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Michelle Y Kibby

Sarah A Vadnais

Audreyana C Jagger-Rickels

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Which Components of Processing Speed are Affected in ADHD Subtypes?

Michelle Y. Kibby, Sarah A. Vadnais, & Audreyana C. Jagger-Rickels

Southern Illinois University

Corresponding Author:

Michelle Kibby, PhD

Department of Psychology

Southern Illinois University

LSII, Room 281

Carbondale, IL 62901-6502

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Abstract

The term 'processing speed' (PS) encompasses many components including perceptual, cognitive and output speed. Despite evidence for reduced PS in ADHD, little is known about which component(s) is most impacted in ADHD, or how it may vary by subtypes. Participants included 151 children, ages 8-12 years, with ADHD Predominantly Inattentive Type, ADHD Combined Type and typically developing controls using DSM-IV criteria. All children completed four measures of processing speed: Symbol Search, Coding, Decision Speed, and simple reaction time. We found children with ADHD-PI and ADHD-C had slower perceptual and psychomotor/incidental learning speed than controls and that ADHD-PI had slower decision speed than controls. The subtypes did not differ on any of these measures. Mean reaction time was intact in ADHD. Hence, at a very basic output level, children with ADHD do not have impaired speed overall, but as task demands increase their processing speed becomes less efficient than controls'. Further, perceptual and psychomotor speed were related to inattention, and psychomotor speed/incidental learning was related to hyperactivity/impulsivity. Thus, inattention may contribute to less efficient performance and worse attention to detail on tasks with a higher perceptual and/or psychomotor load; whereas hyperactivity/impulsivity may affect psychomotor speed/incidental learning, possibly via greater inaccuracy and/or reduced learning efficiency. Decision speed was not related to either dimension. Results suggest that PS deficits are primarily linked to the inattention dimension of ADHD but not exclusively. Findings also suggest PS is not a singular process but rather a multifaceted system that is differentially impacted in ADHD.

Key Words: ADHD subtypes, processing speed, inattention, hyperactivity/impulsivity

Introduction

Individuals with Attention-Deficit/Hyperactivity Disorder (ADHD) often have slower processing speed (PS) than their typically developing peers (e.g., Calhoun & Mayes, 2005; Jacobson et al., 2011; Nikolas & Nigg, 2013; Shanahan et al., 2006; Weiler, Bernstein, Bellinger, &Waber, 2000; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Nonetheless, there is little consensus as to which component(s) of PS is affected in ADHD and how this might vary by subtype. Understanding subtype differences is important to the field because there is debate as to whether ADHD-PI is a separate disorder from ADHD-C/-HI or whether they are subtypes of the same disorder (Diamond, 2005; Milich, Balentine, & Lynam, 2001; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002). Determining whether there are subtype differences in PS will help inform this debate. Thus, our study investigated various aspects of PS (perceptual, cognitive and output speed) that may be affected in ADHD at the subtype level. ADHD-HI type is not assessed in this paper as it is rare after the preschool years (Barkley, 2003; Milich et al., 2001).

Processing Speed

Slow PS can affect speed of performance on various tasks such as reasoning, rate of new learning, comprehension of new information and working memory, and it can lead to mental fatigue (Cepeda, Blackwell, & Munakata, 2013; Prifitera, Weiss, & Saklofske, 1998). Unfortunately, there is no generally agreed upon definition of PS, despite many authors having defined and used the term (e.g., Burns, Nettlebeck, & McPherson, 2009; Cepeda et al., 2013; Fry & Hale, 2000; Horn, 1987; Jacobson et al., 2011; Kail & Hall, 1994; Sattler, 2008; Shanahan et al., 2006; Woodcock, McGrew, & Mather, 2001). Furthermore, the PS tasks used by these authors vary widely in the constructs they assess, making it difficult to compare across studies. To address this issue, Salthouse (2000) compiled a description of the most prominent operational definitions used to measure PS. These constructs include reaction time, which is the time taken to respond to a simple stimulus; psychophysical speed, which is the time taken to accurately perceive stimuli that are presented for very brief periods of time; perceptual speed, which is the time taken to complete a simple task; psychomotor speed, which is the time taken to complete a simple task that requires repetitive movements including marking or drawing lines on a piece of paper; and decision speed, which is the time taken to process and choose a response from moderately complex content. Although all are at least slightly different, each construct contributes to PS in its entirety. Further, not all PS measures utilize each aspect to the same extent. Thus, a component-based representation, similar to Salthouse's, allows for better conceptualization of the different demands required in the various PS tasks. In their study, Shanahan defined PS as the "underlying cognitive efficiency at understanding and acting upon external stimuli, which includes integrating low level perceptual, higher level cognitive, and output speed" (Shanahan et al., 2006, p. 586). Based upon the work of Salthouse (2000) this is an adequate definition of PS, and it is also concise. Therefore, it was used for our study because it includes perceptual, cognitive and output speed components, maps onto tasks that are clinically available, and is not specific to the verbal or nonverbal domain. Within the neuropsychology literature commonly-used measures of perceptual PS include Symbol Search and Trails A; commonly-used measures of cognitive PS include Coding and Trails B; and commonly-used measures of output speed include Coding Copy and reaction time.

