar, 2011). Thus, keeping in mind the limited sample size, the hypoactivity observed in the right ACC and left precuneus, along with hyperactivity in the right IFG may collectively and tentatively suggest that even while reading the story with a low prose complexity, the ADHD subjects required increased neural recruitment than the control subjects in comprehending the narrative portion and less of the ToM portion of the story. Additionally, the right IFG has recently been found to play a role in reorientation of attention (Japee, Holiday, Satyshur, Mukai, & Ungerleider, 2015). Again, with the small sample size as a caveat, this current finding could potentially indicate that the ADHD group needed increased neural resources to process the emotional components of this story as well as continuously reorienting their attention back to the story.

Consistent with our hypothesis, the ADHD group, compared to the CTRL group, demonstrated hypoactivity in a number of areas associated with both ToM and narrative comprehension networks, including the mPFC, bilateral pSTS/TPJ, bilateral anterior temporal areas, and the left IFG (Mar, 2011), while reading the story with higher prose complexity. The

ADHD group also showed hypoactivity in the right IFG and cerebellum and hyperactivity in the left PHG, which are regions involved in the narrative comprehension network but not the ToM network, as well as hypoactivity in the pCC/precuneus, which are regions involved in the ToM network but not the narrative comprehension network (Mar, 2011).

The hypoactivity seen in pCC and precuneus is not surprising. The pCC and precuneus are consistently involved in neuroimaging studies of ToM (Mar, 2011; Spreng, Mar, & Kim, 2008). More specifically, these regions are also involved in tracking causal situational changes (Speer, Reynolds, Swallow, & Zacks, 2009) and perspective taking (Mano, Harada, Sugiura, Saito, & Sadato, 2009), both of which play a role in social cognition (Ruby & Decety, 2004; Uddin, Iacoboni, Lange, & Keenan, 2007).

In addition to being known as the Broca's area, the left IFG has also been associated with processing of syntactic complexity (Caplan, 2006), reappraisal of others' intentions (Grecucci, Giorgetta, Bonini, & Sanfey, 2013), and perception of biological motion (Schubotz & von Cramon, 2004), suggesting that this region is involved in both language processing, social cognition, and possibly possesses a "mirroring" property. Although this latter finding regarding IFG's "mirror neurons" could potentially support the idea that these mirror neurons enable simulation of others' actions and therefore contributes to ToM and other subcomponents of social cognition (Blakemore & Frith, 2005), there is also evidence that the ToM network and mirror neuron network, though may be interactive (Sperduti, Guionnet, Fossati, & Nadel, 2014), are indeed separate systems (Van Overwalle & Baetens, 2009). The above findings, while being mindful that their interpretation and generalizability are limited by the current study's sample size, may suggest that when encountering texts with complex prose, ADHD subjects may experience deficits in both ToM and narrative comprehension.

It is interesting to find that that the left PHG is the sole hyperactive region in the ADHD

group compared to the CTRL while reading the story with a higher prose complexity. Recent

studies on cognitive correlates of amygdala activity, which has strong functional connections to

the PHG, have found that ADHD individuals demonstrate hyperactivity in the amygdala when

shown emotion-neutral faces when compared to those without ADHD (Brotman et al., 2010).

The current finding of hyperactivity in the left PHG, which is involved in the narrative

comprehension network (Mar, 2011) and response to perceived fearful stimuli (Brotman et al.,

2010), may suggest that the ADHD group required more neural recruitment to understand and

reacted more emotionally to the supernatural and perhaps fearful elements of the story (e.g.,

ghosts, skeleton, sudden and unexplained death of the professor's wife).

Study Limitations

Results of the current study and their interpretation and generalizability, as discussed

above, are limited by the small sample size. The cognitive and fMRI measures used in this study

and their analyses may have been sensitive to individual differences rather than representing true

group differences. This may have resulted in false differences or masked potentially true

differences in narrative comprehension and ToM network activation patterns between ADHD

and CTRL groups.

The ADHD group was comprised of only females, which is a confounding variable. A

study assessing test-taking skills in college students with ADHD examined a sample of students

that differed significantly in sex distributions between ADHD (21 men and 14 women) and

comparison (64 men and 121 women) groups, but found no sex-based statistical significance in

reading comprehension scores (Lewandowski et al., 2013). This finding suggests that perhaps

inclusion of males with ADHD in the current study might not produce differential performance

in reading comprehension. However, further empirical studies of and consistent results in reading comprehension in the university setting could further elucidate whether there exists a sex difference in this domain between college students with and without ADHD.

