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Refining the Assessment of ADHD: The Relationship Between Self-Report and Observable Behavioral Symptoms

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Philadelphia College of Osteopathic Medicine

Department of Psychology

REFINING THE ASSESSMENT OF ADHD: THE RELATIONSHIP BETWEEN SELF-
REPORT AND OBSERVABLE BEHAVIORAL SYMPTOMS

By Bryan Gastelle, MS

Submitted in Partial Fulfillment of the Requirements of the Degree of

Doctor of Psychology

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**PHILADELPHIA COLLEGE OF OSTEOPATHIC MEDICINE
DEPARTMENT OF PSYCHOLOGY**

Dissertation Approval

This is to certify that the thesis presented to us by *Erison Castelle*
on the 15th day of May, 20 , in partial fulfillment of the
requirements for the degree of Doctor of Psychology, has been examined and is
acceptable in both scholarship and literary quality.

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Abstract

Individuals with adult attention-deficit/hyperactivity disorder (ADHD) present with deficits in attention, hyperactivity-impulsivity, or a combination of these symptoms. Functional impairment due to inattention, reduced motivation, poor impulse control, emotion dysregulation, and deficits in executive functioning are also frequently seen. Assessment of ADHD, using objective continuous performance tasks, has been introduced in conjunction with widely used self-report measures of ADHD symptom severity. The Conner's Adult ADHD Rating Scale (CAARS) is one such self-report measure of ADHD, consisting of 66 self-report items that measure symptoms of ADHD, including inattention, hyperactivity, impulsivity, and poor self-concept. The Quotient ADHD System purports to provide objective measures of ability to inhibit motor activity, maintain attention, and suppress impulsive responses. The Quotient ADHD System has been found to be sensitive to the pharmacologic effects of ADHD medication. Currently, there is a lack of empirical evidence for the Quotient ADHD System in an adult population, specifically, indicating a relationship between evaluations using the Quotient ADHD System and a widely accepted self-report measurement of ADHD, such as the CAARS. The present study determined that the global scaled score and motion scaled score metrics of the Quotient ADHD System correlate with the Hyperactive/Restlessness scale on the CAARS. Furthermore, the present study found a significant positive correlation between the Inattentive Metric of the Quotient ADHD System and the Inattention/Memory scale on the CAARS.

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Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a pervasive neurodevelopmental disorder that persists from childhood through adulthood for up to 60% of individuals (5th ed., DSM–5; American Psychiatric Association [APA], 2013; Agnew-Blais, Seidman, & Buka, 2013; Kessler et al., 2006; Rowland et al., 2015). According to the *Diagnostic and Statistical Manual of Mental Disorders*, Fifth Edition, (APA, 2013), ADHD is a persistent pattern of inattentiveness, hyperactivity-impulsivity, or a combination of the two.

According to the *DSM–5* criteria, a diagnosis of ADHD includes six or more symptoms in children, or five or more symptoms in adults, that persist for over 6 months and negatively impact academic, occupational, or social activities (APA, 2013). Symptoms of inattention have been characterized as failure to give attention to detail, difficulty sustaining attention in tasks, appearing absent-minded even when spoken to directly, failure to follow through on instructions or schoolwork or occupation-related tasks, difficulty organizing tasks, avoidance of attentionally demanding tasks, losing things, distractibility, and forgetfulness (APA, 2013). Symptoms of hyperactivity and impulsiveness have been characterized as fidgeting, difficulty remaining seated, feelings of restlessness in adults or overactivity in children, difficulty engaging in leisure activities quietly, discomfort with sitting still for extended periods of time, excessive talking, interruption in conversation, difficulty waiting their turn, and frequent intrusion on others' activities (APA, 2013).

The predominately inattentive subtype of ADHD is characterized by the presence of six or more symptoms related to inattention in children or five or more of the symptoms in adolescents or adults. The predominately hyperactive/impulsive subtype of ADHD is characterized by the presence of six or more of the symptoms related to hyperactivity/impulsivity in children or five or more of the symptoms in adolescents or adults. Finally, ADHD – combined type is characterized by the presence of six or more symptoms in children or five or more symptoms in adolescents or adults related to inattention and hyperactivity/impulsivity (APA, 2013).

In adulthood, difficulties related to relationship quality, health, legal issues, unemployment, financial concerns, and academic failure have been found to be more prevalent among individuals with ADHD (Kessler et al., 2006; Ramsay, 2010a). Furthermore, ADHD was estimated to result in an excess annual cost of \$31.6 billion in the United States in 2000, specifically \$1.6 billion for treatment, \$12.1 billion for additional health care costs, \$14.2 billion for additional healthcare costs to families, and \$3.7 billion for work loss costs (Robb et al., 2011).

Assessment of ADHD is often conducted using self-report and other-report surveys, with the latter based upon information collected from collaterals. Self-report measures have demonstrated diagnostic validity and allow the patient to report symptoms as they perceive them (Erhardt, Epstein, Conners, Parker, & Sitarenios, 1999; Kooij et al., 2008). Given the aforementioned considerations, however, individuals with ADHD experience deficits in performance monitoring and self-awareness and therefore often underreport deficits and other symptoms (Erhardt et al., 1999; Kessel & Zimmerman, 1993; Knouse, Bagwell, Barkley, & Murphy, 2005; Prevatt et al., 2011). Other-report

surveys are often included in the assessment of ADHD to provide supplementary information to overcome some of these problems (Erhardt et al., 1999; Kessel & Zimmerman, 1993; Kooij et al., 2008). Ratings of inattention and hyperactivity are often higher based on an informant report than on a self-report prior to medication treatment, whereas following medication treatment, self-report and other report scores show a tendency to converge (Adler et al., 2007; Nelson, 2011; Prevatt et al., 2011).

Incorporation of both self-report and other-report is most often recommended in assessment of ADHD because each method provides unique information that can collaboratively inform diagnosis (Goldstein & Ellison, 2002; Kennedy, 2007). Furthermore, the use of multiple forms of assessment allows the clinician to develop a more comprehensive understanding of presenting symptoms and implications for academic, occupational, and social functioning.

Often, assessment of ADHD incorporates direct behavioral measures. Continuous performance tasks are frequently used because they measure sustained attention. Motion-based continuous performance tasks measure locomotor activity, in addition to accounting for sustained attention (Conners & Staff, 2000; Sumner, 2010; Teicher, Lowen, Polcari, Foley, & McGreenerly, 2004).

Computer-based continuous performance tasks that account for motion have recently been incorporated into the assessment of ADHD, as they provide a means of assessment less susceptible to response bias, demand characteristics, and social desirability (Goldstein & Ellison, 2002; Hall et al., 2015; Kooij et al., 2008; Sumner, 2010). Such measures are suggested to supplement survey report measures in the interest

of providing a more comprehensive diagnostic conceptualization (Hall et al., 2015; Sumner, 2010; Teicher, Polcari, & McGreenery, 2008).

A search of the Google Scholar, PsychInfo, and EBSCO databases failed to find published research on the relationship between ADHD symptom severity as measured by a widely used and psychometrically sound, self-report assessment measure, specifically, the Conners' Adult ADHD Rating Scale (Conners et al., 2002), and ADHD severity as measured by an objective, motion-based assessment test, specifically, the Quotient ADHD System (Sumner, 2010). In contrast, most previous research has measured ADHD severity using only self- and other-report measures (e.g., Goldstein & Ellison, 2002; Kooij et al., 2008; Mörstedt, Corbisiero, Bitto, & Stieglitz, 2015; Sumner, 2010).

The Quotient ADHD System is an example of an objective computer-based continuous performance task (CPT). CPTs provide data that is less susceptible to response bias, demand characteristics, and social desirability (Kooij et al., 2008; Mörstedt, Corbisiero, Bitto, & Stieglitz, 2015; Teicher, Ito, Glod, & Barber, 1996; Teicher et al., 2004). In addition, the Quotient ADHD System incorporates motion measurements into assessment of ADHD, unlike many other continuous performance task measurements (Conners & Staff, 2000; Stein, Snyder, Rugino, & Hornig, 2016; Sumner, 2010; Teicher et al., 2004, 2008).

Literature Review

History of ADHD

ADHD is a neurodevelopmental disorder characterized by problems with executive functions, including attentional control and inhibitory control, that result in attention deficits, hyperactivity, and/or impulsivity (Daley, 2006; Solanto, 2015). It is likely that ADHD has been present among humans throughout recorded history; however, George Still is credited with the first formal clinical identification of ADHD, referring to it as a difficulty with “moral control without general impairment of intellect and without physical disease” (Still & Cantab, 1902, p. 1077). In the 1930s, while working with children with behavioral disorders, pediatrician Charles Bradley discovered the benefits of stimulant medications for reducing impulsivity and promoting behavioral self-control (Bradley, 1937). Bradley noted that children taking Benzedrine appeared “emotionally subdued without, however, losing interest in their surroundings” (Bradley, 1937, p. 580). The use of Benzedrine in children with behavioral disorders produced substantial improvements in academic performance. Bradley noticed that when taking Benzedrine, children with behavioral disorders were also able to demonstrate more appropriate social behavior, although he stressed that medication was a temporary solution and did not correct the underlying problem (Bradley, 1937; Strohl, 2011).

The history of American interest in ADHD can be traced to the encephalitis epidemic, which occurred between 1917 and 1918. A number of children who survived the brain infection were left with significant cognitive and behavioral difficulties (Conners & Staff, 2000; Sumner, 2010; Teicher et al., 1996). During the 1950s, researchers began to investigate potential neurological mechanisms that may underlie the

behavioral symptoms of what was then called *hyperkinetic impulse disorder* and reasoned that deficits resulted from abnormalities in the central nervous system (CNS) (Laufer, Denhoff, & Solomons, 1957, pp. 1). At the time, it was suggested that the existence of an imbalance between subcortical and cortical areas of the brain resulted in diminished control of the subcortical areas responsible for filtering sensation and thus permitted stimulation from sensation to reach the cortex, resulting in overstimulation (Knobel, Wolman, & Mason, 1959). This was thought to result in increased perception of extraneous stimuli and hence difficulties in attention (Knobel, Wolman, & Mason, 1959; Laufer et al., 1957).

The first appearance of a behavioral health disorder resembling what is now known as ADHD occurred in the second edition of the *Diagnostic and Statistical Manual of Mental Disorders* (2nd ed.; *DSM-II*; American Psychiatric Association, 1975), referring to it as a hyperkinetic reaction that occurred during childhood. The *DSM-III* introduced the term *attention deficit disorder* (ADD) (American Psychiatric Association, 1980, p. 41-44). The term was then revised to ADHD in the *DSM-III-R* (American Psychiatric Association, 1987, p. 50). The *DSM-IV* was the first to take into account attention deficits and their occurrence with or without hyperactivity (American Psychiatric Association, 1994). Currently, the *DSM-V* specifies several criteria that must be met to warrant a diagnosis of ADHD (American Psychiatric Association, 2013). Whereas children and young adolescents must have at least six symptoms of inattention and/or hyperactivity-impulsivity, older adolescents and adults (ages 17 and older) must have at least five symptoms of inattention and/or hyperactivity-impulsivity. Moreover, a diagnosis of ADHD is based on symptoms of predominant inattentiveness, predominant

hyperactivity-impulsivity, or combined inattention and hyperactivity-impulsivity (American Psychiatric Association, 2013).

