Published in final edited form as:
J Clin Exp Neuropsychol. 2009 October ; 31(7): 877–888. doi:10.1080/13803390802646973.

Response variability in rapid automatized naming predicts reading comprehension

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Abstract

A total of 37 children ages 8 to 14 years, screened for word-reading difficulties (23 with attention-deficit/hyperactivity disorder, ADHD; 14 controls) completed oral reading and rapid automatized naming (RAN) tests. RAN trials were segmented into pause and articulation time and intraindividual variability. There were no group differences on reading or RAN variables. Color- and letter-naming pause times and number-naming articulation time were significant predictors of reading fluency. In contrast, number and letter pause variability were predictors of comprehension. Results support analysis of subcomponents of RAN and add to literature emphasizing intraindividual variability as a marker for response preparation, which has relevance to reading comprehension.

Keywords

Reading; Attention-deficit/hyperactivity disorder; Dyslexia; Comprehension; Executive function; Variability

Rapid automatized naming and reading

The relationship between rapid naming and reading was first posited by Geschwind and Fusillo (1966) in their description of patients with the visual–verbal disconnection syndrome *alexia with-out agraphia*, in which they argued that color naming and reading relied on the same neurocognitive processes (i.e., reliably and quickly attaching a spoken word to a visual stimulus). Their discussion led investigators to examine inefficiency in color naming as a marker for unexpected reading failure in young children (Denckla, 1972). In the past 35 years, rapid automatized naming has been shown to be predictive of reading success (Cutting & Denckla, 2001; Denckla & Rudel, 1974, 1976a, 1976b; Wolf, 1984, 1991; Wolf & Bowers, 1999) independently from phonological awareness (Wolf, Bowers, & Biddle, 2000). The most widely used measures of rapid automatized naming (Denckla & Rudel, 1974, 1976b; Wagner,

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Portions of this manuscript were written as part of the Honors Thesis (J.L.) in the Department of Psychology and Brain Sciences at Johns Hopkins University and were presented as a poster at the 35th Annual Meeting of the International Neuropsychological Society in Portland, Oregon, 9 February, 2007. Appreciation is expressed to Terry Levine, April Materek, and Cristine Prahme for their assistance assessing participants, and to Becca Martin for her assistance with manuscript preparation.

Torgesen, & Rashotte, 1999; Wolf & Denckla, 2005) require the individual to quickly and accurately name sets of overlearned visual stimuli (e.g., high-frequency letters, simple objects, digits, and colors).

Rapid automatized naming and processing speed

Failure to automatize skills necessary for rapid serial naming is considered a core difficulty among children with reading disabilities (Semrud-Clikeman, Guy, Griffin, & Hynd, 2000a). There are several hypotheses underlying the relationship between rapid automatized naming (RAN) and reading skills, including those in which rapid naming is considered a component of phonological processing (Torgesen, 1997) and those that argue that rapid naming and phonological deficits are independent facets contributing to reading skill (Wolf & Bowers, 1999). Others have argued that rapid naming speed and reading are both influenced (at least in part) by more global processing speed (Cutting & Denckla, 2001; Kail, Hall, & Caskey, 1999). Empirical research also supports the view that global processing speed plays a part in rapid automatized naming. In a sample of 279 third graders, poor readers had much slower response times on measures of processing speed than did good readers. Further, processing speed explained a unique proportion of variance in reading achievement, even after accounting for IQ and phonological awareness (Catts, Gillispie, Leonard, Kail, & Miller, 2002).

Rapid naming in attention-deficit/hyperactivity disorder (ADHD)