Literature on gender differences in social dysfunction related to adult ADHD is limited (Barkley, 2014). In the healthy population, performance in social cognition and empathy tests is found to be better in males than females (Baron-Cohen & Wheelwright, 2004; Eisenberg & Lennon, 1993; Hall, 1978; McClure, 2000). Experimental studies have also found that females are generally better at decoding emotional expressions from faces and eye regions (Alaerts, Nackaerts, Meyns, Swinnen, & Wenderoth, 2011; Kothari, Skuse, Wakefield, & Micali, 2013). With regards to ADHD, boys are more likely to behave aggressively than their female peers, and this tendency is strongly associated with difficulties in peer relations (Bagwell, Molina, Pelham, & Hoza, 2001; Carlson, Tamm, & Gaub, 1997). One particular large study of college students with ADHD has found that college women with ADHD reported higher rates of impairment in daily home and social lives (Fedele, Lefler, Hartung, & Canu, 2012). The underlying cognitive mechanisms that result in this gender difference may be elucidated by further empirical studies on social cognition and potential sex differences in adults with ADHD.

Using fMRI as an analysis method also has its limitations. Neurophysiological studies have found that BOLD signals are correlated with action potentials (Heeger, Huk, Geisler, & Albrecht, 2000; Rees, Friston, & Koch, 2000), and, when combined with electrophysiological recordings, they are closely related to local field potentials, which reflect summation of post-synaptic action potentials (Logothetis, 2003). The underlying assumption regarding the BOLD signal is that it is a surrogate measure of neural response reflected by cerebral blood volume, cerebral blood flow, and oxygen consumption. The BOLD contrast mechanism is also dependent

upon cell types, neuronal circuitry, and hemodynamic response efficiency (Logothetis &

Wandell, 2004). Therefore, while the BOLD signal reflects the neuronal input to relevant areas

of the brain with regards to certain processes, one cannot infer the nature of such input (e.g.,

inhibitory or excitatory) based on the BOLD signal alone. The current study may be improved by

utilizing fMRI in conjunction with other more invasive techniques with better temporal

resolution, such as positron emission tomography (PET) or electroencephalogram (EEG) in order

to yield more explicit results and definitive interpretations.

Despite these limitations, we believe this research to be feasible and promising, and are

confident that continuing this research project to its completion is a worthwhile and valuable

endeavor.

Conclusions

The current study explored reading comprehension and social cognition by interrogating

the relationship between the specific domains narrative comprehension and ToM in college

students with and without ADHD. Results showed that, although the ADHD subjects had

comparable performance on reading comprehension and social cognition tests, these subjects

exhibited hypoactivity in brain regions involved in narrative comprehension and ToM networks

while reading a text with high prose complexity compared to the CTRL group. Due to the limited

sample size, particularly that of the ADHD group, we hesitate to make any definitive conclusions

about these differences, but are encouraged in value of the research question and hope to

continue this line of research.

Possessing intact reading and social cognitive abilities are crucial in the wellbeing of

young adults, especially in the college setting in which courses are reading-intensive and the

environment is largely socially-driven. Deficits in either of the domains would lead to academic

underachievement, lower professional attainment, and social difficulties and rejection (Mrug et al., 2012; Uekermann et al., 2010). Improvement of the aforementioned limitations would potentially lead to a better understanding of the ADHD diagnosis. Additionally, it would facilitate the development of more specific behavioral, educational, and psychosocial interventions, leading to improved learning abilities, self-esteem, social relationships, and overall quality of life.

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Table 1

Sample characteristics (mean, SD)

	CTRL ($n = 9$)	ADHD ($n = 3$)	Statistics	p-value
Sex (male:female)	3:6	0:3	$\chi^2(1) = 1.73$	0.50
Race				
Black/African American	1	0		
White/Caucasian	8	3		
Age	21.28 (0.82)	20.57 (1.66)	$t(10) = 1.02$	0.33
GPA	3.43 (0.40)	2.92 (0.50)	$t(10) = 1.82$	0.10
IQ*	120.00 (10.25)	118.00 (7.94)	$t(9) = 0.30$	0.77
ADHD Total Symptom	43.44 (8.23)	72.00 (12.53)	$t(10) = -4.63$	0.001

*One CTRL participant was familiar with measure and so valid IQ was not obtained. Abbreviations: GPA, grade point average; IQ, intelligence quotient

Table 2

Scores on Nelson-Denny Reading Test (NDRT) and Faux Pas Recognition Test (FPRT)
(mean, SD)