During the mid to late 1990s, neuropsychological research began to examine variations in brain functioning, especially with regard to the frontal lobe, among those meeting ADHD symptom criteria. One study examined verbal fluency in the evaluation of ADHD (Koziol & Stout, 1992). Further investigation was conducted into neurological mechanisms underlying ADHD, including comparison to reading disabilities in children (Hall, Halperin, Schwartz, & Newcorn, 1997). Adult ADHD was investigated in terms of adaptive functioning and comorbidities (Murphy & Barkley, 1996). Another study found deficits in adults with ADHD in semantic verbal encoding, vigilance, and written arithmetic tasks (Seidman, Biederman, Weber, Hatch, & Faraone, 1998).

Contemporary understanding of adult ADHD.

ADHD is currently theorized to be a neurodevelopmental psychiatric disorder with manifestations in biological, psychological, and social domains. According to Barkley, the origin of such manifestations stems from deficits in behavioral inhibition and four related executive abilities: working memory, internalization of speech, self-regulation, and reconstitution (1997). Working memory has been defined as “the ability to keep an item of information in mind in the absence of an external cue and utilize that information to direct an impending response” (Goldman-Rakic, 1995, p. 57).

Internalization of speech is considered a means to provide description, self-questioning, and reflection through language (Flavell, Miller, & Miller, 1985). Self-regulation has been defined as a response that serves to modify the probability of a later consequence related to the event responded to (Kanfer & Karoly, 1972). Reconstitution is the ability

to create multiple novel complex alternative response chains in either language or motor activity (Milner, 1995). Barkley later revised his model to include the following executive functioning abilities: self-monitoring, organization, planning, initiating and completing tasks on a timely basis, tracking and shifting tasks, and self-inhibition (Barkley, 2015).

According to Brown's theory, ADHD is related to deficits of executive functioning, specifically activation, focus, effort, emotion, memory, and action (2002). Activation refers to the ability to organize and prioritize, whereas focus refers to the ability to sustain attention during tasks. Effort refers to the ability to regulate alertness and sustained effort. Emotion refers to frustration management and emotional regulation. Memory refers to utilization of working memory and recall. Finally, action refers to monitoring and self-regulation (Brown, 2002).

Neuropsychological correlates of adult ADHD.

ADHD is conceived of by some as a dimensional disorder, meaning that symptoms are not based simply on the binary presence or absence of symptoms, but that symptoms and corollary problems exist on a continuum. Symptoms may range from the mild, subclinical to severe ADHD, based on extremes of a continuum of inattentive and/or hyperactive-impulsive symptoms (Kern, Geier, Sykes, Geier, & Deth, 2015; Schneider et al., 2010; Stevenson et al., 2005). Recent research has investigated neuropsychological substrates accounting for variability and symptom presentation in ADHD. Specifically, symptoms are theorized to result from a breakdown in the top-down control system, a breakdown in bottom-up capacity for attentional capture, or a

breakdown in top-down regulation of emotion (Nigg, 2015; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002).

A breakdown in the top-down control system presents as disturbance in executive functioning and response inhibition. A breakdown in top-down emotional regulation is thought to present as increased impulsivity (Arnsten & Rubia, 2012; Shaw, Stringaris, Nigg, & Leibenluft, 2014). Top-down processing deficits are thought to influence allocation of attention to emotionally arousing stimuli. Some individuals may allocate increased attention to arousing stimuli, whereas others may allocate decreased attention, which can present as emotional lability or callousness, respectively (Arnsten & Rubia, 2012; Polier, Vloet, & Herpertz-Dahlmann, 2012; Shaw et al., 2014). Finally, breakdown in regulation of negative emotionality is thought to correlate with disturbances in self-concept and self-esteem (Nigg, 2015). A breakdown in bottom-up attentional capture presents as diminished alertness, sometimes characterized as sluggish cognitive tempo.

Additionally, other potential neurobiological and neuropsychological explanations have been proposed, e.g., an abnormality in reward-related circuitry leading to decreased delay gradients and delay aversion (Sonuga-Barke, 2002). Deficits in nonworking visual memory, working memory, attentional set shifting, and stop signal inhibition have been proposed (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Rhodes, Coghill, & Matthews, 2004; Schachar, Mota, Logan, Tannock, & Klim, 2000; Smith, Taylor, Warner Rogers, Newman, & Rubia, 2002).

In past research, it has been suggested that ADHD symptoms may diminish over time, although some studies note that this may partly be a function of developmental changes and acquired coping strategies (Agnew-Blais, Seidman, & Buka, 2013;

Biederman, Mick, & Faraone, 2000; Faraone, Biederman, & Mick, 2006; Hill & Schoener, 1996; Ramsay, 2010a, 2010a). Recent studies suggest, however, that the presentation of ADHD may change but not necessarily diminish (Biederman, Petty, Evans, Small, & Faraone, 2010; Turgay et al., 2012; Wilens, Biederman, & Spencer, 2002). In addition, the decline in symptoms of ADHD has been found to be greater in males than in females (Balint et al., 2009; Biederman et al., 2010). Contradictory evidence suggests symptom persistence is greater in males than in females, however (Bauermeister et al., 2007). As previously discussed, more recent evidence demonstrates that ADHD persists across the lifespan. Thus, treatment for ADHD accounts for developmental challenges and their variation throughout the lifespan (Biederman et al., 2010; Brod, Schmitt, Goodwin, Hodgkins, & Niebler, 2012; Turgay et al., 2012).

Evidence indicates that ADHD is related to variations in neuropsychological, neurological, and behavioral domains. As previously discussed, variations in bottom-up and top-down processing, reward system responsiveness, and executive functioning are proposed neuropsychological contributors to ADHD symptom presentation. Furthermore, ADHD is thought to persist across the lifespan as a function of such variations and neurological variations, which often present as variations in behavior and associated symptoms of ADHD.

Neurological correlates of adult ADHD.

Structural neurological variations and their association with ADHD have been well documented among children and adults (Jadidian, Hurley, & Taber, 2015; Keune, Wiedemann, Schneidt, & Schönenberg, 2015; Krause, la Fougere, Krause, Ackenheil, & St H, 2005; Mohamed, Börger, Geuze, & van der Meere, 2015; Stevenson et al., 2005;

Swanson et al., 2000; Thissen et al., 2015; Tian et al., 2008; Yu-Feng et al., 2007). Functional variations have been observed in individuals with ADHD. Many such variations are thought to relate to structural abnormalities associated with ADHD (Arnsten & Rubia, 2012; Kofler et al., 2014; Nigg et al., 2002).

Genetic and phenotypical variations associated with ADHD.

A growing body of evidence indicates that heritable, genetic risk factors significantly predict many neurological variations associated with ADHD (Daley, 2006; Franke, 2015; Jadidian et al., 2015; Keune et al., 2015; Mohamed et al., 2015, 2015; Stevenson et al., 2005; Thissen et al., 2015). For example, individuals with ADHD are more likely to have phenotypical variations related to dopamine transportation, dopamine receptor expression, serotonin transportation, and norepinephrine transportation (Daley, 2006; Kim et al., 2006; Kollins et al., 2008; Prince, Wilens, Spencer, & Biederman, 2015; Thissen et al., 2015; Wu, Xiao, Sun, Zou, & Zhu, 2012). Also implicated among individuals with ADHD are higher rates of variations in the D4 dopamine receptor gene (Daley, 2006). Response control has been associated with variations in dopamine transporter availability in individuals with ADHD, supporting the assertion that dopamine transportation and receptor expression are central to ADHD (Krause et al., 2005; Swanson et al., 2000; Volkow et al., 2007; Wu et al., 2012). Moreover, evidence suggests that abnormalities in dopamine transportation in addition to functioning and reduced volumetry of the anterior cingulate cortex contribute to the symptom presentation associated with ADHD, specifically, deficits in reward anticipation, impulse control, and emotion regulation (Amico, Stauber, Koutsouleris, & Frodl, 2011; Brown et

al., 2010; Bush et al., 1999; Castellanos et al., 2008; Fallgatter et al., 2004; Seidman et al., 2006).

Dopamine transportation and reception in the nucleus accumbens is thought to influence motivation and goal oriented behavior (Goto & Grace, 2005). A recent study found that dopamine D2 receptor (D2R) postsynaptic expression enhancement relates to enhanced motivation in adult mice, supporting this assertion (Trifilieff et al., 2013). Moreover, a study of adult rats found that following an artificial increase in the postsynaptic expression of D2R, increased risk proneness and impulsive behavior were more likely to be expressed (Adriani et al., 2009). Theories of dopamine pathway variations in ADHD posit that reception and transportation of dopamine in the nucleus accumbens, including the ventral striatum, may account in part for motivational deficits noted in ADHD (Bédard et al., 2010; Goto & Grace, 2005; Ikemoto & Panksepp, 1999; Swanson et al., 2000; Wu et al., 2012).

Structural neurological variations associated with ADHD.

The steroid sulfatase axis (STS) has been associated with ADHD; polymorphisms in the STS gene were linked to a diagnosis of ADHD (Brookes et al., 2008, 2010; Davies et al., 2014). A recent study examined the effect of pharmacological modulation of STS and found that modulation improved response control. Though the STS has not been a subject of systematic study, it represents an important consideration in the study of ADHD neurology.

Research indicates that differences in frontal brain asymmetry may relate to both depressive and ADHD symptoms (Avila, 2011; Jadidian et al., 2015; Keune et al., 2015). Positive asymmetry refers to increased activation in the left hemisphere relative to the

right hemisphere, whereas the opposite is true of negative asymmetry (Stevenson et al., 2005). Individuals with ADHD are more likely to have negative asymmetry, suggesting excessive behavioral approach tendencies (as opposed to a more cognitive style) and predisposition to depression (Keune et al., 2015; Mohamed et al., 2015; Stevenson et al., 2005).

In addition, evidence suggests that variations in the structure of the caudate nucleus play a role in deficiencies in procedural learning and executive functioning (Castellanos et al., 1994; Hynd et al., 1993; Volkow et al., 2007). A recent study found that deficits in executive functioning could, in part, be attributable to deficits in simple processes or subexecutive functions, such as subvocal articulation or internal speech (Hale, Bookheimer, McGough, Phillips, & McCracken, 2007).