ADHD and Processing Speed

There is a great deal of literature demonstrating PS is affected in ADHD (e.g., Calhoun & Mayes, 2005; Jacobson et al., 2011; Nickolas & Nigg, 2013; Nigg et al., 2002; Shanahan et al., 2006; Weiler et al., 2000; Willcutt et al., 2005), although findings vary depending upon the measure of PS assessed, as discussed below. The field is less conclusive when considering PS differences between ADHD subtypes/presentations, as some studies find differences (Barkley, DuPaul & McMurray, 1990; Mayes, Calhoun, Chase, Mink, & Stag, 2009; Nikolas & Nigg, 2013; Nigg et al., 2002; Thaler, Bello & Etcoff, 2012), whereas others do not (Nigg et al., 2002; Yang et al., 2013). Some of these differences may be related to the categorical nature of the DSM diagnostic system, as the criteria for the Predominantly Inattentive type/presentation do not require an absence of H/I symptoms, but that there are fewer than 6 H/I symptoms currently. The differences between study findings also may occur because controls could have subclinical ADHD symptoms that obscure group differences. Further, some of the differences between studies appear to be related to the component of PS assessed, as noted subsequently.

In terms of perceptual PS, the findings are inconclusive when comparing ADHD as a group to controls (Jacobson et al., 2011; Johnson et al., 2001; Nikolas & Nigg, 2013; Seidman, 2006; Shanahan et al., 2006; Weiler et al., 2000). The same is true at the subtype level. For example, ADHD-Predominantly Inattentive Type (ADHD-PI) may be more impaired than Combined Type (ADHD-C) and controls on Trail Making Test, Part A (Nigg et al., 2002). In contrast, although children with ADHD tend to have slower performance than their typically developing counterparts on measures such as Color or Word naming on the Stroop, subtype differences are not commonly found on these measures (Nigg et al., 2002). When using WISC-IV Symbol Search, Weiler and colleagues (2000) found the ADHD-PI group was slower than the control group, but their study did not include an ADHD-C group. Taken together, it appears that slow perceptual PS is comparably impaired, or more impaired, in ADHD-PI than in ADHD-C. As both subtypes share attention problems, deficits in perceptual speed may be related to the inattention dimension of ADHD (Calhoun & Mayes, 2005; Chhabildas, Pennington & Willcutt, 2001; Goth-Owens, Martinez-Torteya, Martel & Nigg, 2010; Roberts, Milich, & Barkley, 2015; Rommelse et al., 2007; Willcutt et al., 2005) as opposed to the hyperactivity/impulsivity dimension. Inattention may lower stimuli processing efficiency (Salum et al., 2014), and the addition of hyperactivity/impulsivity symptoms may hasten overall performance on some of these simple, perceptual speed tasks, as the Combined group performed more similarly to controls on most measures except the Stroop.

In the cognitive PS literature, Coding is a commonly studied measure, and research consistently shows that children with ADHD perform more slowly than their typically developing counterparts (Bridgett & Walker, 2006; Jacobson et al., 2011; Shanahan et al., 2006; Weiler et al, 2000). Similarly, PS tasks that include working memory, cognitive flexibility and/or decision-making skills tend to be affected in ADHD (Johnson et al., 2001; Shanahan et al., 2006), although not all agree (Rommelse et al., 2007). When focused on ADHD subtypes, some research indicates the Inattentive group may be more impaired than the Combined group on tasks such as Coding (Barkley et al., 1990) and a PS factor that includes Trails sequencing time (Nikolas & Nigg, 2013). In contrast, another study found both subtypes performed similarly but worse than controls on Coding (Chhabildas et al., 2001). The literature also is mixed with respect to whether there are significant differences between controls and children with ADHD-C, such that some studies support a difference (Chhabildas et al., 2001; Goth-Owens et al., 2010), whereas others do not (Barkley et al., 1990; Nigg et al., 2002). It is important to note that cognitive PS tasks assess multiple constructs (e.g., cognitive, perceptual and output speed), and that the measures used varied across studies, which contributes to the variability in findings. For example, Coding appears to measure psychomotor speed as well as working memory (Jacobson et al., 2011) and incidental learning (Ashendorf, 2012; Joy, Kaplan, & Fein, 2004). Regardless, it appears that slow cognitive PS may be related to the inattention dimension of ADHD, as both subtypes have been shown to have impaired cognitive PS, and the Combined group performs comparably to, or better than, those with ADHD-PI (Calhoun & Mayes, 2005; Chhabildas et al., 2001; Goth-Owens et al., 2010; Rommelse et al., 2007; Willcutt et al., 2005).