	CTRL ($n = 9$)	ADHD ($n = 3$)	Statistics	p-value
NDRT				
Reading Comprehension	230.89 (14.26)	225.67 (13.65)	$t(10) = 0.55$	0.59
Reading Rate	206.33 (17.35)	245.33 (60.39)	$t(10) = -1.88$	0.09
FPRT				
Faux Pas Detection Score	36.00 (4.69)	35.67 (4.93)	$t(10) = 0.11$	0.92
Inappropriateness	17.67 (2.45)	17.33 (2.89)	$t(10) = 0.20$	0.48
Intentions	15.11 (3.30)	11.67 (0.58)	$t(10) = 1.75$	0.11
Beliefs	17.11 (3.06)	16.67 (2.31)	$t(10) = 0.23$	0.82
Empathy	17.56 (2.74)	17.33 (3.06)	$t(10) = 0.12$	0.91

Table 3

Repeated measures ANOVA on Group (ADHD vs. CTRL) and Prose Complexity (Simple vs. Complex) (mean, SE)

Between-Subject						
Group	CTRL ($n = 9$)	ADHD ($n = 3$)	df	F	p	η^2
SPMI	0.33 (0.13)	0.50 (0.22)	1	0.42	0.53	0.04
MSR	10.56 (1.00)	7.00 (1.73)	1	3.17	0.11	0.24
Comprehension	8.56 (0.49)	7.67 (0.85)	1	0.81	0.39	0.08
Within-Subject						
Prose Complexity	Simple	Complex				
SPMI	0.28 (0.16)	0.56 (0.18)	1	1.65	0.23	0.14
MSR	10.06 (1.29)	7.50 (1.02)	1	4.63	0.06	0.32
Comprehension	8.61 (0.53)	7.61 (0.64)	1	2.50	0.15	0.20
Prose Complexity * Group						
SPMI			1	0.07	0.80	0.01
MSR			1	0.01	0.93	0.00
Comprehension			1	2.50	0.15	0.20

Abbreviations: MSR, mental state reasoning; SMSI, spontaneous mental state inference.

Table 4

Clusters resulting from the fMRI analysis of ADHD minus CTRL while reading text with simple prose

Laterality		Cluster Extent	BA	X	Y	Z
Hyperactivity						
	R	IFG	47	44.24	40.1	-9.94
	R	ACG	32	6.71	39.6	10.87
Hypoactivity						
	L	Precuneus	7	-5.12	-44.31	46.34
	R	Cingulate gyrus	32	2.23	18.12	30.75
	L	Declive		-11.86	-87.75	-22.55
				-35.27	-80.09	-22.81

Note: All BAs were estimated using the Talairach daemon and should be interpreted with caution. Coordinates are reported in Talairach space. Abbreviations: ACG, anterior cingulate gyrus; BA, Brodmann area; IFG, inferior frontal gyrus; L, left; R, right.

Table 5

Clusters resulting from the fMRI analysis of ADHD minus CTRL while reading text with complex prose

Laterality		Cluster Extent	BA	X	Y	Z
Hyperactivity						
	L	PHG	35	-18.40	-17.35	-9.51
	L	Tuber		-50.62	-61.80	-27.30
Hypoactivity						
R, L		IFG	44, 45	51.98	25.67	17.73
				-48.38	9.00	18.91
				-56.07	31.12	6.52
R, L		MFG	6, 8, 9	21.46	1.38	45.72
				26.71	30.64	24.19
				-25.34	12.00	37.24
R, L		SFG	8, 10	15.90	55.25	19.54
				-16.67	17.66	45.05
	R	mFG	9	7.18	42.95	29.56
	R	ACG	24	1.17	21.42	-5.19
	R	MOG	18	21.91	-84.81	-9.56
	R	Lingual gyrus	17	21.93	-91.56	-3.64
	R	Insula	13	36.91	-27.97	20.66
	L	Angular gyrus	39	36.91	-27.97	20.66
	L	MTG	21	-62.51	-53.56	3.24
	L	Thalamus		-15.93	-14.29	-1.96
R, L		Pyramis		15.99	-68.33	-29.84
				-23.2	-62.21	-30.94
	L	Cerebellar tonsil		-4.11	-52.42	-32.04

Note: All BAs were estimated using the Talairach daemon and should be interpreted with caution. Coordinates are reported in Talairach space. Abbreviations: ACG, anterior cingulate gyrus; BA, Brodmann area; IFG, inferior frontal gyrus; L, left; MFG, middle frontal gyrus; mFG, medial frontal gyrus; MOG, middle occipital gyrus; MTG, middle temporal gyrus; PHG, parahippocampal gyrus; R, right; SFG, superior frontal gyrus.