Similarly, the cerebellum has been the subject of consideration, although it has not been the subject of systematic study. Some evidence suggests that individuals with ADHD are more likely to have reductions in the volume of the cerebellum (Bledsoe, Semrud-Clikeman, & Pliszka, 2009; Carmona et al., 2005; Cortese et al., 2012; Emond, Joyal, & Poissant, 2009; Frodl & Skokauskas, 2012; Krain & Castellanos, 2006; Tiemeier et al., 2010; Valera, Faraone, Murray, & Seidman, 2007).

Functional neurological variations associated with ADHD.

Variations in baseline brain activity and oxygenation have been found in both children and adults with ADHD (Hale et al., 2007; Konrad & Eickhoff, 2010; Tian et al., 2008; Yu-Feng et al., 2007). Specifically, individuals with ADHD were found to have decreased lateral prefrontal oxygenation during a working memory task, compared to non-ADHD peers (Auer, 2008; Ehlis, Bähne, Jacob, Herrmann, & Fallgatter, 2008;

Schecklmann et al., 2010). A growing body of evidence suggests that difficulties with response inhibition and inefficient cognitive control are characteristic of ADHD symptom presentation, theorized to be the province of the frontal cortex (Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2010; Clark et al., 2007; King, Colla, Brass, Heuser, & von Cramon, 2007; Konishi et al., 1999; McLoughlin et al., 2009; Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004; Rubia, Smith, Brammer, & Taylor, 2003; Verbruggen & Logan, 2008). Physical exercise has been found to alleviate difficulties with response inhibition and cognitive control and to increase oxygenation in the prefrontal cortex in individuals with ADHD (Archer & Garcia, 2014; Archer & Kostrzewa, 2012; Choi, Han, Kang, Jung, & Renshaw, 2015). Similarly, medication for ADHD has been associated with increased blood flow and activation in the prefrontal cortex (Lee et al., 2005; Spalletta et al., 2001). Moreover, recent evidence suggests that cognitive behavioral therapy (CBT) increases regional functional connectivity strength in the fronto-parietal network and cerebellum. Increases in functional coupling between bilateral superior parietal gyrus were found to positively correlate with improvement in ADHD symptoms following CBT treatment (Wang et al., 2016).

Recent fMRI studies show that dysregulation in alertness levels, such as enhanced resting state brain activity, disturbed regulation, and disturbed sleep, are associated with ADHD (Cortese, Konofal, & Lecendreux, 2008; Hale et al., 2007; Tian et al., 2008). One such study suggested the hypocretin/orexin system, which is implicated in arousal, could contribute to the observed variations (Cortese et al., 2008).

Electroencephalography (EEG) has been used to assess ADHD since the de novo device approval in 2013 (U.S. Food and Drug Administration, 2013). Theta to beta ratio

(TBR) has been investigated as a potential biomarker for ADHD (Arns, Conners, & Kraemer, 2012; Loo & Arns, 2015; Snyder, Rugino, Hornig, & Stein, 2015). The TBR is a ratio of slow-wave theta bands to the faster beta bands (Loo & Arns, 2015; Snyder et al., 2015). EEG-indicated theta band activity is known to reflect cortical slowing or drowsiness, whereas beta band activity is often reflective of concentration and focused mental activity (Loo & Arns, 2015). Increases in slow-wave activity and thus a higher TBR prior to psychopharmacological treatment have been found to be positively correlated with positive responses to stimulant medication (Arns, Heinrich, & Strehl, 2014; Loo & Arns, 2015). Evidence suggests that individuals with ADHD have greater levels of theta band waves relative to beta band waves than neurotypical individuals, although there is some contradictory evidence (Faraone, Bonvicini, & Scassellati, 2014; Lenartowicz & Loo, 2014; Øgrim, 2014). However, replication of these findings has proven difficult (Loo & Arns, 2015; Saad, Kohn, Clarke, Lagopoulos, & Hermens, 2015). The cause is unknown, although one explanation for the increase in TBRs among non-ADHD samples is increasing development and use of portable technology (Loo & Arns, 2015).

Finally, individuals with ADHD are more likely to experience sleep disturbances, which can exacerbate symptoms of ADHD and result in decreased sustained attention, working memory impairment, and reduced ability to perform tasks that require attention (Alhola, & Polo-Kantola, 2007; Kolb, & Wishaw, 2005; Schredl, Alm, & Sobanski, 2007). For both neurotypical individuals and those with ADHD, sleep disturbances and insomnia decrease attentional ability and working memory (Cortese et al., 2006;

DeCrescenzo, et al., 2015; Gruber et al., 2012; Hoban 2008; Schredl, Alm, & Sobanski, 2007; Kooij et al., 2008).

Behavioral correlates of adult ADHD.

Individuals with ADHD may exhibit differences in behavior from individuals without ADHD, especially prior to and during execution of tasks that require sustained attention and effort. Some common examples include the tendency of individuals with ADHD to engage in more procrastination, aggressive confrontation, and impulsive decision making than others (Young, 2005). As previously discussed, individuals with ADHD are often more focused on preparation for a task (i.e., preparing workspace, avoiding potential obstacles) than the task itself, due to negative asymmetry in the prefrontal cortex (Avila, 2011; Keune et al., 2015). Thus, without appropriate planning, these individuals must rely on more reevaluation and adaptation during tasks than individuals without ADHD (Avila, 2011; Keune et al., 2015). To compound matters, reevaluation and adaptation are some of the executive functions often lacking in individuals with ADHD. However, the ability to reevaluate and adapt to a unique situation has been found to relate to coping ability in individuals with ADHD (Young, 2005; Zametkin & Ernst, 1999). Issues related to reduced self-control, difficulty planning, and problems processing the long-range consequences of a potential action are characteristic of ADHD and may produce negative outcomes in many important life domains, such as financial planning and maintaining physical health (Kessler et al., 2006; Ramsay, 2010a; Solanto, 2015; Young, 2005).

Research indicates that adults with ADHD are more likely to engage in dysfunctional health behaviors such as nicotine use, sedentary lifestyle, poor diet, and

lack of exercise than non-ADHD controls (Combs, Canu, Broman-Fulks, Rocheleau, & Nieman, 2015; Solanto, 2015; Young, 2005). Individuals with ADHD are also at increased risk for psychoactive substance use disorders (Biederman et al., 1997; Wilens, Biederman, Spencer, & Frances, 1994). Research suggests two potential reasons why ADHD and substance use disorder (SUD) may be related. First, dopamine neurotransmission plays a central role in current models of ADHD and substance use models (Bédard et al., 2010; O'Hara et al., 1993; Ray et al., 2010). Second, children of adults with SUD are more likely to develop psychopathology including ADHD (Biederman et al., 1992, 1997). Given the aforementioned considerations, similarities in etiological origin may account for the relation of SUD to ADHD.

Deficits in executive functioning are thought to be central to many symptoms characteristic of ADHD (Barkley, 1997; Brown, 2002). As mentioned, Brown's theory of ADHD posits that deficits in executive functioning, specifically activation, focus, memory, effort, emotion, and action are contributors to ADHD symptoms (2002). Alternately, Barkley's revised model proposes that executive functioning includes self-monitoring, organization, planning, initiating and completing tasks in a timely basis, tracking and shifting tasks, and self-inhibition (2015a). Research seems to corroborate Barkley's and Brown's respective theories (Boonstra, Oosterlaan, Sergeant, & Buitelaar, n.d.; Hall et al., 1997; Solanto, 2015).

Children with ADHD also frequently experience greater difficulty with motivation and effortful control (Dovis, Van der Oord, Huizenga, Wiers, & Prins, 2015). Deficits in working memory have been found in children with ADHD, as well (Kofler et

al., 2014). Adults with ADHD experience heightened perceptions of stress, specifically when tasked with an activity with a high attentional demand (Combs et al., 2015).

Motivation plays an important role in academic outcomes, and individuals with ADHD experience greater difficulty with motivation (Linnenbrink & Pintrich, 2002). Motivation has been found to relate to academic success among students with ADHD and has been a focus of recent research (Brim & Whitaker, 2000). Research also suggests a relationship between ADHD and emotional regulation (Barkley, 1997; Brown, 2002; Hall et al., 1997; Solanto, 2015).

Treatment of ADHD

Cognitive distortions and stress have been associated with ADHD severity; the latter is generally operationalized as scores on psychometrically sound but subjective self-report measures (Mitchell et al., 2013; Roberts, 2015 Schmidt, Stark, Carlson, & Anthony 1998; Strohmeier, 2013). Cognitive behavioral therapy (CBT; Beck 1976) has been empirically validated as a treatment for ADHD in child, adolescent, and adult populations (Canu & Wymbs, 2015; Knouse, 2015; Ramsay, 2010c; Ramsay & Rostain, 2011). CBT focuses upon the interplay between thoughts, emotions, and behaviors (Beck, 1976, 2005). Modifying cognitive distortions is a focal point of treatment for CBT of ADHD (Mitchell et al., 2013; Ramsay, 2010). The origin of these distortions is thought to be distressing emotions related to functional impairments in attentional ability, motivation, impulse control, and memory. According to Ramsay (2010), these impairments can lead to maladaptive compensatory strategies, such as avoidance of demanding tasks in the aforementioned areas. This pattern can create and maintain maladaptive beliefs over time. These maladaptive beliefs are thought to be further

strengthened by the related problematic behaviors (e.g., procrastination and avoidance) (Ramsay, 2010b). During childhood, individuals with ADHD may receive negative feedback from others regarding their abilities, which may result in negative feelings regarding the self by adulthood. Such feelings often lead to negative thoughts, thus facilitating avoidance behavior and reducing motivation, exacerbating preexisting difficulties (Ljusberg & Brodin, 2007; Nelson, 2011; Tabassam & Grainger, 2002). Adults who hold inaccurate perceptions and interpretations of symptoms related to ADHD may attribute their difficulties to their own moral flaw or personality, which may facilitate further negative self-evaluation (Dan & Raz, 2012; Nelson, 2011; Tabassam & Grainger, 2002). Adults with ADHD have higher levels of negative self-views and pessimism (Dan & Raz, 2012; Nelson, 2011; Ramsay, 2010c).

CBT for ADHD addresses cognitive distortions and often incorporates psychoeducation to help the client understand the disorder, identify deficits and symptoms, and more effectively manage deficits and symptoms (Christner, Stewart, & Freeman, 2007; Ramsay, 2007; Young, 2002). Psychological intervention for ADHD focuses on the adaptation of the surrounding environment to make accommodations that facilitate the achievement of success (Ramsay, 2010c; Young, 2002). In addition, CBT for ADHD focuses on assisting the individual to develop skills necessary to achieve goals set in therapy and cope with associated deficits and symptoms (Canu & Wymbs, 2015; Ramsay, 2010c; Young, 2002, 2005). A recent study supports these techniques and suggests that CBT increases regional functional connectivity strength in the fronto-parietal network and cerebellum, the brain regions most often affected by medication (Wang et al., 2016).