One way to assess output speed is simple reaction time. When assessing mean reaction time, slower reaction time has been found in individuals with ADHD as compared to controls (Kalff et al., 2005; Nigg et al., 2002; Willcutt et al., 2005), but not always (Johnson et al., 2001; Karalunas, Huang-Pollock & Nigg, 2012; Rommelse et al., 2007). Other researchers focused on reaction time variability, and more variability was found in the ADHD group than in controls (Kalff et al., 2005; Karalunas et al., 2012; Willcutt et al., 2005), which may account for the slower mean response time. In general, the reaction time literature has focused on ADHD as a whole rather than separating subtypes. Of the limited research conducted on subtypes, Nigg and colleagues (2002) did not find differences between subtypes in mean reaction time, but they did find that ADHD was slower than controls, suggesting slower reaction time may be associated with the inattention dimension, as both subtypes functioned poorly on this dimension and the Combined group did not perform worse than the inattentive group. Another way to assess output speed is psychomotor speed. Less research in this area was found, but it showed individuals with ADHD have slower psychomotor speed than controls (Johnson et al., 2001; Walker et al, 2000). Only one study on subtypes was discovered, and it suggested that reduced psychomotor speed is related to having inattention with minimal hyperactivity, as opposed to ADHD more broadly (Ercan et al., 2016), again linking output speed with the inattention dimension.

Taken together, it appears the PS deficit in ADHD could be due to the cognitive, perceptual and/or output speed components of PS, although findings on mean reaction time are the most disparate. At the subtype level, individuals with ADHD-PI are frequently slower than controls on all aspects of PS assessed. In contrast, the literature is more disparate regarding the performance of individuals with ADHD-C, although perceptual PS may be spared when hyperactivity/impulsivity hastens performance on these simple tasks. Based on the subtype literature showing ADHD-PI is comparably impaired, or more impaired, in PS than ADHD-C, it is suspected that deficits in the PS components are related to the inattention dimension as opposed to the hyperactivity/impulsivity dimension of ADHD. While this notion has been suggested elsewhere (e.g., Calhoun & Mayes, 2005), limited research has examined ADHD symptomology and PS components using a continuous approach, such as linear regression; most studies on PS in ADHD use the categorical, subtype approach as reviewed above.

The primary purpose of our study was to identify which type(s) of PS is affected in ADHD-Predominately Inattentive versus -Combined type when comparing groups on perceptual, cognitive, and output speed. For all group-based analyses, ADHD-PI, ADHD-C and typically developing controls are assessed in order to compare the subtypes to each other and to determine where shared differences occur versus controls. Based upon the literature reviewed, it was hypothesized that children with ADHD-PI would perform slower than controls on output speed, as measured by simple reaction time, and on perceptual speed, as measured by Symbol Search. Both tasks allow for hasty responding given the simple nature of the tasks, which may help ADHD-C to perform more rapidly despite having inattention. It was hypothesized that both subtypes would perform worse than controls on Coding based upon the literature reviewed. The analysis on Decision Speed was largely exploratory given the lack of research on ADHD using this task, but it was expected that both subtypes would perform worse than controls based upon the literature on cognitive PS in general. In addition, PS deficits were hypothesized to be related to the Inattention Dimension of ADHD, as opposed to the hyperactivity/impulsivity dimension, when analyzing the data from a continuous approach.

Methods

Participants

Participants included 151 children, ages 8-12 years. Children were recruited from the greater community (3 States' regions), and most were recruited as part of grant-funded projects focused on reading disabilities and ADHD (see Acknowledgements). Parents brought their children to the first author's laboratory for the study. Fifty participants had ADHD-PI, 40 had ADHD-C, and 61 were typically developing children. Groups were equated on age, gender, race/ethnicity, maternal education (as a measure of SES) and verbal intellect (see Table 1 for demographic information by group). The Verbal Comprehension Index (VCI) was used to assess IQ instead of FSIQ because FSIQ includes measures of processing speed, whereas the subtests comprising the VCI are untimed. Neither the PRI nor the GAI, the amalgamation of VCI and PRI, were used because most measures of Perceptual Reasoning (PRI) are timed.