Rapid naming deficits may not be specific to reading disabilities (Waber, Wolff, Forbes, & Weiler, 2000), and recent studies have linked naming-speed deficits with attention-deficit/hyperactivity disorder (ADHD), even in the absence of word-reading difficulties (WRD; Semrud-Clikeman et al., 2000a; Tannock, Martinussen, & Frijters, 2000). For example, Schuerholz et al. (1995) found that children with WRD who also scored high on ratings of inattention or hyperactivity were slower at naming letters and numbers than were children with WRD who were not rated as inattentive or hyperactive. There is also evidence that rapid color naming may be separable from letter naming and may involve a different neural substrate than that for letter or digit naming in ADHD (Moore & Price, 1999). Ghelani, Sidhu, Jain, and Tannock (2004) reported that children with ADHD had longer response latencies only on rapid naming of colors and objects, while those with WRD had deficits on all rapid naming tasks (colors, objects, letters, numbers). Similarly, Wodka et al. (2008) found that children with ADHD (screened for WRD) were slower than controls on the color-naming trial (but not the word-reading trial) of a Stroop-like rapid-naming test from the Delis–Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001). Semrud-Clikeman et al. (2000a) reported slower naming speed in ADHD for colors, letters, and objects, but not numbers, although color naming (but not letter, object, or number) speed was significantly associated with bilaterally reduced anterior-superior white matter volumes (Semrud-Clikeman et al., 2000b). Both Tannock et al. (2000) and Bedard, Ickowicz, and Tannock (2002) reported that children with ADHD (with and without WRD) were slower than controls on color naming. These studies further reported that treatment with methylphenidate improved, but did not normalize, color naming (but not letter or number naming) in the ADHD groups (Bedard et al., 2002; Tannock et al., 2000). Tannock et al. (2000) explained the conflicting findings as a function of the different processing demands of various naming tasks, as color and object naming may require greater effort and perceptual and/or semantic processing than does letter or digit naming. Following this argument, children with ADHD may have deficits in color naming because they are less proficient on tasks involving effortful processing. Alternatively, color and object naming are considered by some to be more semantically based, while letter and number naming may be more phonologically based (Wolf & Obregon, 1992). Another factor to be considered is that numbers and letters remain in sets as updated stimulus–response repertoires (or even habits), while color naming drops out of academic daily practice. Naming

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sets of colors (RAN or D-KEFS format) is thus a novel challenge to efficient response preparation, especially in older students.

Components of rapid automatized naming

With few exceptions, studies employing measures of rapid automatized naming have used total time (i.e., the total amount of time it takes an individual to name the entire series of stimuli) as the variable of interest. Some researchers have argued that since total time is not item based, it fails to reflect the underlying processes of the responses (Neuhaus, Foorman, Francis, & Carlson, 2001b; Neuhaus & Swank, 2002). It has been suggested that the total time score can be segregated into separate components that better reflect the online cognitive processes utilized in completing the task (Neuhaus & Swank, 2002). These component processes include articulations and pauses (Neuhaus, Carlson, Jeng, Post, & Swank, 2001a), each having their own distributions (i.e., patterns of intraindividual variability). Articulations represent the actual production of speech and may be influenced by stimulus familiarity (Balota & Abrams, 1995; Hulme, Roodenrys, Brown, & Mercer, 1995), whereas pauses represent the elapsed time in between each articulation and may be influenced by automatization of memory retrieval (Anderson, Podwall, & Jaffe, 1984; Hulme, Newton, Cowan, Stuart, & Brown, 1999), processing speed (Kail et al., 1999), and/or attention (Neuhaus et al., 2001b). Indeed, RAN articulation and pause time appear to differentially predict reading performance and may involve different neural processes. Cobbold, Passenger, and Terrell (2003) studied children ages 4 to 5 years and reported that there was no significant relationship between articulation time and pause time. Similarly, in a sample of 50 first- and second-grade students, Neuhaus et al. (2001b) reported that letter pause time (but not articulation time) was strongly predictive of word-reading scores. Further, articulation speed has been observed to be reduced in dyslexia (Kasselimis, Margarity, & Vlachos, 2008), but not in ADHD (Ackerman & Dykman, 1993; Kasselimis et al., 2008).

Processing speed and reading

Reading fluency refers to the accuracy and rate at which decoding is relatively effortless, at which oral reading is smooth and accurate with correct prosody, and at which attention can be allocated to comprehension (Wolf & Katzir-Cohen, 2001). As word reading becomes more automatized, residual attentional resources can be allocated for the semantic processing of word sequences within text. This process facilitates comprehension, and those children who have poor reading fluency may also have difficulties with reading comprehension due to reduced attentional resources (or working memory) available to allocate to semantic processing. In children with ADHD (even those without WRD), reading fluency may be affected by associated processing-speed deficits (Willcutt, Sonuga-Barke, Nigg, & Sergeant, 2008). Hurks et al. (2004) examined controlled oral fluency in children with ADHD and found that performance was significantly impaired on letter fluency tasks compared to controls. They concluded that children with ADHD might be delayed in developing the automaticity required for tasks involving rapid verbal retrieval. This delay in controlled automatic retrieval may underlie the slowing observed in ADHD on visual–verbal (i.e., naming) tasks as well. While their study provides a better understanding of verbal fluency as it relates to ADHD, less known is the nature and reciprocity of the relationship between reading fluency and comprehension in children with ADHD who do not have WRD (Lovett, Barron, & Benson, 2003). Thus, a more detailed analysis of the cognitive skills contributing to processing speed (e.g., RAN pause, articulation, response variability) may help identify the underlying deficits associated with slowed response times in children with ADHD (even in the absence of word-reading difficulties).