Pharmacotherapy remains a common first-line treatment for ADHD (Brown & La Rosa, 2002; Dodson, 2005; Mészáros et al., 2009; Prince et al., 2015). Cognitive therapy combined with pharmacotherapy is regarded as the most efficacious treatment for ADHD in adults because the interventions target symptoms (Brown & La Rosa, 2002; Dodson, 2005; Prince et al., 2015; Ramsay, 2010c; Rostain, Jensen, Connor, Miesle, & Faraone, 2015), such as time management, organization, self-esteem, planning, and procrastination, that are apparently less amenable to treatment with medication (Brown & La Rosa, 2002; Dodson, 2005; Prince et al., 2015).

Although evidence supports the efficacy of ADHD treatment, challenges in assessment and diagnosis of ADHD, such as variability in symptom presentation, symptom overlap with other disorders, and the prevalence of comorbid disorders, pose an inherent challenge to treatment (Goldstein & Ellison, 2002; Kennedy, 2007; Shemmassian, 2015). To avoid misdiagnosis of ADHD, multitrait, multimethod assessment is widely considered an integral component of treatment (Jensen et al., 1999; Kennedy, 2007; Montano & Weisler, 2011; Shemmassian, 2015).

Presentation of Behavioral and Neurological Variations in ADHD

As previously discussed, behavioral, neuropsychological, and neurological variations contribute to observable and reported symptoms and deficits. Inhibitory control is thought to relate to inattentive symptoms as well as to hyperactive and impulsive symptoms of ADHD (Clark et al., 2007; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005; Ossmann & Mulligan, 2003; Quay, 1997; Schachar et al., 2000).

Deficits in the inhibition of motor control are thought to relate to hyperactive/impulsive symptoms, whereas deficits in cognitive inhibition are thought to

relate to deficits related to inattention (Barkley, 1997; Clark et al., 2007; Ossmann & Mulligan, 2003; Quay, 1997). Inhibitory control shares involvement with executive functioning processes and is thought to account in part for deficits in executive functioning. For example, according to Brown's model, focus is a component of executive functioning and requires cognitive inhibition of extraneous stimuli, and according to Barkley's model, self-inhibition is considered a direct component of executive functioning (Barkley, 1997; Brown, 2002).

Difficulty planning, reduced self-control, and difficulty processing the long-range consequences of a potential action are characteristic of ADHD (Kessler et al., 2006; Ramsay, 2010b; Solanto, 2015). A recent study found that problems with self-concept predicted ADHD symptom severity (O'Brien, 2016). In addition, increased likelihood of being diagnosed with an emotional disorder has been found among individuals with ADHD; men with ADHD are at risk (28%), whereas women are at even greater risk (49%) (Rasmussen & Levander, 2009). The risk for suicidal ideation is increased for individuals with ADHD; specifically, one study found that whereas adolescent males are at risk (5.9%), adolescent females demonstrate greatly increased risk (17.9%) (Rucklidge & Tannock, 2001).

ADHD and Psychiatric Comorbidities

ADHD is often comorbid with other psychiatric disorders, including depression, anxiety, bipolar disorder, oppositional defiance disorder, obsessive-compulsive disorder, and substance use disorders (Adler et al., 2007; Jensen, 2001; Kennedy, 2007; Kessler et al., 2006; Klassen, Katzman, & Chokka, 2010; Mayes et al., 2009; Murphy & Barkley, 1996; Shemmassian, 2015; Young, Toone, & Tyson, 2003). Comorbidity may be

explained as a long-standing history of functional impairment likely to result in low self-esteem and demoralization, causing individuals to avoid certain situations, lack confidence, anticipate failure, and feel misunderstood (Ramsay, 2010a; Young et al., 2003). As discussed previously, individuals with ADHD often have deficits in executive functioning. Deficits in executive functioning may negatively affect self-perceptions as a function of effects on effortful control and decision-making (Murray & Kochanska, 2002). An analysis from a national comorbidity survey indicated that among individuals diagnosed with ADHD, 38.3% were diagnosed with a co-occurring mood disorder, 47.1% were diagnosed with a co-occurring anxiety disorder, 15.2% were diagnosed with a substance disorder, and 19.6% were diagnosed with an impulse control disorder (Kessler et al., 2006). A reciprocal effect may also exist. For example, whereas the prevalence of ADHD was estimated to be 6 to 8% of the overall population in 2006, the national comorbidity survey found that 14% of individuals with social phobia were diagnosed with ADHD, 25.4% of individuals who were diagnosed with drug dependence were also diagnosed with ADHD, 22.6% of individuals with dysthymia were also diagnosed with ADHD, and finally 21.2% of individuals with bipolar disorder were diagnosed with ADHD (Kessler et al., 2006; Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014).

Assessment Techniques for ADHD

The assessment of ADHD typically includes obtaining a complete history of symptoms and measures of academic, psychological, and neuropsychological functioning (Adler & Alperin, 2015; Kennedy, 2007; Shemmassian, 2015). The format of these

measures may be self-report or behavioral, the latter including objective motion-based measurement.

Self-report measurement used in the assessment of ADHD.

Measurement of ADHD symptoms and related constructs through the use of self- or other-report questionnaires offers the clinician information reflective of the individual's perceived functioning beyond current behaviors and often within the scope of various contexts such as academic, social, and occupational functioning (Adler et al., 2007; Erhardt et al., 1999; Jiang & Johnston, 2011; Kooij et al., 2008). Whereas self-report questionnaires elicit information from the patients themselves, other-report questionnaires elicit information based upon observations of the patients' family, friends, acquaintances, significant others, coworkers, or clinician (Kooij et al., 2008). In contrast to behavioral measures, described below, self-report measures of ADHD rely upon the reporter for information, which is filtered through subjective perceptions and interpretations (Erhardt et al., 1999; Kennedy, 2007; Kooij et al., 2008; Shemmassian, 2015; Sumner, 2010; Teicher et al., 1996). Some examples of widely accepted assessment tools include the Brown Attention–Activation Disorder Scale (BAADS), the Adult ADHD Self-Report Scale for Screening for Adult Attention-Deficit/Hyperactivity Disorder version 1.1 (ASRS v1.1), the Barkley Adult ADHD Scale Version IV (BAARS–IV) and the Conners' Adult ADHD Rating Scale (CAARS) (Barkley, 2011a; Brown, 1992; Conners, Erhardt, & Sparrow, 1999; Kessler et al., 2006). The BAADS consists of 40 self-report items that measure core symptoms of ADHD (Brown, 1992). The scale assesses five symptom clusters: sustained attention, activation, affect, effortful control, and memory (Adler, n.d.; Brown, 1992). The CAARS is an ADHD scale

consisting of 66 self-report items that measure inattention, hyperactivity, impulsivity, and self-concept (Conners et al., 2002, 1999). The ASRS-v1.1 is a six-item screening tool for adult ADHD for evaluating patients in a busy primary care setting (Hines, King, & Curry, 2012; Kessler et al., 2005). The BAARS-IV is a 27-item screening tool for ADHD that incorporates measures of inattention, sluggish cognitive tempo, hyperactivity, and impulsivity (Barkley, 2011a).

Clinical observation is also frequently used in ADHD assessment. Clinical observation allows incorporation of behavioral observations, often made by a mental health professional (Goldstein & Ellison, 2002; Kennedy, 2007; Shemmassian, 2015). The addition of informant report measures offers further information regarding observable behavior outside of treatment (Goldstein & Ellison, 2002; Kennedy, 2007; Kooij et al., 2008; Shemmassian, 2015).

Advantages of subjective/self-report assessment of ADHD.

Self- and other-report instruments are widely used to measure ADHD symptoms and severity. The benefits of this type of assessment are that it does not require special, costly equipment or technology, only training, a survey form, and a manual. Thus, this method often requires less time, personnel, equipment, and expense (Goldstein & Ellison, 2002; Hall et al., 2015; Kennedy, 2007; Kooij et al., 2008; Shemmassian, 2015). Unlike objective assessment, subjective assessment is able to measure behaviors outside of the context of the therapy in the experiential context in the individual's daily life (Kennedy, 2007; Kooij et al., 2008). In addition, self-report questionnaires are capable of measuring constructs otherwise immeasurable via objective means. Cognitive distortions, for example, can not be measured using objective assessment.

Limitations of self- and other-report assessment of ADHD.

Self-report measures of ADHD are often limited in their ability to rule out explanations other than ADHD for the presenting problem and generally do not include assessment for other psychiatric disorders, trauma, or significant life events (Erhardt et al., 1999).

Self- and other reports and even clinical observation are reactive measures and, therefore, reports may be subject to personal bias and the extent of executive functioning (Barkley, 1997; Kooij et al., 2008; Solanto, 2015). Thus, ADHD patients completing self-report measures are likely influenced by cognitive distortions, often found in individuals with ADHD and related comorbidities, as well as by deficits in executive functioning, a hallmark of ADHD itself. They may perceive the severity of their ADHD differently, based on these limitations (Kooij et al., 2008; Mitchell, Benson, Knouse, Kimbrel, & Anastopoulos, 2013; Ramsay, 2010c; C. Strohmeier, 2013). Many difficulties and frustrations with ADHD occur publicly, for example (e.g., forgetting an appointment, difficulty managing tasks at work, not remembering a promise to a friend), and the resulting negative feedback may heighten perceived deficits. In summary, answers from respondents to both self- and other reports are filtered through their subjective interpretations and perceptions (Erhardt et al., 1999; Kennedy, 2007; Kooij et al., 2008; Shemmassian, 2015; Sumner, 2010; Teicher et al., 1996). Executive functions can be defined as self-directed actions of an individual used to self-regulate (Barkley, 1997).

For example, individuals with ADHD, and specifically with deficits in executive functioning, might value education highly, yet have difficulty motivating themselves to

apply extra effort and behave in a way that is congruent with their beliefs. They might then report themselves to be more attentive in academic situations than they realistically tend to be based on their beliefs about themselves, demonstrating a positive illusory bias.

Objective measurement used in the assessment of ADHD.

Objective measures of ADHD offer supplementary data to further inform ADHD assessment and provide information that may be less subject to influence by personal bias, cognitive distortions, or deficits in self-monitoring (Hall et al., 2015; Heiser et al., 2004; Stein et al., 2016; Sumner, 2010; Teicher et al., 1996). Continuous performance tasks (CPT) are often used as objective measures for ADHD. Recently, some CPTs have incorporated motion-based measurement into their analysis (Edebol, Helldin, & Norlander, 2013; Heiser et al., 2004; Sumner, 2010; Teicher et al., 1996, 2008). The incorporation of motion-based measurement into CPT assessments for ADHD provides additional information based on locomotor activity, which has been shown to relate to ADHD symptom severity and predict a diagnosis of ADHD (Epstein et al., 2003; Hall et al., 2015; Losier, McGrath, & Klein, 1996; Teicher et al., 2004; Teicher, Polcari, Fourligas, Vitaliano, & Navalta, 2012; Teicher et al., 2008).