Insert Table 1 about here

ADHD was diagnosed by a child clinical neuropsychologist based upon DSM-IV criteria, as this was the version in use at the time of data collection. The diagnostic process is described in more detail in prior manuscripts using this database (Kibby et al., 2014, 2015). In brief, interview data, questionnaires, and behavior observations were used to determine whether DSM-IV criteria for ADHD were met and to determine subtype. As part of the questionnaires, parents and teachers completed the Behavior Assessment System for Children – Second Edition (BASC-2; Reynolds & Kamphaus, 2004) to assess behavioral functioning in daily life, including inattention and hyperactivity/impulsivity, and parents also completed a questionnaire that contained the diagnostic criteria for ADHD from the DSM-IV. Some of the children with ADHD had been diagnosed prior to our testing and were being treated with stimulant medication, but participants were off medication at the time of testing. We did not have anyone with ADHD-HI in our sample. This likely is because the -H/I presentation is more prevalent in preschoolers/early childhood, and then it tends to mature into ADHD-C or typical development by the age period used in this study (Barkley, 2003; Milich et al., 2001). As illustrated in Table 1, ADHD-PI and ADHD-C differed significantly on the H/I dimension as assessed by Parent and Teacher BASC-2 scores (*p*s < .001) but not on Attention Problems. When assessing DSM-IV symptom count via Chi-Square analyses, ADHD-PI and ADHD-C did not differ in number of Inattention symptoms ($X^2 = 2.54$, $p = .924$), but they did differ in number of Hyperactivity/Impulsivity symptoms ($X^2=53.55$, $p < .001$) with the -Combined type having more H/I symptoms. When defining ‘subclinical’ as 4 or more symptoms, 30% percent of children with ADHD-PI had subclinical H/I symptom levels. Twenty-eight percent of controls had subclinical Inattention, and 5% had subclinical H/I symptoms.

A participant was classified as a control if he/she did not meet diagnostic criteria for ADHD. For both groups, children were excluded from the current study if they had a history of medical or neurological disorders (e.g., TBI, tics, immune disorders), severe environmental problems (e.g., suspected neglect or abuse), other psychiatric diagnoses (e.g., major depression, generalized anxiety disorder), reading disability/developmental dyslexia, or an IQ below 80. The original sample from which this project was drawn consisted of 284 children, but after the exclusionary criteria were applied, the final sample contained 151 children. Consistent with groups not having an anxiety or mood disorder diagnosis, mean depression and anxiety values for all three groups were in the mid 50s or lower for parent- and teacher-report BASC-2 scores.

Measures

Intelligence. To assess intellectual ability across groups, the Wechsler Intelligence Scale for Children (WISC-III or WISC-IV depending upon the time at which data was collected; Wechsler, 1991, 2003) was administered. A Verbal Comprehension Index (VCI), which included Similarities, Vocabulary, and Comprehension subtests across versions, was used to represent intellectual ability given the high prevalence of working memory and processing speed weaknesses in those with ADHD (Calhoun & Mayes, 2005) and that the VCI subtests are not as influenced by either of these abilities as opposed to FSIQ, GAI, and PRI, as noted earlier. All of the measures used for this study have adequate or better psychometric properties according to their respective manuals.

Attention and Hyperactivity/Impulsivity. To aid in the diagnosis of ADHD, severity of symptoms of inattention and hyperactivity/impulsivity were measured by parent and teacher report on the BASC-2, as noted earlier. The Attention Problems and Hyperactivity/Impulsivity scales measure common symptoms of inattention and hyperactivity/impulsivity, respectively, that are seen in daily life. Age and gender-specific norms were used.

Processing Speed. Simple Reaction Time (SRT) was assessed with a computerized measure of reaction time. An auditory tone was presented, and the child was asked to press the spacebar as quickly as possible after hearing the tone within a 500-2500 ms response time frame. It had a variable inter-stimulus interval. The tone was presented at a volume that was comfortable for the child and was at 700 hz. The task consisted of 100 trials and lasted for 3 minutes, 25 seconds. The SRT score was calculated by averaging the RT from the trials in which the child responded.

The Symbol Search and Coding subtests from the WISC-III or WISC-IV were administered (depending upon the time of testing) to obtain measures of perceptual and cognitive processing speed, respectively. Symbol Search requires the participant to quickly and accurately examine a set of symbols and decide whether the target symbols are present within that set. Each set is different. Hence, it is a measure of perceptual speed. Coding requires the child to match symbols with their corresponding numbers and to copy the corresponding symbols as quickly and accurately as possible. Thus, it is a measure of psychomotor speed. As the same set of 9 number-symbol pairs is used throughout the subtest, this subtest has a cognitive component also as it measures incidental learning (Ashendorf, 2012; Joy et al., 2004).

The Decision Speed test from the Woodcock-Johnson III Test of Cognitive Abilities (WJ-III; Woodcock et al., 2001) was used as a measure of semantic decision speed. In this test, the child is asked to circle two pictures out of seven that are the most conceptually similar (e.g., a sun and a moon) for each item. Hence, this task may be a purer measure of cognitive PS as it has less psychomotor speed demands than Coding.

Procedure

The children participated in a neuropsychological evaluation that included the measures described above, as well as other measures, as part of larger, grant-funded projects. Parents completed various questionnaires and a clinical interview on their child. Teachers completed the BASC-2 as well. The Institutional Review Board's Human Subjects Committee approved the project from which this data was derived.