Response variability within executive control

Children with ADHD commonly exhibit deficits in executive control, including difficulties with inhibition (Barkley, 1997), working memory (Nigg, Blaskey, Stawicki, & Sachek, 2004; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005), and response preparation (Denckla, 1989; Harris et al., 1995; Willcutt et al., 2008)—all of which potentially impact reading efficiency, independently from decoding and language skills (Sesma, Mahone, Levine, Eason, & Cutting, in press). Within response preparation, inefficient motor speed and coordination (Watemberg, Waiserberg, Zuk, & Lerman-Sagie, 2007), slowed processing speed (Shanahan et al., 2006; Willcutt et al., 2008), and variability of responding (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Johnson et al., 2007a; Sonuga-Barke & Castellanos, 2007) all potentially contribute to the reduced speed and efficiency observed on timed tasks. Increased intraindividual response time variability has been consistently observed in children with ADHD (Hurks et al., 2005; Johnson et al., 2007a) and linked to anomalous function of frontal/subcortical circuits (Castellanos et al., 2007; Chuah, Venkatraman, Dinges, & Chee, 2006; MacDonald, Nyberg, & Backman, 2006). The sensitivity and specificity (Johnson et al., 2007b) of increased intraindividual response time variability in ADHD has led some to propose it as a possible endophenotype (Castellanos & Tannock, 2002), linked with top-down attention control processes (Cao et al., 2008; Hervey et al., 2006). It remains unclear, however, whether intraindividual variability is a stable cognitive deficit in ADHD, independent of motivational factors (Andreou et al., 2007; Wodka et al., 2007). To date, most research examining RAN responses has not directly assessed item-level, intraindividual variability, despite evidence that response variability more strongly correlates with symptoms of ADHD than do other measures of accuracy or total response times (Russell et al., 2006).

Summary

The present study examined RAN performance as a measure of response preparation and processing speed in children with and without ADHD, screened for word-reading difficulties (WRD). Within naming speed, pause time, articulation time, and intraindividual variability of pauses and articulations were analyzed separately. Three hypotheses were examined. First, it was hypothesized that children with ADHD would have slower naming speed than controls, and that these differences would be most pronounced on color naming trials. Second, it was expected that pause time (but not articulation time) within rapid-naming tasks would predict reading fluency. Third, it was hypothesized that intraindividual variability of pause and articulation times would predict reading performance, especially among children with ADHD.

METHOD

Participants

Participants were recruited as part of several larger studies examining the brain mechanisms in reading comprehension. All participants and their parents signed consent forms that met the Institutional Review Board standards. Children included in the study were between 8 and 14 years and had Full Scale IQ (FSIQ) scores of 70 or higher, based on present performance on Wechsler Intelligence Scale for Children–Fourth Edition (WISC–IV; Wechsler, 2003) or school assessment within one year of study participation. Children were excluded from participation if there was history of speech/language disorder or word-reading difficulties, either screened out before a visit or based on prior school assessment (completed within one year of the current assessment). Further exclusion criteria included evidence of visual or hearing impairment, or history of other neurological or psychiatric disorder. Parents of participants were screened by telephone to obtain demographic information, school, and developmental history. Parents of children with ADHD were asked not to administer stimulant medication on the day of and day prior to testing. Children with ADHD taking psychotropic medications other than stimulants were excluded. Participants provided written consent (caregivers) and assent (children) before beginning testing and received a copy of the consent form. A total of 37 children (14 control, 23 ADHD) were included.