CPT measures include the Test of Variables of Attention (TOVA), the Gordon Diagnostic System (GDS), the Conner's Continuous Performance Test (CCPT), and the Integrated Visual and Auditory Continuous Performance Task (IVA+CPT) (Conners et al., 2002; Edebol, Helldin, & Norlander, 2013; Gordon, McClure, & Aylward, 1996; Hall et al., 2015; Tinius, 2003).

Examples of motion-based continuous performance tasks (CPTs) include the Quotient ADHD System (formerly known as the McLean Motion and Attention System [MMAT] and prior to that as the Optical Tracking and Attention test [OPTAx]) and the Quantified Behavior (QB), each of which incorporates a measure of both attention and activity (head movement), in contrast to other CPTs (Edebol et al., 2013; Sumner, 2010). Although the TOVA, GDS, CCPT, and IVA+CPT seem to have good psychometric properties (e.g., test-retest reliability), they do not include a motion parameter, whereas the Quotient and QB Test do (Chae, Kim, & Noh, 2003; Hall et al., 2015; Heiser et al., 2004; Kim et al., 2015; Losier, McGrath, & Klein, 1996; Matier, Halperin, Sharma, Newcorn, & Sathaye, 1992; Mayes et al., 2009; Wang et al., 2011).

The QB Test is a motion-based CPT that requires the user to differentiate between letters that appear on a screen and is effective in differentiating individuals who meet criteria for ADHD from those who do not (Edebol et al., 2013; Hall et al., 2015). Similarly, the Quotient ADHD System is a motion-based CPT that has also been found to be more effective in differentiating individuals who meet the criteria for ADHD than CPTs that do not include a motion parameter (Hall et al., 2015; Jensen, 2001).

The Quotient ADHD System is a computer-based, noninvasive, objective measure of ADHD that is usually completed in 15 to 20 minutes, in a single session (Sumner, 2010). The procedure includes a go/no-go task, wherein target stimuli (5-, 6-, and 7-pointed stars) and nontarget stimuli (4-pointed stars) appear at a random position on a computer screen and in a random sequence for 200 ms each, at 2000 ms intervals at a 3:1 ratio (Murillo et al., 2015; Teicher et al., 1996). Subjects are instructed to press a button with their right hand in response to target stimuli, which comprise about half of the

stimuli presented (Teicher et al., 1996). Variables measured for the go/no-go task are percent accuracy, percent omission errors (nonresponse to the occurrence of the target), percent commission errors (responses made when the target stimuli is not displayed), reaction time latency (response latency after the target occurrence), reaction time variability (intra-individual standard deviation [SD] of response times), and coefficient of variation (response time SD/mean latency) (Murillo et al., 2015; Teicher et al., 1996). The aforementioned variables provide analysis of response accuracy and response latency over the duration of the assessment, which previous studies have found to predict ADHD symptom severity (Epstein et al., 2003; Teicher et al., 1996, 2008; Wang et al., 2011).

The Quotient ADHD System also measures locomotor activity using technology that detects positional stability in space (i.e., head movements), response accuracy, and response latency (Murillo et al., 2015; Sumner, 2010; Teicher et al., 2012). The displacement of a spherical reflector secured with elastic bands on the forehead measures the movement variables. Movement variables are head movement, which measures the average number of position changes greater than 1 mm over 4 intervals each 5 minutes in duration; head immobility duration, which is measured over each 5-minute interval; head displacement, which is the total distance traveled, in meters, on average during each 5-minute interval; head area, referring to the two-dimensional space in which the reflector moved; head spatial complexity, referring to the fractal complexity of the movement path, with values of one or two; and head temporal scaling, indexing the frequency of movement (Murillo et al., 2015; Teicher et al., 1996). In a recent meta-analysis, significant differences were found between ADHD and non-ADHD participants on measures of head movement, head displacement, head area, head temporal scaling, and

reaction time variability, suggesting the importance of the recent addition of motion variables to objective ADHD assessment (Losier et al., 1996). Moreover, assessment of motion-based variables provides measurement of hyperactive/impulsive motor activity and inattention; evidence suggests that this increases the test's effectiveness with regard to differentiating individuals who meet criteria for ADHD from those who do not (Edebol et al., 2013; Hall et al., 2015).

Advantages of objective assessment of ADHD.

Objective assessment of ADHD severity measures observable behaviors such as the Quotient and thus, may be less reactive, given that it is thought to be less likely to be influenced by individual perceptions and biases than self-report instruments (Teicher et al., 2012). Motion-based and continuous performance tasks used to measure ADHD offer precise measurements of locomotor activity and attentional impairment and allow signs and symptoms of specific difficulties to be isolated (Hall et al., 2015; Murillo et al., 2015; Teicher et al., 1996, 2012).

Research indicates that individuals with ADHD frequently engage in cognitive distortions, which could inform their perceptions, reduce accuracy, or increase ambiguity of their self-report of symptoms (Kooij et al., 2008; Mitchell et al., 2013; O'Brien, 2016; Rosenfield, 2004; Strohmeier, Rosenfield, DiTomasso, & Ramsay, n.d.).

Disadvantages of objective assessment of ADHD.

Computer-based objective assessment, such as the Quotient, measures observable behavior within an artificial environment, usually a treatment or research setting. Thus, important contextual influences on symptoms may not be present and, therefore, results may not capture a complete picture of real-world behavior, thereby reducing external

validity (Riccio & Reynolds, 2001). Additionally, computer-based objective assessment for ADHD is less useful for measuring daily or routine behavior outside the clinical setting and cannot measure past behavior (Erhardt et al., 1999; Hall et al., 2015; Heiser et al., 2004). In addition, the findings of one study suggest that anxiety may play a role in performance on CPT tests (Epstein, Goldberg, Conners, & March, 1997).

Multitrait multimethod assessment of ADHD.

Construct validity is based on integrated interpretation of evidence, and in construct validation, the assessment outcome is not directly equated with the construct it endeavors to measure, but rather is considered one indicator of the construct (Cronbach & Meehl, 1955; Messick, 1995). Multitrait multimethod assessment of ADHD relies upon multiple measures to formulate a comprehensive view of related symptoms and functioning (Calderon & Ruben, 2008; Kennedy, 2007; Shemmassian, 2015).

Research demonstrates that ADHD varies widely in symptom presentation and symptom severity (Adler, n.d.; Adler & Alperin, 2015; Kennedy, 2007; Mayes et al., 2009; Ramsay, 2010a; Shemmassian, 2015; Teicher et al., 2012). Attention deficit-hyperactivity disorder can present as symptoms related to inattention, symptoms related to hyperactivity/impulsivity, or as a combination of symptoms related to inattention and to hyperactivity/impulsivity (APA, 2013). In addition to having multiple exclusive sets of symptom criteria, ADHD symptoms present with varying levels of severity among individuals with the disorder (Rasmussen & Levander, 2009).

To further complicate assessment, individuals with ADHD tend to engage in compensatory behaviors that alter the manifestation of ADHD symptoms. (Erhardt et al., 1999; Kooij et al., 2008; Young, 2005). For example, one person may compensate for

inattention and distractibility by taking copious notes during conversations (Ramsay, 2010b; Bradley M Rosenfield, Ramsay, & Rostain, 2008). This compensatory strategy may vary in degree of acceptability, depending on context, e.g., in a business meeting versus in a casual conversation. However, when asked about distractibility, such an individual may underreport or even deny inattention (on self-report) because the compensatory strategy has reduced the severity of the problem or has become so automatic that he or she may no longer be cognizant of it. In such a case, a behavioral measure such as the Quotient may be a more valid and reliable measure of attention. On the other hand, the Quotient would be completely blind to early childhood history of symptoms, for which self- and other-report measures would be more appropriate.

Moreover, a major goal of ADHD assessment is not only to determine the presence or absence of ADHD, but also to identify comorbidities (Adler & Alperin, 2015; Barkley, 2015a; Kennedy, 2007). Given the aforementioned considerations, the importance of the use of multiple methods across multiple traits is widely recognized to be necessary for accurate diagnosis (Adler & Alperin, 2015, 2015; Barkley, 2015a; Calderon & Ruben, 2008; Goldstein & Ellison, 2002; Kennedy, 2007; Shemmassian, 2015).

Purpose of the Study

The purpose of this study was to determine whether ADHD symptom self-report predicts ADHD symptom severity, as measured by behavioral assessment. Specifically, this study sought to determine if the Quotient ADHD System is a valid and reliable measure of ADHD symptoms and if the Quotient correlates with a widely accepted, psychometrically sound self-report ADHD measure, the CAARS. A comparison of

objective and self-report measures of ADHD severity may help to clarify the nature of the relationship between these divergent measures of ADHD. Improved understanding may inform assessment procedures and improve treatment planning related to adult ADHD.

Hypotheses

Accordingly, it was hypothesized that:

H1: Self-report measurement of ADHD symptom severity (operationalized as the CAARS Inattention/Memory Problems, Hyperactivity/Restlessness, and Impulsivity/Emotional Lability scales) will predict and positively correlate with the Quotient ADHD System global scaled score metric.

H2: Self-reported inattention/memory problems on the CAARS will predict behavioral measures of distractibility on the Quotient distracted metric, based on errors of omission.

H3: Self-reported hyperactive/impulsive symptoms on the CAARS will predict impulsiveness Quotient scores on impulsiveness metric.

H4: Hyperactivity/Restlessness and Impulsivity/Emotional Lability scale scores on the CAARS will predict behavioral impulsivity Quotient impulsive metric, based on errors of commission.

H5: Hyperactivity/Restlessness, Impulsivity/Emotional Lability, and Inattention/Memory Problems scale scores on the CAARS will predict and behavioral hyperactivity on the Quotient Motion Global Scale.

Methods

Research Design

The study used a correlational research design to explore the relationship between self-report measurement of ADHD symptom and observable behavioral symptoms of ADHD. Symptom severity was operationalized for the CAARS as the percentile rank derived from the T score associated with the total raw score of the ADHD Index and the Inattention/Memory Problems, Hyperactivity/Restlessness, and Impulsivity/Emotional Lability scales. For the Quotient ADHD System, symptom severity was operationalized as the percentile rank, comprised of the global scaled score and metrics from the Attention State Summary report, including the Number of Shifts, Attentive, Impulsive, and Distracted; and Disengaged scales.