Results

Preliminary Analyses

Variables that violated statistical assumptions were appropriately corrected. However, Decision Speed was kurtotic, and the use of various transformations did not correct this issue;

thus, the Decision Speed variable was left uncorrected for ease of interpretation. To verify groups were comparable on verbal intellect, age, socio-economic status (maternal education), race/ethnicity and sex, they were compared using chi-square analyses and one-way ANOVAs. Groups did not differ on any of the equated variables (*ps* > .05). See Table 1.

Main Results

A single-factor MANOVA was performed to compare ADHD-PI, ADHD-C, and control groups on the measures of processing speed: Simple Reaction Time, Symbol Search, Coding, and Decision Speed. Results indicated that there was a significant difference between the groups, Wilks' Lambda = .87, $F(8, 290) = 2.66$, $p = .008$, partial $\eta^2 = .07$. See Table 2 for univariate results and descriptive data.

Insert Table 2 about here

Post-hoc analysis with Games-Howell revealed that the ADHD-PI group ($p = .004$) had worse performance than the control group on Symbol Search, and the ADHD-C group displayed a strong trend in that direction ($p = .050$). The ADHD-PI group ($p = .042$) and the ADHD-C group ($p = .015$) performed worse than the control group on Coding. On Decision Speed, only the ADHD-PI group performed worse than controls ($p = .004$). Significant differences between subtypes were not found on any task (*p*s > .50). All groups were comparable on Simple Reaction Time.

WISC Coding Copy is similar to Coding, but it measures psychomotor speed without an incidental learning component, using the same figures. Only a subset of the sample was administered Coding Copy, as it was added during the last third of data collection. Hence, data was collected on 49 children with ADHD or controls. Due to small sample size and the subtypes being comparable on Coding, ADHD was coded as a single group and compared to controls using ANOVA. ADHD performed worse than controls on Coding [$F(1, 48) = 4.83$, $p = .033$] and Coding Copy [$F(1,48) = 6.24$, $p = .016$].

To test whether the PS variables were better associated with the Inattention or Hyperactivity/Impulsivity dimension of ADHD, multiple regression was used. Coding, Symbol Search and Decision Speed were entered to predict teacher-rated BASC-2 Inattention or Hyperactivity/Impulsivity scales. Teacher BASCs were used rather than parents BASCs, as teachers may be less variable raters of Hyperactivity/Impulsivity (Crystal, Ostrander, Chen, & August, 2001; Loeber, Green, & Lahey, 1990). Simple RT was not included as it did not differ between groups. The equation predicting Inattention was significant [adjusted $R^2 = .08$, $F(3,147) = 5.52$, $p = .001$]. The equation predicting Hyperactivity/Impulsivity was not, although it displayed a trend [adjusted $R^2 = .03$, $F(3,147) = 2.40$, $p = .070$]. Symbol Search was a significant predictor of Inattention, but Decision Speed was a very poor predictor of it; see Table 3. The only significant predictor of Hyperactivity/Impulsivity was Coding; see Table 4. To assess the relationship between Coding Copy and the two dimensions, Pearson correlations were used due to the small sample size for Coding Copy. Coding Copy displayed a trend towards significance with Inattention ($r = -.27$, $p = .059$), but the relationship with Hyperactivity/Impulsivity was not significant ($r = -.16$, $p = .266$). Higher scores for Inattention and Hyperactivity/Impulsivity indicate greater impairment.

Insert Tables 3 and 4 about here

Discussion

Slow processing speed (PS) is a common problem in children with ADHD. Based upon the literature reviewed, it was hypothesized that children with ADHD-PI would perform more slowly than controls on the simpler tasks where the H/I dimension may hasten performance:

output speed (simple reaction time) and perceptual speed where only making slash marks is required (Symbol Search), and that both subtypes would perform slower than controls on the cognitive PS measures where potentially greater concentration/processing is required: psychomotor speed/incidental learning (Coding) and decision speed (Decision Speed). Hence, our hypotheses were partially supported. The ADHD-C group displayed the fastest performance on reaction time of the three groups, consistent with this hypothesis, although the differences were not statistically significant. ADHD-C and -PI were comparably impaired on Coding and Symbol Search, but only the -PI group performed worse than controls on Decision Speed.

There are variable findings across studies comparing individuals with ADHD as a group to their typically developing peers on perceptual speed measures, as noted in the literature review (Jacobson et al., 2011; Johnson et al., 2001; Nikolas & Nigg, 2013; Seidman, 2006; Shanahan et al., 2006; Weiler et al., 2000). Our findings that the ADHD-PI and ADHD-C groups performed worse on perceptual speed than controls is generally consistent with prior work, which has demonstrated that individuals with ADHD perform worse than controls on Symbol Search (Jacobson et al., 2011; Mayes et al., 2007), and that those with ADHD-PI have worse performance on Symbol Search compared to controls (Weiler et al., 2000). However, contrary to Calhoun and Mayes's (2005) findings, children with ADHD-PI and -C were comparable in performance in our sample. Our regression results are consistent with prior findings that the visual scanning and processing demands of perceptual speed tasks are related to the inattention dimension of ADHD, which is shared by both subtypes (Calhoun & Mayes, 2005; Chhabildas et al., 2001; Goth-Owens et al, 2010; Rommelse et al., 2007; Willcutt et al., 2005). Therefore, the hypothesis that perceptual speed is related to inattention was supported. Inattention may reduce the efficiency of visual-perceptual task completion (Salum et al., 2014), especially when attention to small detail is required.