Following initial telephone screening, participants were screened for psychiatric diagnoses using a structured parent interview (Diagnostic Interview for Children and Adolescents, Fourth Edition, DICA–IV; Reich, Welner, & Herjanic, 1997). Additionally, ADHD-specific and broad behavior-rating scales (Conners' Parent and Teacher Rating Scale–Revised, Long Form, CPRS–R/CTRS–R; Conners, 1997) were used to confirm ADHD diagnosis. Children with DSM–IV (*Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition*; American Psychiatric Association, 1994) diagnoses other than oppositional defiant disorder and specific phobias were excluded. Additional exclusion criteria for control group included history of mental health services for behavior or emotional problems, parent or teacher report of previous diagnosis of conduct disorder (CD), history of academic problems requiring school-based intervention services, or history of defined primary reading or language-based learning disability. Parents of children in the control group also completed the DICA–IV and CPRS–R, and teachers completed the CTRS–R. Controls with *T*-scores greater than 60 on the ADHD (DSM–IV Inattention; DSM–IV Hyperactivity) subscales of CPRS–R or CTRS–R were also excluded from the study. Participants were also screened for basic word-reading difficulties, which were defined as a score less than the 25^{th} percentile on the Word Identification subtest of the Wood-cock Johnson–III Tests of Achievement (WJ–III; Woodcock, McGrew, & Mather, 2001), or the Word Reading subtest of the Wechsler Individual Achievement Test–II (WIAT–II; Wechsler, 2002).

On the day of the assessment, children were administered the WISC–IV (if no recent IQ test was available), measures of word reading, reading comprehension, and the RAN. While children completed the assessment, parents completed a brief background questionnaire and parent behavior rating forms.

Study measures

Rapid Automatized Naming (RAN; Wolf & Denckla, 2005)—Three RAN subtests were used: Color, Number, and Letter trials. Each chart contained the items in a randomized order for a total of 50 stimuli, arrayed in five horizontal rows of 10 items per row. Each child was asked to name each stimulus item as quickly as possible without making any mistakes. The Color trial includes red, green, black, blue, and yellow; the Letter trial includes o, a, s, d, and p; and the Number trial includes 2, 6, 9, 4, and 7.

Gray Oral Reading Test–Fourth Edition (GORT–IV; Wiederholt & Bryant, 2000)—The GORT–IV is an individually administered test of oral reading, accuracy, speed, and comprehension. The test was normed on a sample of 1,600 students aged 6 though 18 years, stratified to correspond to key demographic variables including race, gender, ethnicity, and geographic region. Internal consistencies are high (.90 or above), as well as test–retest reliability. Scaled scores are provided for rate, accuracy, fluency, and comprehension. The fluency score is derived from the rate and accuracy scores. For the present study, fluency and comprehension scaled scores were analyzed.

Procedure

Each RAN administration was digitally recorded using a personal computer, computer headset/microphone (Plantronics Audio 90 Multimedia Stereo PC Headset), and recording software (Audacity®; Andrews et al., 2008), an open-source software for recording and editing sounds. Each RAN administration was also marked for analysis using Audacity®, which was used for detailed visual and auditory replay and inspection of sound waves. Individual sound waves for each RAN component were created for all trials. Analysis for each sound wave file was made using the procedures similar to those described by Neuhaus et al. (2001b). Articulation onset was marked at the point where acoustical energy of the appropriate response exceeded the mean noise level; offset was measured at the point where acoustical energy dropped below the mean noise level. *Articulation time* for each individual response (from onset to offset of acoustical energy) was measured in milliseconds. *Pause time* was measured as time between two articulations (i.e., the difference, in milliseconds, between the subsequent articulation onset and the previous articulation offset). *Pause variability* was defined as the degree to which the pauses varied for the individual on a particular RAN subtest, and *articulation variability* was defined as the degree to which the articulations varied on the particular RAN subtest. For both pauses and articulations, variability was defined as follows: standard deviation/mean.

A total of 50 articulation time responses and 49 pause times were calculated. RAN total time for each subtest was calculated by adding total articulation times and total pause times. Any extraneous verbalizations, such as coughs, incorrect responses, or other undistinguishable sounds, were included in the pause time, as they were assumed to represent variable attentional focus (Neuhaus et al., 2001b). Also, for articulation responses that extended into another articulation (thus forming a wave that did not cease for the particular response), pause time was scored as zero. Neuhaus et al. (2001b) reported adequate internal consistency scores (Cronbach's alpha) for pause time (.86) and articulation time (.97), and split-half reliability (.64) for consistency scores of RAN Letters.