Subjects

Archival data was gathered from 209 adults who participated in assessment and/or treatment at a university-based, outpatient clinic specializing in the treatment and research of adult ADHD. The clinic is located in a large northeastern U.S. city. Fees are mainly private payment and university-based insurance reimbursement. The subjects included physician-, clinician- and self-referred patients. Data was included in this study if the subject was between 18 and 88 years old and had completed the Conner's Adult ADHD Rating Scale and the Quotient ADHD System assessment. In addition, subjects had to have been diagnosed with ADHD – predominately inattentive type, ADHD – predominately hyperactive/impulsive type, or ADHD – combined type, based on a full developmental interview for relevant history and the *DSM-5* diagnostic criteria (APA, 2013). Data for individuals with co-occurring substance abuse disorders and/or psychotic

disorders, as determined through the clinical interview process at intake, were excluded from the study. Power analysis for multiple regression with three predictors was conducted in G*Power to ensure a sufficient sample size using an alpha of .05, a power of .80, and a medium effect size ($f^2 = .015$) (Faul, Erdfelder, Buchner, & Lang, 2009). Based on the aforementioned assumptions, the desired sample size was 77. Data in this study was collected from 216 archived intake records to allow for incomplete records and to increase statistical power. Seven records failed to meet the inclusion criteria and were excluded from the study; 209 records were used for the analysis ($N = 209$). Data were analyzed using SPSS v. 25.0.

Measures

Quotient ADHD System.

The Quotient ADHD System is an office-based continuous performance task developed to provide objective measurements of hyperactivity (ability to maintain positional stability), sustained attention, and impulsive inhibition, which correlate with severity and symptom presentation of ADHD and ADHD types with the use of similar motion-based assessment systems (Sumner 2010, Teicher et al., 2012). When administered to an adult, the continuous performance task takes approximately 20 minutes to complete (Murillo et al., 2015; Teicher et al., 2004). Test-retest reliability for the Quotient ADHD System has been established at $r = .95$ for both accuracy and latency and $r = .91$ for the number of microevents (Murillo et al., 2015; Teicher et al., 2008). Concurrent validity, external validity, construct validity, and predictive validity have yet to be determined (Murillo et al., 2015). The Motion Analysis report consists of the following metrics; immobility duration, movements, displacement, area, spatial

complexity, and temporal scaling. *Immobility duration* refers to the average time sitting still and not moving; *movements* refers to the number of position changes greater than 1 mm; *displacement* refers to the total distance moved by the marker; *area* refers to the total area covered by the markers path; *spatial complexity* refers to the complexity of the movement path; and *temporal scaling* refers to the frequency of movement over time.

The Attention Response Analysis report consists of eight metrics: speed of responses for non-target hits, speed of responses for target hits, accuracy, omission errors, commission errors, latency, variability, and coefficient of variance (COV). Speed of responses for nontarget hits refers to the time elapsed between the presentation of a nontarget stimulus and a response; speed of responses for target hits refers to the time elapsed between the presentation of a target stimuli and response; accuracy refers to the percentage of correct responses; omission errors refers to the percentage of missed targets; commission errors refers to the percentage of incorrect responses to nontargets; latency refers to the average time to respond correctly; variability refers to variation in response times to the correct target, and coefficient of variance (COV.) is a normalized measure of response time variation. The Attention State report consists of the following metrics: number of shifts, attentive, impulsive, distracted, and disengaged. Number of shifts is a measure of how frequently a change in behavioral states occurs over the course of a test (i.e., attentive to impulsive, attentive to distracted, attentive to disengaged, impulsive to distracted, impulsive to attentive, impulsive to disengaged, distracted to attentive, distracted to impulsive, distracted to disengaged, disengaged to attentive, disengaged to impulsive, disengaged to distracted); the total number of shifts in attention state may range from 0 to 39. The Attentive metric is comprised of the percentage of time wherein subjects

perform with high accuracy and consistent response latency; specifically, it is based on the combination of correct and incorrect target and nontarget responses and time to respond. The Impulsive metric refers to the percentage of time wherein subjects produce an excessive number of commission errors or are too rapid in their responses. The Distracted metric refers to the percentage of time wherein subjects make an excessive number of omission errors or are slow or inconsistent in their responses. The Disengaged metric refers to the percentage of time in which subjects performed no better than chance. The Quotient testing report also yields a global scaled score, ranging from 0 to 10, which indicates the average of the Motion and Attention scaled scores and quantifies the patient's overall performance. Motion and Attention scaled scores are calculated from the six motion metrics and the 13 attention metrics.

**Conner's Adult ADHD Rating Scale – Self-Report: Long Form
(CAARS–S:L).**

The CAARS–S:L is a 66-item self-report questionnaire designed to measure core symptoms of ADHD. The items are organized into four scales (Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, and Problems With Self-Concept) (Conners et al., 1999). The CAARS–S:L also contains questions to assess *DSM-IV* ADHD inattentive symptoms, hyperactive-impulsive symptoms, and total symptoms. Further, the measure contains an ADHD index that incorporates these.

The CAARS is presented in a checklist format, and each item is rated from 0 (*not at all, never*) to 3 (*very much, very frequently*). Individuals with a T score ≥ 65 on a given scale are considered to have clinically elevated symptoms in that area. The greater

the number of scales that indicate clinically relevant elevations, the greater the likelihood of a clinically significant problem.

Analysis of the internal reliability of the CAARS scale yielded coefficient alphas for the four scales ranging from .86 to .92 for both males and females, suggesting that the scales have excellent internal reliability (Erhardt et al., 1999). Using Pearson product-moment correlations, the CAARS scales had the following test-retest correlations: .88 ($p < .05$) for Inattention, .90 ($p < .05$) for Hyperactivity/Restlessness, .80 ($p < .05$) for Impulsivity/Emotional Lability, and .91 ($p < .05$) for Problems With Self-Concept (Erhardt et al., 1999). The CAARS was compared to the Wender Utah Rating Scale (WURS). The WURS requires adults to retrospectively report childhood ADHD symptomatology, whereas the CAARS measures current symptoms. However, the two scales are expected to relate because ADHD is now considered by many to be a developmental disorder that persists across the lifespan (Ramsay, 2010b; Ramsey & Rostain, 2005). Based on the procedures for comparison originally outlined by Kessel and Zimmerman (1993), a recent study calculated efficiency statistics for the CAARS; specificity was 87%, sensitivity was 82%, negative predictive power was 83%, positive predictive power was 87%, false positive rate was 13%, false negative rate was 18%, kappa was 0.692; and the overall correct classification rate was 85% (Erhardt et al., 1999). These findings suggest that the CAARS does indeed represent a reliable and valid measure for ADHD.

Procedure

Archival data was gathered from 216 clinical charts of participants at the aforementioned specialty clinic. For charts meeting criteria for inclusion in the study, the

data relevant to the study was extracted and de-identified by the investigator, and each participant was assigned a unique identifier. The de-identified data was transferred to a password-protected electronic database for data analysis. Data consisted of the completed Quotient (global scaled score percentile rank) and three metrics of the Attention State results (Attentive, Impulsive, and Distracted), the CAARS *DSM-IV* Hyperactive/Impulsive Symptom Count, and three CAARS scales (Memory Problems, Hyperactivity/Restlessness, and Impulsivity/Emotional Lability), which were interpreted based on the associated percentile rank to the T score.

Results

Statistical analyses were conducted to determine whether self-report measurement of ADHD symptom severity predicted observable measurement of ADHD symptom severity. Additionally, the present study endeavored to determine if increased self-reports of specific symptom subsets of ADHD predicted increased observable ADHD symptom severity. Self-reported ADHD symptom severity was operationalized as three dimensions of ADHD symptom subsets (as measured by the CAARS). These were a cognitive dimension (measuring inattention and memory), a behavioral dimension (hyperactivity and restlessness), finally a dimension assessing inhibition (impulsivity and emotional lability). T- scores derived from normative data for the symptom subset measures were used as values for comparison. Behavioral hyperactivity was operationalized as an analysis based on six motion metrics from the Quotient ADHD System (immobility duration, movements, displacement, area, spatial complexity, and temporal scaling), measured based on motion tracking readings from a sensor worn on the forehead while engaging in a continuous performance task. These metrics were analyzed normatively to form a composite metric called the motion tracking scaled score. The value of this metric was used for comparison to the aforementioned self-report measures. The motion-based metrics were also used in conjunction with 13 metrics of CPT performance (speed of responses for non-target hits, speed of responses for target hits, accuracy, omission errors, commission errors, latency, variability, coefficient of variation [COV], number of shifts, attentive, impulsive, distracted, and disengaged). These six motion-based metrics and 13 CPT performance metrics were analyzed

normatively to produce a global scaled score. The value of the global scaled score was used to determine a value for the measurement of observable ADHD symptoms.

Table 1 provides the means, standard deviations, range, minimum, and maximum for the CAARS Inattention/Memory, Hyperactivity/Restlessness, and Impulsivity/Emotional Lability scales. The Quotient ADHD System's global scaled score and motion scaled score are presented in Table 1, as well.

Table 1

Summary Statistics for CAARS Symptom Subset Scale Scores and Quotient ADHD System Global and Motion-Based Scores

Variable	<i>M</i>	<i>SD</i>	Range	Minimum	Maximum
CAARS Inattention/Memory Problems	69.56	12.41	57.00	33.00	90.00
CAARS Hyperactivity/Restlessness score	57.02	11.37	54.00	28.00	82.00
CAARS Impulsivity/Emotional Lability score	57.95	12.04	59.00	31.00	90.00
Quotient global scaled score	6.04	2.05	8.21	1.19	9.40
Quotient motion scaled score	5.93	2.71	9.55	.11	9.66

Statistical Analyses

Demographic analysis.

The sample consisted of 134 males and 75 females, with a mean age of 35 and an age range of 18 to 72. Participants identified as 82.5% Caucasian, followed by 8.5% Other, 3.8% African American, 3.3% Hispanic, and 1.9% Asian American. Participants had a mean education level of 15.8, years with a standard deviation of 2.46. They had a minimum of 11 years and a maximum of 23 years of education.

It was hypothesized that self-report of the severity of ADHD symptoms, as measured by the CAARS, would predict the observable severity of ADHD symptoms, as measured by the Quotient ADHD System global scaled score. We tested for independence of variables. Table 2 summarizes the correlations, means, and standard deviations.

Table 2

Summary of Intercorrelations, Means, and Standard Deviations for Overall Score on the Quotient ADHD System and Symptom Subset Scales on the CAARS

Measure	1	2	3	4	<i>M</i>	<i>SD</i>
1. Quotient ADHD System Global Scaled score	--	.033	.268*	.073	6.04	2.05
2. CAARS Inattention/Memory score	.033	--	.341*	.518*	69.56	12.41
3. CAARS Hyperactivity/Restlessness score	.268*	.341*	--	.508*	57.02	11.37
4. CAARS Impulsivity/Emotional Lability score	.073	.518*	.508*	--	57.95	12.04

*Correlation is significant at the 0.01 level (2-tailed)

Pearson product-moment correlations identified no significant correlation between self-reported severity of inattention/memory symptoms and observable ADHD severity ($r = .033$). Additionally, no significant correlation was found between self-reported severity of impulsivity/emotional lability symptoms and observable ADHD severity ($r = .073$). However, a significant and positive correlation was found between self-reported severity of hyperactivity/restlessness symptoms and observable severity of ADHD symptoms ($r = .268$). Given the lack of correlation for the other variables, a linear regression analysis was appropriate to determine if self-reported hyperactivity/restlessness would predict observable severity of ADHD symptoms (Field, 2009).