In terms of psychomotor speed/incidental learning, which was assessed with Coding, results indicate that both subtypes tend to perform worse than the control group. This finding is consistent with studies showing that ADHD as a group is slower than controls on Coding (Bridgett & Walker, 2006; Jacobson et al., 2011; Shanahan et al., 2006; Weiler et al, 2000), and that both ADHD subtypes tend to be slower than controls when studied separately (Chhabildas et al., 2001; Goth-Owens et al., 2010). In one study, children with ADHD-PI were slower than those with ADHD-C and controls (Barkley et al., 1990), but this sample was primarily male, and the ADHD-PI group had more reported depressive symptoms than the other groups, which may have contributed to the incongruence of their findings with ours and other studies in this area.

Hence, when examining subtypes it would appear psychomotor speed/incidental learning is related to the inattention dimension, as both subtypes share inattention and both were similarly affected on Coding and Symbol Search. However, regression results indicated that psychomotor speed/incidental learning performance (Coding) was related to Hyperactivity/Impulsivity. Coding was not significantly related to Inattention, although the two Beta values are not significantly different. Moreover, psychomotor speed (Coding Copy) tended to be related to Inattention. Thus, it appears that psychomotor speed/incidental learning may be related to both the hyperactivity/impulsivity and inattention dimensions. Given the correlation between teacher-rated Attention Problems and Hyperactivity/Impulsivity in the total sample (r = .68, p < .001), this is not surprising. Inattention may reduce the accuracy and efficiency of attention to detail and psychomotor speed when copying the figures in this task. Hyperactivity/impulsivity may further heighten inaccuracy, and/or hastiness may lessen the development/use of strategies which affect the child's symbol learning efficiency. Further research is needed to determine which of these are contributing factors or both.

No literature was found that utilized Decision Speed, or similar measures, in ADHD. Thus, this analysis was largely exploratory, but it was expected that both subtypes would perform worse than controls based upon the literature reviewed on cognitive PS in general. We found that only the ADHD-PI group performed worse than controls, but the ADHD-C group's scores were not significantly better than those of the ADHD-PI group. It was noted that the ADHD-C sample had slightly more variable Decision Speed scores, as well as verbal reasoning scores, compared to the ADHD-PI and control groups. Decision Speed requires more complex semantic comparison skills, so it is possible that the variable verbal skills within our ADHD-C group accounted for the lack of significant findings in the ADHD-C group given VCI and Decision Speed were correlated [$r = .33$, $p < .001$].

At first glance, group-level findings suggest the inattention dimension is contributing to the Decision Speed findings, as ADHD-PI and -C did not differ on this task. Nonetheless, regression analyses showed that Decision Speed performance was not related to the Inattention or Hyperactivity/Impulsivity dimension, indicating that other factors must be impacting performance, such as verbal reasoning. While prior work has not utilized Decision Speed or similar measures with ADHD, other studies have found slower PS in ADHD-PI than controls on tasks that contain a cognitive component (Barkley et al., 1990; Chhabildas et al., 2001; Goth-Owens et al., 2010), providing further evidence that cognitive PS is affected in ADHD-PI. More work should be conducted using a variety of PS measures that have a wider range of cognitive demands to further parse apart areas of cognitive inefficiency across the subtypes.

Based upon prior literature, our hypothesis was that the control group would outperform the ADHD-PI group in simple RT/output speed, but this hypothesis was not supported. It appears that inattention and hyperactivity/impulsivity do not interfere with simple, easily automatized tasks, and RT only becomes significantly slower when additional perceptual and/or cognitive demands are introduced. Upon further examination of past methodology, Johnson and colleagues (2001) did not find RT differences on the simple RT task, similar to our study, but performance slowed when additional distraction and inhibition/rule processing demands were introduced. Furthermore, most studies tend to isolate reaction time from the “go” trials within a go/no-go task to demonstrate slower RT in ADHD (Kalff et al., 2005; Nigg et al., 2002; Willcutt et al., 2005). Although this is theoretically a pure measure of RT, the child is faced with additional inhibition demands throughout the task. The child must monitor for the “no-go” trials, which likely impacts their performance on the “go” trials. A further variable that may impact RT functioning in ADHD is that of RT variability, which is a common deficit in ADHD (Kalff et al., 2005; Karalunas et al., 2012; Willcutt et al., 2005) due to difficulties with attention regulation. Although a RT variability measure was not available in our study, use of it would be beneficial in future studies in this area.