Data analysis

Distributions of all variables were examined, and log transformations were used for those variables showing excessive skewness. Group comparisons of demographic, IQ, reading, and RAN Total score and component variables were analyzed using analyses of variance (ANOVAs) for continuous variables and chi-square tests for categorical variables. Next, correlations were examined between GORT–IV scores (Fluency, Comprehension) and pause time, articulation time, pause variability, articulation variability, and total time on the RAN Color, Number, and Letter trials. Finally, a series of six hierarchical multiple regression analyses were used to predict GORT–IV Fluency and Comprehension scores from RAN pause times, articulation times, and variability from the Color, Letter, and Number trials. In each hierarchical regression analysis, predicted variables were entered in the following order, in accordance with a priori hypotheses: age, group, mean articulation time, mean pause time, articulation variability, and pause variability. By analyzing the data in this manner, it was possible not only to control for age and group effects, but also to examine the unique contribution of each of the four RAN components and to determine whether variability adds to the prediction of reading fluency and comprehension, over and above pause and articulation times. Effects sizes for each step in hierarchical regression analyses were calculated using partial R^2.

RESULTS

Demographics

Descriptive statistics are shown in Table 1. The study consisted of 37 participants (23 children with ADHD and 14 controls), of which 95% were Caucasian, and 5% were African-American. Participants ranged in age from 8 to 14 years, with an average age of 11.4 years. There were no significant differences between ADHD and control groups in age, sex distribution, racial composition, or FSIQ scores.

Group differences for reading variables

Means and standard deviations for word reading, reading comprehension, and RAN variables are listed in Table 1. There were no significant differences between ADHD and control groups on word reading or either of the GORT–IV scores analyzed. Similarly, there were no significant group differences on any of the RAN total time or subcomponent scores for any of the three trials analyzed (Colors, Numbers, Letters).

Correlations between RAN and reading measures

Correlations between RAN and reading measures are listed in Table 2. Across groups, RAN total time *standard scores* for all three trials were significantly correlated with reading fluency (all *p*s ≤ .001), but not with word reading or reading comprehension. After controlling for age, pause time (Colors and Letters, both *p*s < .05), but not articulation time, was significantly correlated with single word reading. Further, pause time (Colors, Letters, and Numbers, all *p*s < .01) and articulation time (Numbers, $p = .01$) were significantly correlated with reading fluency, suggesting that longer pause and articulation times are related to slower and less accurate reading fluency. In contrast, pause variability (Letter trial), but not articulation time or pause time from any RAN trial, was significantly correlated with reading comprehension ($p < .05$), such that greater variability was associated with lower comprehension scores. Pause and articulation variability were not significantly correlated with single word reading or reading fluency for any of the RAN trials.

Prediction of reading fluency and comprehension from RAN components

Results of the hierarchical regression analyses predicting GORT–IV Fluency from RAN components are presented in Table 3. After controlling for age and group, *pause time* (Colors, $p = .002$; Letters, $p = .005$) was a significant predictor of reading fluency, accounting for a large proportion of unique variance (24% and 20%, respectively). Similarly, after controlling for age and group, *articulation time* (Numbers, $p = .008$) was a significant predictor of reading fluency, also accounting for a large proportion of unique variance (19%). Pause and articulation variability did not add significantly to the prediction of oral reading fluency on any of the RAN trials.

Results of the hierarchical regression analyses predicting GORT–IV Comprehension from RAN components are presented in Table 4. After controlling for age and group, pause and articulation times were not significant predictors of comprehension scores for any of the RAN trials. *Pause time variability*, however, contributed a significant proportion of unique variance to predicting comprehension scores on the RAN Number ($p = .04$) and Letter trials ($p = .02$) trials, accounting for a large proportion of unique variance (12% and 14%, respectively). Articulation variability did not add to the prediction of comprehension for any RAN trial.

DISCUSSION

The current study sought to delineate the response preparation components of processing speed that are tapped by performance on rapid automatized naming tests. The objectives of this study were two-fold: (a) to examine whether children with ADHD (without word-reading difficulties) had deficits in rapid automatized naming, reading fluency, and/or comprehension; and, (b) to examine the relationship between more clearly delineated components of rapid automatized naming (i.e., pause and articulation times, pause and articulation variability) and reading fluency and comprehension. In the present study, children with ADHD did not differ from controls on any reading measure or on RAN trials, including RAN articulation, pause, and total times, and intraindividual variability. Across groups, however, pause and articulation times were unique predictors of reading fluency, highlighting the potential salience and separability of articulation time from pause time in understanding factors related to RAN (or reading) slowing.