Additional analyses of assumptions were accordingly conducted (Field, 2009). Standardized residuals were plotted against standardized predicted values, revealing that assumptions of homoscedasticity and linearity were met. Specifically, the normality of the residuals was assessed through an examination of a normal probability plot (see Figure 1). The normal probability plot, examining observed cumulative percentages to expected cumulative percentages, supported the assumption of normality.

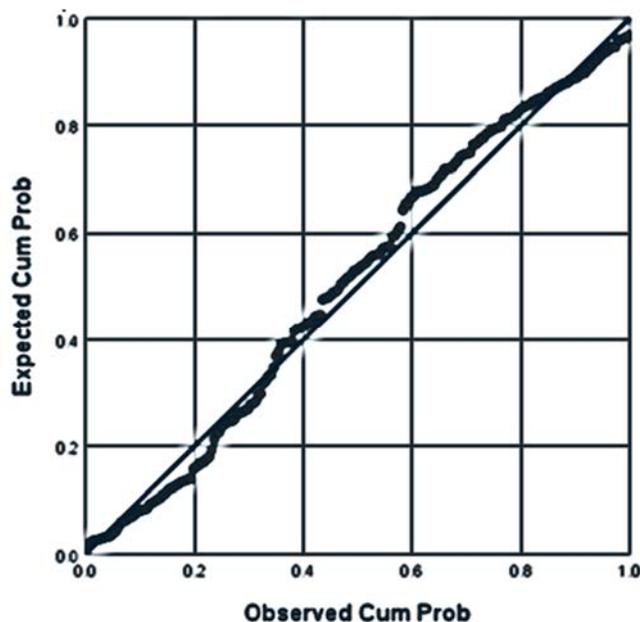


Figure 1. Standardized residuals and standardized predicted values for the Quotient ADHD System global scaled score.

A linear regression analysis was conducted to identify whether self-reports of hyperactivity/restlessness would predict observable assessment scores of overall ADHD symptom severity. The results revealed that increased hyperactivity/restlessness predicted increased observable symptoms of ADHD.

The results of the linear regression analysis, as shown in Table 2, reveal a coefficient of correlation of .268 ($R = .268$), with a coefficient of determination of .072 ($R^2 = .072$). The regression analysis revealed a significant regression, $F(1, 208) = 16.051, p = .000$ indicating that hyperactivity/restlessness made a significant contribution to the global presentation of observable ADHD symptoms. This indicates that approximately 7.2% of the Hyperactivity/Restlessness scale of the CAARS predicted the Quotient ADHD System global scaled score.

A Pearson product-moment correlation analysis was conducted to determine if self-reported inattention/memory problems significantly and positively correlated with behavioral measures of distractibility (errors of omission). Results indicated a significantly positive relationship between inattention/memory and observable distracted attention state ($r = .170$, $r^2 = .029$; $p = .007$). Correlations, means, and standard deviations are presented in Table 3.

Table 3

Linear Regression Statistics for the Quotient ADHD System Global Scaled Score as the Dependent Variable

Predictor Variable	R	R^2	Adjusted R^2	SE of Estimate	R^2 Change	F Change	$df1$	$df2$	Sig. F Change
CAARS Hyperactivity/ Restlessness score	.268	.072	.067	1.975	.072	16.051	1	208	.000

A Pearson product-moment correlation was conducted to determine if increases in self-reported hyperactive/impulsive symptoms significantly positively and correlated with observable measurement of impulsiveness. Results indicated no significant correlation between these measures ($r = .108$, $p = .06$). Correlations, means, and standard deviations are presented in Table 4.

Table 4

Intercorrelations, Means, and Standard Deviations for the Quotient ADHD System

Distracted Metric and the CAARS Inattentive Memory Scale

Measure	1	2	<i>M</i>	<i>SD</i>
1. Quotient ADHD System distracted metric score	--	.170*	14.26	13.00
2. CAARS Inattentive/Memory score	.170*	--	69.56	12.42

*Correlation is significant at the 0.01 level (2-tailed)

Pearson product-moment correlational analyses were conducted to determine if hyperactivity/restlessness and impulsivity/emotional lability would correlate with behavioral impulsivity (errors of commission). There was not a significant positive correlation ($r = .010, p = .444$) between observable measurement of impulsivity and self-report measurement of impulsivity/emotional lability. Moreover, observable measurement of impulsivity and self-report measurement of hyperactive/restlessness did not have a significant positive correlation ($r = .065, p = .174$). A significant correlation was found between self-report measurement of impulsivity/emotional lability and hyperactivity/restlessness, however ($r = .508, r^2 = .258, p = .000$). Table 5 summarizes the correlations, means, and standard deviations for hyperactivity/impulsivity, impulsivity/emotional lability and behavioral impulsivity.

Table 5

Intercorrelations, Means, and Standard Deviations for the Quotient ADHD System Impulsive Metric and the CAARS Hyperactive/Impulsive Symptom Scores

Measure	1	2	<i>M</i>	<i>SD</i>
1. Quotient ADHD System impulsive metric	--	.108	43.40	22.25
2. CAARS Hyperactive/ Impulsive Symptoms score	.108	--	60.77	14.33

To examine whether scores on scales of hyperactivity/restlessness, impulsivity/emotional lability, and inattention/memory problems would predict observable behavioral hyperactivity Pearson correlation analyses and linear regression analysis were conducted.

As Table 6 shows, the only significant and positive correlation found was between the self-reported severity of hyperactivity/restlessness symptoms and observable behavioral hyperactivity ($r = .231$, $r^2 = .053$; $p = .001$). Additional significant and positive correlations were found within self-report measures of ADHD symptom subsets. Specifically, a significant positive correlation was found between self-report measures of inattention/memory and hyperactivity/restlessness ($r = .341$, $r^2 = .116$; $p = .000$). A significant positive correlation was also found between self-report measures of inattention/memory and impulsivity/emotional lability ($r = .518$, $r^2 = .268$; $p = .000$). Finally, a significant positive correlation was found between self-report measures of

hyperactivity/restlessness and impulsivity/emotional lability ($r = .508$, $r^2 = .258$; $p = .000$). Given the aforementioned considerations, linear regression analysis was necessary only to determine if self-reported hyperactivity/restlessness would predict observable severity of ADHD symptoms. Tests of assumptions and multiple linear regression were met. Table 6 summarizes the correlations, means, and standard deviations for self-reported hyperactivity/restlessness symptoms and observable behavioral hyperactivity.

Table 6

Intercorrelations, Means, and Standard Deviations for the Quotient ADHD System Impulsive Metric and the CAARS Impulsivity/Emotional Lability and Hyperactive/Restlessness Symptom Scores

Measure	1	2	3	<i>M</i>	<i>SD</i>
Quotient impulsive metric	--	.010	.065	43.40	22.25
CAARS Impulsivity/Emotional Lability score	.065	--	.508*	57.95	12.04
CAARS Hyperactive/Restlessness score	.010	.508*	--	57.02	11.37

*Correlation is significant at the 0.01 level

Standardized residuals were plotted against standardized predicted values, revealing that assumptions of homoscedasticity and linearity were met. The normality of the residuals was tested through an examination of a normal probability plot (see Figure

2). The normal probability plot examining observed cumulative percentages to expected cumulative percentages supported the assumption of normality.

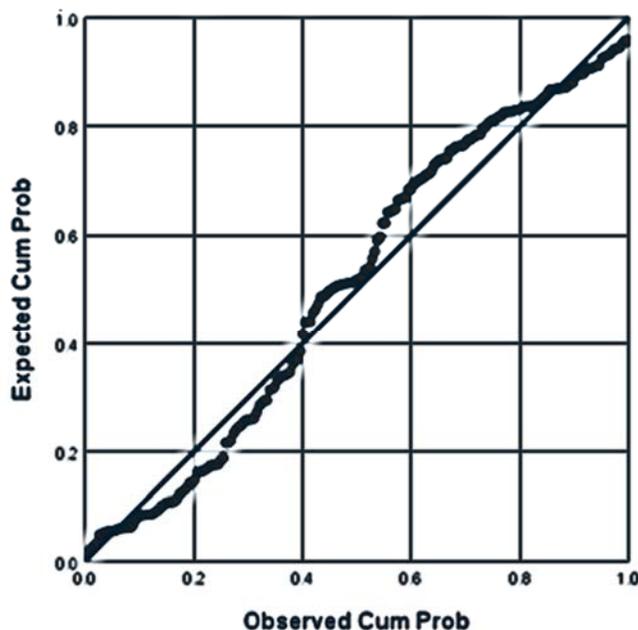


Figure 2. Standardized residuals and standardized predicted values for the Quotient ADHD System global scaled score.

A linear regression determined that hyperactivity/restlessness predicted increased behavioral hyperactivity. As shown in Table 7, the results of the simple regression analysis revealed a coefficient of correlation of .231 ($R = .231$), with a coefficient of determination of .053 ($R^2 = .053$); minimal shrinkage was shown with the adjusted coefficient of determination ($R^2 = .049$). The regression analysis revealed a significant regression $F(1, 208) = 11.796, p = .001$ indicating that the CAARS Hyperactivity/Restlessness scale explained almost 5% of observable symptoms of behavioral hyperactivity on the Quotient ADHD System.

Table 7

Summary of Intercorrelations, Means, and Standard Deviations for the Motion Scaled

Score on the Quotient ADHD System and Symptom Subset Scales on the CAARS

	1	2	3	4	<i>M</i>	<i>SD</i>
Quotient ADHD	--	-.045	.231*	-.004	5.93	2.71
System motion scaled score						
CAARS Inattention/ Memory score	-.045	--	.341*	.518*	69.56	12.41
CAARS Hyperactivity/ Restlessness score	.231*	.341*	--	.508*	57.02	11.37
CAARS Impulsivity/ Emotional Lability score	-.004	.518*	.508*	--	57.95	12.04

*Correlation is significant at the 0.01 level

Table 8

*Summary of Linear Regression Statistics for the Quotient ADHD System Motion Scaled**Score as the Dependent Variable*

Predictor Variable	<i>R</i>	<i>R</i> ²	Adjusted <i>R</i> ²	<i>SE</i> of Estimate	<i>R</i> ² Change	<i>F</i> Change	<i>df</i> 1	<i>df</i> 2	Sig. <i>F</i> Change
Hyperactivity/ Restlessness (CAARS) score	.231	.053	.049	2.645	.049	11.796	1	209	.001

Discussion

This study examined the relationship between self-reported measurement of ADHD symptom severity, as measured by the Conner's Adult ADHD Rating Scale (CAARS), and observable measurement of ADHD symptom severity, as measured by the Quotient ADHD System. Given previous research supporting a relationship between self-report measurement of ADHD symptom severity and motion-based ADHD assessment, similar to the Quotient ADHD System, it was hypothesized that self-report measurement of ADHD symptom severity would predict motion-based behavioral measurement of ADHD symptom severity (Hall et al., 2015; Losier et al., 1996; Riccio & Reynolds, 2001; Teicher et al., 1996).