It has been suggested that ADHD-PI and -C should be classified as distinct disorders rather than subtypes of the same disorder (Diamond, 2005; Milich et al., 2001). These arguments are based upon potentially distinct cognitive and behavioral profiles associated with ADHD-PI and -C. For example, children with ADHD-PI are more likely to have a sluggish cognitive tempo, a higher rate of learning problems, a passive social style, and more selective attention problems; whereas children with ADHD-C often have more oppositional behavior, behavior dysregulation, and conduct problems (Barkley, 2003; Weiss, Worling & Wasdell, 2003).

Nevertheless, there also are proponents of the subtype classification system (e.g., Nigg et al., 2002) who suggest that given the greater number of cognitive similarities between the subtypes than differences, they should be kept as subtypes of the same disorder. The latter conclusion is supported by studies finding non-significant differences in performance between subtypes across a wide range of cognitive skills, including intelligence, memory, attention and executive functioning (e.g., Cockcroft, 2011; Frazier, Damaree & Youngstrom, 2004; Houghton et al., 1999; Huang-Pollock, Nigg & Carr, 2005; Lemiere et al., 2010; Mayes et al., 2009; Pasini et al., 2007; Schweitzer et al., 2006). Our findings are consistent with this conclusion as well, in that both subtypes demonstrated comparably impaired perceptual and psychomotor/incidental learning speed with no differences in decision speed, suggesting they are subtypes of the same disorder. Further, both perceptual and psychomotor speed were related to the inattention dimension of ADHD. This finding is consistent with the dimension conceptualization of ADHD (Roberts et al., 2015), in that the cognitive deficits found in ADHD often are associated with the inattention dimension, whereas the hyperactivity/impulsivity dimension often is associated with behavioral regulation deficits (Barkley, 2003; Castellanos et al., 2006; Chhabildas et al., 2001; Nigg et al., 2005; Schmitz et al., 2002; Weiss et al., 2003; Willcutt et al., 2005).

A strength of our study is that it is the only one to compare PS performance across a variety of components in two ADHD subtypes. Due to the heterogeneous nature of PS, it is important to open this area of research in order to better understand the differential PS deficits in ADHD and how they may vary across subtypes and dimensions of ADHD. With regard to the study’s limitations, one of the greatest limitations is the mild nature of the sample. It is a community sample, and children with more severe ADHD and/or a clinical sample may have had more pronounced deficits. Nonetheless, differences were found between ADHD and controls. In addition, 30% of the ADHD-PI group had subclinical levels of hyperactivity/impulsivity and approximately 30% of controls had subclinical ADHD symptoms. Although we still found differences versus controls, subclinical symptoms may have affected our ability to find differences between the subtypes. Nonetheless, -PI and -C PS means are still quite close despite 70% of the PI sample having few H/I symptoms. Including the subclinical participants in these groups facilitates comparisons with what is seen in clinical practice and with the literature, as this is common practice, but further research is warranted comparing ADHD-PI with minimal H/I symptoms to the other groups. Further, the greater project from which these data were drawn did not have orally presented PS measures. Because individuals with ADHD are often impaired on visually presented, nonverbal tasks (Brocki et al., 2008; Gau & Chiang, 2013; Kibby, 2012; Martinussen et al., 2005; Martinussen & Tannock, 2006; Sonuga-Barke et al., 2008; Willcutt et al., 2005) but the literature on verbal tasks is more disparate, it would be beneficial to compare performance on visual versus oral PS tasks for the verbal and nonverbal domains, to better understand the speed at which individuals with ADHD can process information, disassociating presentation format (oral, visual), domain (verbal, nonverbal) and levels of complexity across components. Furthermore, more research is needed on components not assessed in our study, such as psychophysical speed. Further work also is needed to determine how much poor Coding performance in ADHD is due to psychomotor speed versus incidental learning, especially given the small sample who completed Coding Copy in our study and the dearth of research in this area. Thus, future research should use a measure such as the WISC Integrated that includes measures of psychomotor speed (Coding Copy) and incidental learning (Coding Recall), along with the traditional Coding measure.

In conclusion, our study compared children with ADHD-PI, ADHD-C, and typically developing children on various PS measures (i.e., simple output speed, perceptual speed, psychomotor/incidental learning speed, and decision speed). Children with both subtypes were slower to complete perceptual and psychomotor/incidental learning speed tasks than controls, and children with ADHD-PI were slower than controls to complete a decision speed task. No group differences were found in simple output speed. This indicates that at a very basic output level, children with ADHD do not have impaired mean RT, as most are able to easily automatize this skill. As task demands increase, however, their processing speed becomes less efficient. Specifically, based upon prior literature inattention may contribute to less efficient performance and worse attention to detail on tasks with a higher perceptual load. Further, on more complex tasks with psychomotor/ incidental learning demands, inattention may impact attention to detail when copying the figures, whereas hyperactivity/impulsivity may further affect accuracy and/or learning efficiency. Finally, when reasoning-based, semantic comparison demands are added to the task, thus further increasing the cognitive load, those with ADHD-PI continue to struggle and perform worse than controls. The variability in findings across the PS measures provides further support that PS is not a unitary, but rather a multi-component system. Thus, more precise terminology referring to the specific components affected (e.g., perceptual speed, psychomotor speed, cognitive speed) should be used to ensure better communication across research and clinical settings as opposed to just ‘processing speed’.