This pattern of findings suggests that among individuals without word-reading problems, articulation time and pause time are both uniquely predictive of reading efficiency (where longer latency would indicate less efficient reading). Whereas pause latency may be more related to processing speed, articulation times may be more indicative of stimulus familiarity, natural speech patterns (Neuhaus et al., 2001b), or retrieval of a memorized or highly familiar representation (De Jong & van der Leij, 1999)—all of which are important in oral reading speed. Unlike the Neuhaus et al. (2001b) findings, RAN pause time in the present study was not a consistent predictor of reading comprehension, perhaps due to the younger age of participants in the Neuhaus sample.

Across groups, pause variability on RAN Number and Letter trials was a significant predictor of reading comprehension, even after controlling for pause and articulation times, with strong and robust effect size. The unique relationship between naming variability and comprehension suggests that intraindividual variability may be an important component of response preparation within executive control that can be garnered from decomposing RAN responses to the item level. This finding is not surprising, given that response variability is considered to demonstrate the efficiency with which limited attentional resources are allocated in the face of demands for effortful cognitive control (Clare Kelly, Uddin, Biswal, Castellanos, & Milham, 2008; Stuss, Murphy, Binns, & Alexander, 2003). Further, response variability is associated with activation in frontal-subcortical brain circuits, which are important for response preparation and processing speed (Castellanos et al., 2006; Fox, Snyder, Zacks, & Raichle, 2006; Simmonds et al., 2007). Indeed, total response time on rapid-naming tasks can be thought of as being composed of a chain of processes, including perceptual analysis, response preparation, and response execution (Pashler & Johnson, 1989). Increased variability in responding may depend on all these processes; however, the frequent intrusion of large reaction times may also be an indication of loss of vigilance or factors independent of stimulus familiarity or long-term memory processes (Gilden & Hancock, 2007).

A steady pattern of response latencies during a visual–verbal (i.e., “see-it/say-it”) rapid automatized naming task depends on functional efficiency of multiple cortical and subcortical connections. When reading a written word on a page, the visual cortex relays information to the parietal lobe (left angular gyrus), and then projects information to Wernicke’s area via the superior longitudinal fasciculus. The signal is then translated into an auditory form and comprehended, and the arcuate fasciculus projects the translated information into Broca’s area in the frontal lobe, where production of speech (either out loud or internally) is initiated (Geschwind & Fusillo, 1966). Among typically developing children, faster naming speed and higher reading scores have been linked to white matter integrity in the left temporal lobe (Nagy, Westerberg, & Klingberg, 2004). Thus, in children without word-reading deficits, response inefficiencies or “slowing” may involve a breakdown in the connections (arcuate/superior longitudinal fasciculus) between the back and the front of the brain. The link between naming variability and comprehension in the current sample suggests that the inefficiency may be, at least in part, more “toward the front.”

Unlike the earlier studies (Tannock et al., 2000; Wodka et al., 2008), children with ADHD in the present study did not demonstrate slowing on the rapid color naming trials. There may be several reasons for this pattern of findings. First, the self-paced nature of the RAN response allows for motivational factors associated with going fast (Andreou et al., 2007) potentially affecting processing speed. Alternatively, it may be that the relatively short period of responding (i.e., less than a minute) minimizes the effortful demands associated with the task itself. Second, the mean IQ and reading scores indicated that the children in the current study sample (both ADHD and control groups) were relatively high functioning, which may reduce the sensitivity of executive function measures (Mahone et al., 2002). Third, because the samples were recruited as part of several larger studies, some of which included neuroimaging, they were highly screened for comorbidities, including learning disabilities, language disorders, mood, and anxiety disorders, which may have eliminated some of the factors associated with slowed rapid naming in previous samples. In particular, exclusion of children with word-reading difficulties (WRD) is in deference to literature suggesting that language impairments (indexed by WRD) may, developmentally, influence performance measures of executive control, including those emphasizing response preparation (Willcutt et al., 2008). Given that 25–40% of children with ADHD also meet criteria for reading disability (Willcutt et al., 2005), our sample of children with ADHD is more pure diagnostically than those typically observed in outpatient settings. As a result, some of our “ADHD-specific” findings (or lack thereof) may be less generalizable to the typical clinic attendee with ADHD.