Table 6

Clusters resulting from the fMRI analysis of complex story minus simple story in the ADHD group

Laterality		Cluster Extent	BA	X	Y	Z
Hyperactivity						
	L	ACG	24	-5.97	9.25	33.01
	L	PHG		-26.91	0.96	-13.16
	R	Caudate		13.39	26.62	2.21
	L	Culmen		-39.54	-53.62	-26.09
	L	Uvula		-33.02	-80.24	-23.80
	L	Tuber		-46.40	-66.54	-29.27
Hypoactivity						
R, L		IFG	45	52.87	23.93	16.68
				-52.05	31.59	7.43
R, L		MFG	8, 9	18.37	23.42	41.82
				-26.99	22.73	34.68
				-46.17	9.13	21.06
	R	STG	22	48.86	-42.93	5.96
	R	Insula	13	41.59	-26.11	5.05
	R	PCG	31	5.73	-54.44	27.19
	R	Precuneus	7	4.34	-61.71	37.76
	L	MTG	21	-61.92	-55.39	3.23
	L	Angular gyrus	39	-48.94	-57.70	31.73
				-44.28	-53.26	14.99

Note: All BAs were estimated using the Talairach daemon and should be interpreted with caution. Coordinates are reported in Talairach space. Abbreviations: ACG, anterior cingulate gyrus; BA, Brodmann area; IFG, inferior frontal gyrus; L, left; MFG, middle frontal gyrus; MTG, middle temporal gyrus; PCG, posterior cingulate gyrus; PHG, parahippocampal gyrus; R, right; STG, superior temporal gyrus.