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Disclosure Statement

There is no known conflict of interests for this study.

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Table 1

Participant Demographic Variables

Variables	Controls	ADHD-PI	ADHD-C	*df*	X^2	*p*-values
Gender (% Male)	44.26	50.00	65.00	2	4.24	.12
Race (% Caucasian)	90.16	92.00	87.50	8	2.40	.97
	M(SD)	*M(SD)*	*M(SD)*	*df*	*F*	*p*-values
Age	9.74(1.38)	9.54(1.25)	9.73(1.54)	2, 148	0.33	.72
	[9.39 - 10.09]	[9.19 - 9.90]	[9.23 - 10.22]			
Maternal Education	5.61(1.02)	5.75(0.97)	5.13(1.73)	2, 139	2.85	.06
	[5.34 - 5.88]	[5.46 - 6.04]	[4.57 - 5.69]			
VCI	104.87(11.60)	99.60(12.78)	100.98(15.54)	2, 148	2.41	.09
	[101.90 - 107.84]	[95.97 - 103.23]	[96.01 - 105.94]			
BASC-2 PRS[a]	48.66(9.39)	66.08(6.46)	68.20(6.39)	2, 148	102.44	<.001
Attention Problems	[46.25 - 51.06]	[64.24 - 67.92]	[66.16 - 70.24]			
BASC-PRS[b]	45.36(8.47)	54.66(10.24)	69.13(11.96)	2, 148	67.19	<.001
Hyperactivity	[43.19 - 47.53]	[51.75 - 57.57]	[65.30 - 72.95]			
BASC-2 TRS[a]	46.51(8.40)	59.40(9.69)	63.69(8.15)	2, 148	54.21	<.001
Attention Problems	[44.36 - 48.66]	[56.65 - 62.16]	[61.09 - 66.30]			
BASC-2 TRS[b]	45.50(7.32)	51.80(9.41)	65.50(13.01)	2, 148	50.98	<.001

Hyperactivity	[43.62 - 47.37]	[49.13 - 54.48]	[61.34 - 69.66]

Note. [a]Controls < ADHD-PI and ADHD-C; [b]Controls < ADHD-PI < ADHD-C; Maternal Education: 5 = some college; VCI: Verbal Comprehension Index; BASC-2: Behavior Assessment System for Children, 2nd ed.; *** $p < .001$; 95% confidence intervals for the means are presented in brackets.

Table 2

Dependent Variable Performance between Groups

Dependent Variables	Controls	ADHD-PI	ADHD-C			
	M(SD)	*M(SD)*	*M(SD)*	*F*(2, 148)	Partial η^2	*p*
Simple Reaction Time	330.09(57.15)	340.18(47.70)	320.19(49.78)	1.64	.02	.20
	[316.87 - 343.32]	[325.58 - 354.78]	[303.87 - 336.52]			
Symbol Search[a]	10.34(2.79)	8.71(2.48)	8.82(3.30)	5.63	.07	.004
	[9.62 - 11.05]	[7.91 - 9.50]	[7.94 - 9.71]			
Coding[a]	9.32(2.63)	8.08(2.67)	7.65(3.01)	5.19	.07	.007
	[8.62 - 10.01]	[7.31 - 8.85]	[6.79 - 8.51]			
Decision Speed[b]	104.85(13.62)	97.56(9.89)	100.93(18.27)	3.77	.05	.03
	[101.31 - 108.39]	[93.65 - 101.47]	[96.56 - 105.30]			

Note. [a]ADHD-PI and ADHD-C < Controls; [b]ADHD-PI < Controls; 95% confidence intervals for the means are presented in brackets. Simple Reaction Time is in transformed raw scores; Symbol Search and Coding are in scaled scores, and Decision Speed is in standard scores.

Table 3

Multiple Linear Regression Predicting Inattention

Predictor	*β*	*t-values*	*p-values*	95% CI of B
Symbol Search	-0.25	-2.75	0.007	[-1.68 - -0.28]
Coding	-0.12	-1.30	0.194	[-1.23 – 0.25]
Decision Speed	0.01	0.11	0.915	[-0.13 – 0.15]

Table 4

Multiple Linear Regression Predicting Hyperactivity/Impulsivity

Predictor	*β*	*t-values*	*p-values*	95% CI of B
Symbol Search	-0.09	-0.91	0.363	[-1.16 – 0.43]
Coding	-0.19	-2.03	0.044	[-1.70 - -0.02]
Decision Speed	0.09	0.98	0.327	[-0.08 – 0.24]