A comprehensive search of Google Scholar, PsychInfo, and EBSCO databases failed to find a single study investigating the validity and clinical utility of the Quotient ADHD System in an adult ADHD population, specifically as a means of supplemental diagnostic assessment for adults with ADHD. However, some studies identified the sensitivity of the Quotient ADHD System to medication effects in children with ADHD (Heiser et al., 2004; Losier et al., 1996). In addition, CPT derived motion-based assessments, including the OptaX system (past version of the Quotient ADHD System) and the Test of Variables of Attention (TOVA) have shown sensitivity to ADHD symptoms in children (Sumner, 2010; Teicher et al., 2008). The QB Test was also found to be sensitive to ADHD in adults, but lacking in specificity to ADHD subtypes (Edebol et al., 2013; Lis et al., 2010). Therefore, the present study endeavored to identify empirical support for the Quotient in the assessment of adults with ADHD and to inform the clinical utility of this ADHD CPT System.

Observable and Self-Report Measures of ADHD Symptom Severity

The self-reported severity of hyperactive/restlessness symptoms, as measured by self-report on the CAARS, predicted 7.2 % of the variance in observable global scaled scores on the Quotient. However, no significant relationship was identified between self-reported inattention/memory symptoms (CAARS) and the global scaled score (Quotient ADHD System). Moreover, no relationship was found between self-reported symptoms of impulsivity/emotional lability (CAARS) and the global scaled score (Quotient). These findings suggest that Quotient measurement of observable symptoms of ADHD severity is sensitive to hyperactivity and restlessness, although possibly less sensitive to symptoms of ADHD related to inattention, memory, emotional lability, and impulsiveness (CAARS).

This study also found that symptoms related to inattention and memory (as measured by the Inattention/Memory scale on the CAARS) accounted for 2.9% of the variance in observable. Finally, hyperactivity and restlessness (as measured by the Hyperactivity/Restlessness scale on the CAARS) accounted for 5.3% of the variance in observable behavioral hyperactivity (as measured by the motion scaled score on the Quotient ADHD System).

Implications

Previous studies of motion-based continuous performance tasks have found that these measurements are sensitive to ADHD in children. This may be explained by the current understanding of ADHD and recent findings, which suggest decreased motor activity with age and frequent reduction in hyperactivity and observable restlessness into adulthood (Turgay et al., 2012; Wilens et al., 2002).

Inattention and errors of omission.

The current study found that CAARS self-reported inattention/memory shared a significant positive correlation with observable measurement of distraction, as measured by the Quotient ADHD System. Past literature suggests that CPTs are sensitive to adult groups with a diagnosis of ADHD, but does not address specific subtypes of ADHD (Riccio & Reynolds, 2001; Teicher et al., 2008). CPT performance tasks require sustained attention to a task. Individuals with inattentive symptoms of ADHD have difficulty with such tasks. Thus, lapses in attention or reduced attention may offer an explanation for increased errors of omission. From a clinical perspective, further exploration of this potential connection could inform assessment of the ADHD – predominately inattentive type because CPT assessment could offer quantification of inattentive symptoms, as well as information on the specific presentation of these deficits.

Identification of an association between ADHD symptom severity, as measured by self-report and ADHD symptom severity, as measured by motion-based assessment, contains several implications from a clinical standpoint. Specifically, assessment of observable behavior circumvents the issues inherent with self-report measures, which are affected by reporting biases, a well-documented concern among individuals with ADHD (Adler et al., 2007; Erhardt et al., 1999; Knouse et al., 2005; Kooij et al., 2008; Nelson, 2011; Prevatt et al., 2011). CBT for adult ADHD has gained increasing support in recent years (Canu & Wymbs, 2015; Ramsay, 2010c, 2012; Ramsay & Rostain, 2011). Moreover, the use of multimodal, multidimensional, and contextually appropriate diagnostic assessment is recommended in assessing ADHD, and assessment of

observable behaviors contributes to a comprehensive assessment (Barkley, Knouse, & Murphy, 2011; Calderon & Ruben, 2008; Kennedy, 2007).

Hyperactivity, impulsivity, and errors of commission.

The current study found that no significant relationship existed between self-report of hyperactive/impulsive symptoms (as measured by the CAARS) and observable measurement of impulsivity using errors of commission (as measured by the Quotient ADHD System). The Quotient ADHD System determines the Impulsive metric based upon the frequency of errors of commission (the participant enters an incorrect answer in a limited time). Although the metric attempts to capture the essence of impulsivity (action without thinking), no relationship was found between self-reported and observable measures of impulsivity. Adults with ADHD have difficulty in self-management, including organization, planning, initiating and completing tasks on a timely basis, tracking and shifting tasks, self-monitoring, and self-inhibition. In the aggregate, these are executive functions (EFs), which are those self-directed actions needed to choose goals and to create, enact, and sustain actions toward those goals (Barkley, 1997; Ramsay, 2010b; Solanto, 2015). This difficulty in self-regulation typically results in reduced productivity, inefficiency, missed deadlines, poor planning, careless errors, and losing and forgetting things because of disorganization. In some cases, reduced inhibitory control may also lead to emotional dysregulation and inappropriate verbal and/or physical behavior in interpersonal interactions. Over the lifetime of the individual, these difficulties contribute to failure to achieve goals personally, academically, and occupationally. These failures, in turn, likely contribute to the high rates of anxiety and depression in adults with ADHD (Brown, 2002; Solanto,

2015b; Swanson, 2003). Thus, individuals with ADHD may not exhibit observable inhibitory control deficits, given the lack of extraneous stimuli or demand on executive functioning during the continuous performance task offered by the Quotient ADHD System.

Although these findings are surprising, they may be related to the characteristics of sample, which consisted of individuals who were more of a higher SES and higher functioning than the general ADHD population. High levels of functioning, advancing through college, and maintaining productive and even higher paying employment may require the ability to inhibit errors of commission that are detectable by the Quotient. This finding deserves additional investigation and replication of the research.

Discrepancy between self-report and CPT measured impulsivity.

No significant relationship was found between self-reported hyperactivity/restlessness (as measured by the CAARS) and observable measurement of impulsivity (as measured by the Quotient ADHD System). No significant positive relationship was found between self-reported impulsivity/emotional lability (as measured by the CAARS) and observable impulsivity (as measured by the Quotient ADHD System). Previous literature suggests a connection between self-reports of ADHD and observable reports of impulsive symptoms within a CPT task when assessing children (Heiser et al., 2004; Teicher et al., 2008). No relationship was found using the Quotient ADHD System Impulsive metric and the Impulsivity/Emotional Lability scale of the CAARS in the sample of adult participants in the present study. The discrepancy may be explained by the changes in executive functioning ability developmentally from childhood to adulthood, as well as changes in coping strategies for deficits in executive

functioning from childhood to adulthood (Boonstra et al., n.d.; Fischer, Barkley, Smallish, & Fletcher, 2005; Wilens et al., 2002; Young, 2005). Lack of significance here may also indicate that the two measures assess distinct manifestations of impulsivity. Specifically, the Quotient ADHD System motion metrics may indicate a manifestation of impulsivity that is underrepresented on self-report measures such as the CAARS due to lack of self-awareness. Specifically, the CAARS requires self-awareness, whereas the Quotient ADHD System does not.

Self-reported and behavioral hyperactivity.

The present study found that self-reported hyperactivity/restlessness (as measured by the CAARS) predicted observable measurement of behavioral hyperactivity (as measured by the motion scaled score of the Quotient ADHD System). In contrast, no significant relationship was found between self-report measures of inattention/memory (as measured by the CAARS) and observable measurements of behavioral hyperactivity. Furthermore, no significant relationship was found between self-reported impulsivity/emotional lability and observable behavioral hyperactivity (as measured by the motion scaled score of the Quotient ADHD System).

The findings suggest that observable assessment of behavioral hyperactivity using the Quotient may be sensitive to hyperactive traits associated with ADHD. This is supported by the predictive relationship between a widely utilized self-report measurement of ADHD symptoms and subsets, including hyperactivity/restlessness (the CAARS Hyperactivity/Restlessness Scale), and motion-based measurement of behavioral hyperactivity (motion scaled score on the Quotient ADHD System). These findings suggest that increased behavioral hyperactivity (as measured by the Quotient ADHD

System) is most directly influenced by symptoms of hyperactivity/restlessness. In addition, these findings suggest that motion-based measurement may not capture symptoms related to inattention/memory or impulsivity/emotional lability (as measured by the CAARS). This shows good sensitivity, as well as convergent and discriminant validity of the Quotient motion scaled score.

The present study addresses a concern among clinicians as to whether to include objective assessment of ADHD and the extent to which it should inform case conceptualization and diagnosis.

Limitations

The current study used archival data, and therefore no direct behavioral observation interview and assessment were conducted. With the exception of the Quotient and reports from collaterals, the majority of the data collected for the present study was gathered from self-report inventories. Challenges to validity inherent in self-report assessment create additional limitations. In addition, the CAARS-S:L measures ADHD in accordance with the *DSM-IV* (Conners et al., 1999) and has not yet been updated for the *DSM-5*. Moreover, results may have been impacted by the fact that individuals with ADHD have been shown to have lower self-awareness and may underreport their symptoms, as previously discussed (Barkley et al., 2011; Jiang & Johnston, 2011; Kooij et al., 2008; Nelson, 2011).

Generalizability of the present study's findings are limited by characteristics of the sample, which consisted of individuals seeking assessment for ADHD at a university-based outpatient adult ADHD specialty clinic in a large northeastern city. Subjects were

high functioning individuals with the financial means to seek assessment and decidedly higher than average educational levels.

Future Directions

Future studies should investigate in greater detail the value of objective assessment of ADHD, the extent to which it relates to ADHD symptom severity, and its relationship to specific subsets of ADHD symptoms (e.g., inattentiveness and impulsivity/hyperactivity).

Additional investigation as to whether specific scales within the CAARS predict ADHD symptom severity, as measured by motion-based assessment, may provide additional information that may further improve assessment and treatment planning. Investigation of the clinical utility of observable measures of symptom presentation may address this concern. Moreover, future researchers may wish to compare the Quotient ADHD System to self-report assessments for ADHD that examine executive functioning directly, such as the Barkley Deficits in Executive Functioning Scale (Barkley 2011b). Finally, some results may be attributable to extraneous additional factors, such as distraction during testing, ADHD medication, and previous treatment. The extent to which such factors influence outcomes may merit future investigation, as well.

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