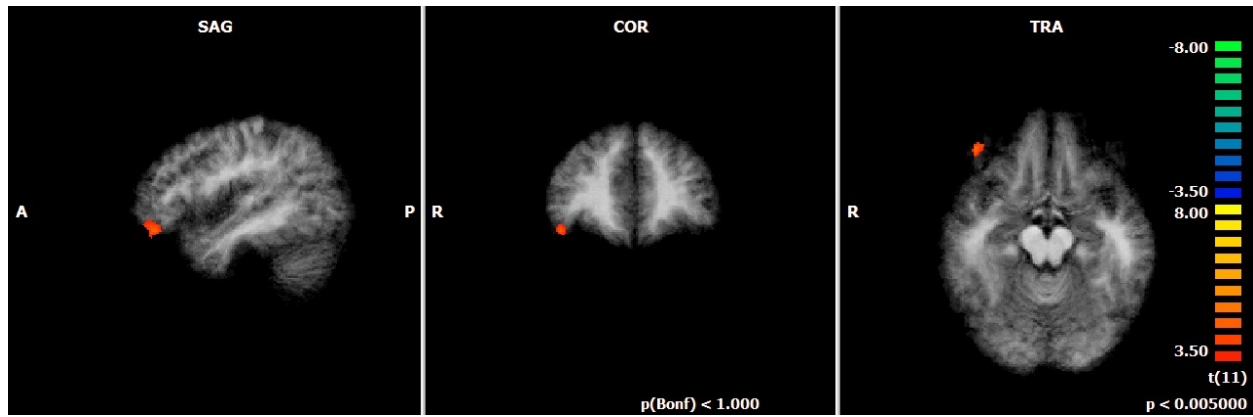
Figure 1. Results of fMRI contrasting ADHD and CTRL groups while reading the simple story. The ADHD group exhibited increased activation in BOLD activity within the right inferior frontal gyrus (red), $p < 0.005$, cluster threshold corrected.
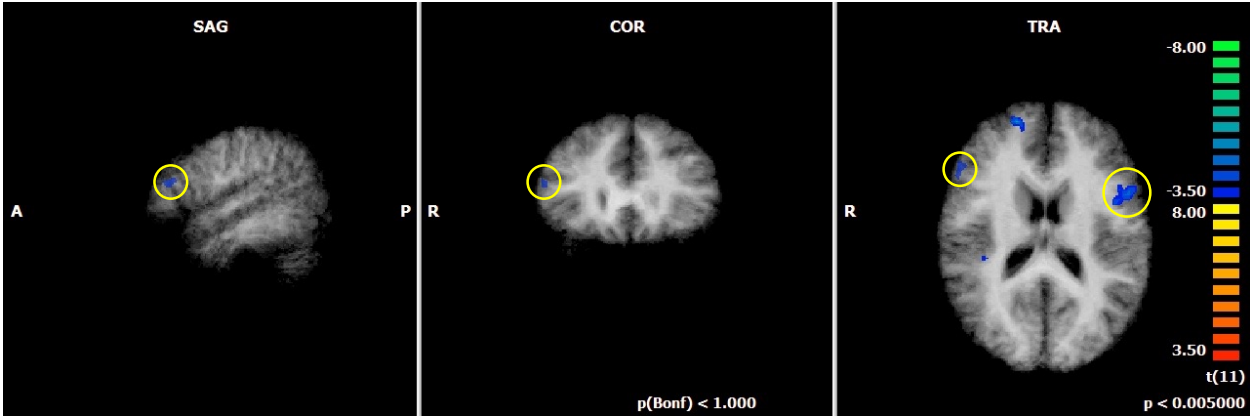
Figure 2. Results of fMRI contrasting ADHD and CTRL groups while reading the complex story. Circle indicates reduced activation in BOLD activity in right and left inferior frontal gyrus, *p* < 0.005, cluster threshold corrected.
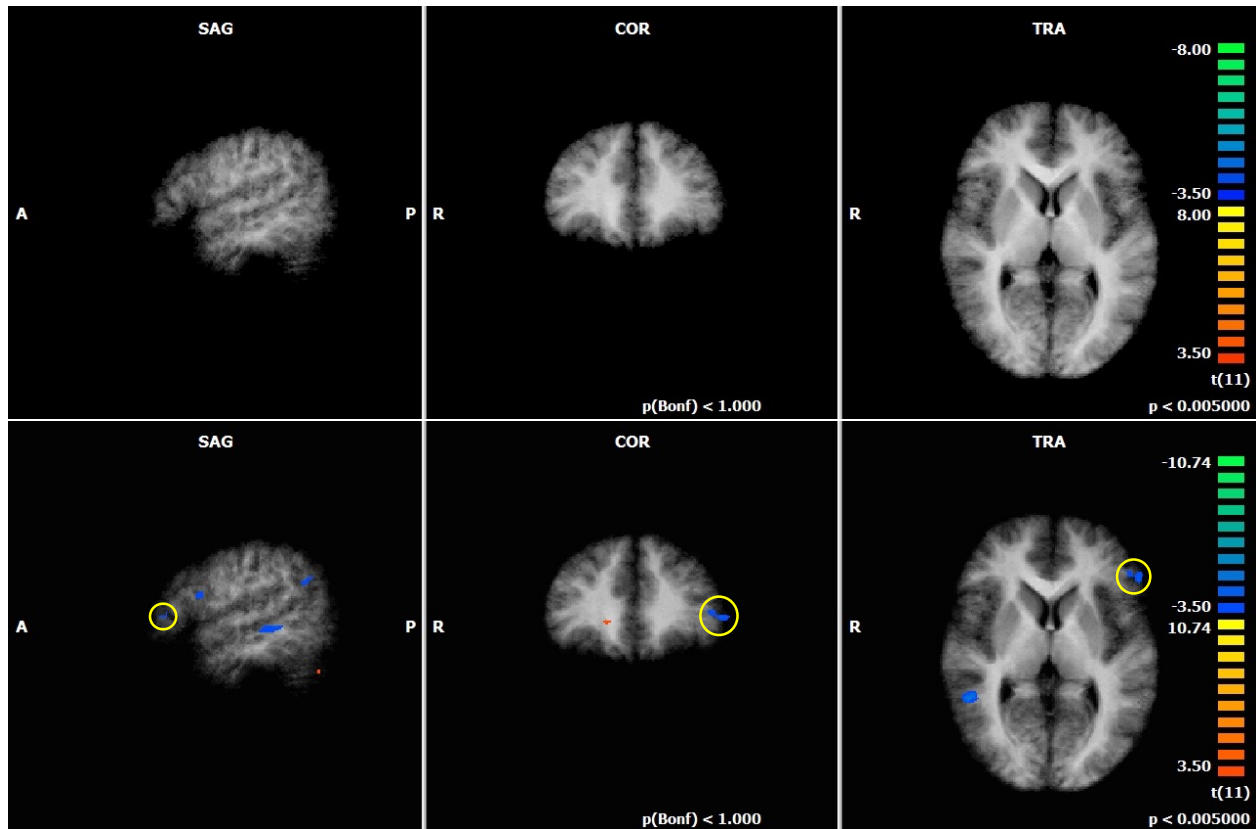
Figure 3. Results of fMRI contrasting complex story minus simple story in control (top) and ADHD (bottom) groups. The control group did not exhibit differential neural activation patterns between reading complex story and simple story. Circle indicates reduced activation in BOLD activity within the left inferior frontal gyrus, $p < 0.005$, cluster threshold corrected.