The present pattern of findings may have also have been influenced by the wide age range in the sample (8–14 years). This age range was chosen because of the study emphasis on reading comprehension. That is, the youngest study participants were in the third grade. Prior to third grade, reading instruction emphasizes word decoding or “learning to read,” whereas the emphasis shifts to reading comprehension or “reading to learn” in later primary grades. The wider age range was used in order to measure the range of executive control skills (captured by the RAN) that are salient in predicting later developing reading skills, especially reading comprehension. Given the potential for age-related change in executive control throughout this age range, future research should consider examining these relationships in larger samples, for which age-related developmental changes in executive control can be more adequately delineated.

The current findings highlight the utility of brief assessments such as the RAN in predicting reading performance, even among children who do not present with reading problems. In particular, variability in rapid naming may represent a marker for anomalies in executive control of attention, perhaps related to spontaneous fluctuations in neuronal activity unrelated to the task or stimulus (Fox et al., 2006; Sonuga-Barke & Castellanos, 2007). While these fluctuations may provide a basis for under-standing attentional lapses in ADHD (Helps, James, Debener, Karl, & Sonuga-Barke, 2008), they may also allow for more direct assessment of factors contributing to reading comprehension in typically developing children as well (Simmonds et al., 2007). Future research should continue to use available methods to further explore and decompose intraindividual variability, with efforts to link variability to its neural correlates and to skills dependent on executive control of attention (e.g., reading). These methods may be especially fruitful in the study of executive control in children with ADHD, considering recent findings regarding the specificity of responses at particular frequency bands (over and above response variability alone), in predicting group membership (Di Martino et al., 2008).

Acknowledgments

We would also like to thank Graham Neuhaus for her assistance and guidance in the early phases of this study. Supported by HD-24061 (Developmental Disabilities Research Center), R01 NS043480, P50 HD 52121, and the Johns Hopkins University School of Medicine Institute for Clinical and Translational Research, an NIH/NCRR CTSA Program, UL1-RR025005.

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TABLE 1

Demographic information

Variable	Control (n = 14) M	SD	%	ADHD (n = 23) M	SD	%	p	η^2
Demographic								
Age	11.5	1.5		11.3	1.8		.77	.003
No. male	7		50.0	18		78.3	.15	.06
No. Caucasian	10		71.4	20		87.0	.12	.07
FSIQ	110.5	16.7		109.7	14.9		.87	.001
Word reading	107.4	9.1		110.0	10.5		.46	.02
GORT–IV								
Fluency	11.5	3.7		11.4	4.0		.96	.00
Comprehension	11.9	3.4		12.5	3.1		.59	.01
RAN								
Color articulation time	21.7	4.0		24.0	3.9		.10	.08
Color pause time	16.9	10.0		19.5	10.2		.47	.02
Color articulation variability	0.3	0.0		0.2	0.1		.47	.02
Color pause variability	1.3	0.3		1.2	0.4		.62	.01
Color total time	38.7	11.1		43.7	12.9		.23	.04
Color standard score	104.7	16.4		97.8	17.8		.25	.04
Number articulation time	17.9	4.6		20.7	5.4		.12	.07
Number pause time[a]	0.7	0.3		0.7	0.3		.92	.00
Number articulation variability[a]	−0.6	0.1		−0.6	0.1		.67	.01
Number pause variability	1.7	.67		1.7	0.3		.65	.01
Number total time	24.7	9.7		27.1	8.9		.44	.02
Number standard score	106.6	18.0		101.3	17.3		.38	.02
Letter articulation time	15.4	2.6		17.0	3.4		.14	.06
Letter pause time[a]	0.8	0.3		0.90	0.2		.37	.02
Letter articulation variability[a]	−0.7	0.1		−0.7	0.1		.79	.00
Letter pause variability	1.2	0.3		1.4	0.5		.15	.06

	Control (n = 14)			ADHD (n = 23)				
Variable	**M**	**SD**	**%**	**M**	**SD**	**%**	**p**	η^2
Letter total time	23.8	8.1		25.9	6.8		.41	.02
Letter standard score	107.8	17.0		102.3	14.1		.29	.03

Note. η^2 = eta squared effect size. ADHD = attention-deficit/hyperactivity disorder. FSIQ = full-scale intelligence quotient. GORT–IV = Gray Oral Reading Test–Fourth Edition, scaled scores. RAN = rapid automatized naming, in s. Word reading = Word Identification, Woodcock Johnson–III, or Word Reading from Wechsler Individual Achievement Test–II; times are in s.

[a]Log transformation.

p = significance for *t* test with *df* 36.

TABLE 2

Partial correlations among RAN components and reading scores

RAN trial	Variable	Fluency	Comprehension	Word reading
Color	Articulation Time	−.24	.17	−.05
	Pause Time	***−.53***	−.13	*−.37*
	Articulation Variability	.06	.05	.05
	Pause Variability	−.05	.20	−.06
	Total Time	***−.52***	−.05	−.31
	Standard Score[b]	***.61***	−.02	.25
Number	Articulation Time	***−.43***	.07	−.24
	Pause Time[a]	**−.49**	−.08	−.24
	Articulation Variability[a]	−.04	.08	−.05
	Pause Variability	.04	−.27	−.06
	Total Time	***.48***	−.04	−.25
	Standard Score[b]	***.55***	−.06	.22
Letter	Articulation Time	−.28	.08	−.22
	Pause Time[a]	***−.52***	−.16	*−.35*
	Articulation Variability[a]	−.09	−.26	.01
	Pause Variability	−.11	−.38	−.04
	Total Time	***−.52***	−.12	−.42
	Standard Score[b]	***.51***	−.04	.28

Note. $n = 37$ for fluency and comprehension; $n = 35$ for word reading. Correlations in italics are $p < .05$; correlations in bold are $p < .01$. RAN = rapid automatized naming. Fluency = Gray Oral Reading Test–Fourth Edition (GORT–IV) Fluency scaled score. Comprehension = GORT–IV Comprehension scaled score. Word Reading = Word Identification from Woodcock Johnson–III Tests of Achievement, or Word Reading from Wechsler Individual Achievement Test–II. Partial correlations are age corrected.

[a]Log transformation.

[b]Pearson correlation (not age corrected).

TABLE 3

Hierarchical regression analysis predicting GORT–IV fluency from RAN

RAN trial	Predictor	β	ΔR^2	p
Colors	Age	.068	.005	.693
	Group	−.026	.001	.884
	Articulation Time	−.298	.057	.171
	Pause Time	−.578	.243	**.002**
	Articulation Variability	.088	.007	.577
	Pause Variability	−.324	.085	.052
Numbers	Age	.070	.005	.679
	Group	−.005	.000	.978
	Articulation Time	−.535	.194	**.008**
	Pause Time[a]	−.382	.059	.121
	Articulation Variability[a]	−.008	.000	.962
	Pause Variability	−.222	.033	.247
Letters	Age	.070	.005	.679
	Group	−.005	.000	.978
	Articulation Time	−.337	.081	.097
	Pause Time[a]	−.551	.203	**.005**
	Articulation Variability[a]	.070	.004	.674
	Pause Variability	−.270	.049	.143

Note. Predicted variables entered in the following order: age, group, articulation time, pause time, articulation variability, and pause variability. RAN = rapid automatized naming; GORT–IV = Gray Oral Reading Test–Fourth Edition. Correlations in bold are $p < .01$.

[a]Log transformation.

TABLE 4

Hierarchical regression analysis predicting GORT–IV comprehension from RAN

RAN variable	Predictor	β	ΔR²	p
Colors	Age	−.276	.076	.104
	Group	.073	.005	.664
	Articulation Time	.179	.021	.398
	Pause Time	−.193	.027	.332
	Articulation Variability[a]	.031	.001	.860
	Pause Variability	.160	.021	.407
Numbers	Age	−.275	.075	.100
	Group	.078	.006	.638
	Articulation Time	.053	.002	.795
	Pause Time	−.240	.023	.369
	Articulation Variability[a]	.160	.021	.391
	Pause Variability	−.416	.116	**.040**
Letters	Age	−.275	.075	.100
	Group	.078	.006	.638
	Articulation Time	.071	.004	.722
	Pause Time	−.242	.039	.240
	Articulation Variability[a]	−.203	.035	.266
	Pause Variability	−.447	.136	**.022**

Note. Predicted variables entered in the following order: age, group, articulation time, pause time, articulation variability, and pause variability. RAN = rapid automatized naming. GORT–IV = Gray Oral Reading Test–Fourth Edition. Correlations in bold are $p < .01$.

[a]Log transformation.