Connecting Rapid Automatized Naming (RAN), Reading Difficulties, and Inattention

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Abstract

The relations between reading development and attention difficulties are not clearly understood. This thesis contributed to understanding their interrelatedness through the use of rapid automatized naming (RAN) tasks. The first article is a review, and the second and third articles are empirical follow-up studies. The focus of the thesis is on the interrelations among the continuous rapid naming of color and letter stimuli, behavioral ADHD-symptoms of inattention, hyperactivity, and impulsivity, and the alphabetic language-based reading fluency of children in elementary school. Ninety-six elementary school students participated in the two-year study. Participating students were tested initially in the spring, with a second assessment conducted one-year later. Slower rapid naming of letters, and making errors or self-corrections on letter naming were all associated with poorer oral passage reading fluency and lower single-word reading achievement. Making errors or self-corrections on color naming were associated with teacher-rated and examiner-rated symptoms of hyperactivity or impulsivity and with teacher-rated inattention symptoms. Slower rapid naming of letters at baseline were associated with lower scores on oral-passage reading fluency, single-word reading achievement, and a speeded semantic decision-making and reading fluency task one-year later. Slower rapid naming of colors at baseline were associated with more teacher-rated symptoms of inattention as well as lower scores on passage oral-reading fluency and the speeded semantic decision-making and reading fluency task measured one-year later. Self-corrections on color naming were associated with one-year teacher-rated symptoms of inattention and hyperactivity or impulsivity. Auditory and visual-spatial working-memory measures were inconsistent and unreliable predictors of reading performance or symptoms of ADHD in this age group at both baseline and one-year later in comparison to RAN measures. This research contributed a deeper understanding to the processes underlying continuous RAN and provided evidence in support of a doubly dissociative relation among RAN types, reading skills, and ADHD-symptoms. We encourage the use of varied continuous RAN tasks as part of reading and attention difficulty assessment for children in the early grades.

Keywords: reading, rapid automatized naming, fluency, achievement, ADHD, inattention, hyperactivity, impulsivity

Résumé

La relation entre le développement de la lecture et les difficultés d'attention n'est pas bien comprise. Cette thèse a contribué à comprendre leur interdépendance à l'aide de tâches de dénomination rapide automatisée (DRA). Le premier article est une revue d'ensemble, et les deuxième et troisième articles sont des études de suivi empiriques. La thèse a pour objectif d'examiner les interrelations entre la dénomination rapide continue des couleurs et la dénomination de lettres, les symptômes du TDAH, l'inattention, l'hyperactivité et l'impulsivité, et la fluidité de la lecture fondée sur la connaissance de l'alphabet par des enfants fréquentant l'école primaire. Quatre-vingt-seize élèves du primaire ont participé à l'étude de deux ans. Les participants ont tout d'abord eu une évaluation au printemps, ainsi qu'une deuxième réalisée un an plus tard. Le fait de réaliser une dénomination rapide de lettres plus lente et celui de faire des erreurs ou des autocorrections au moment de nommer les lettres ont été associés à une moins bonne fluidité de la lecture orale en contexte et une moins bonne maîtrise de la lecture de mots seuls. Les erreurs ou les autocorrections dans la dénomination de couleurs ont été associés à des symptômes d'hyperactivité ou d'impulsivité notés pas les enseignants et par les examinateurs, et des symptômes d'inattention remarqués par les enseignants. Une dénomination rapide de lettres plus lente au départ a été associée à des résultats plus faibles pour la fluidité de la lecture orale en contexte, à la maîtrise de la lecture de mots seuls, ainsi qu'à une prise de décision sémantique accélérée et à une fluidité de la lecture évaluées un an plus tard. Une dénomination rapide de couleurs plus lente au départ a été associée à plus de symptômes d'inattention notés par les professeurs, à des résultats plus faibles dans la fluidité de lecture en orale en contexte, ainsi qu'à une prise de décision sémantique accélérée et à une fluidité de la lecture évaluées un an plus tard. Les autocorrections dans la dénomination de couleurs ont été associées à des symptômes d'inattention et d'hyperactivité ou d'impulsivité observés par les enseignants pendant un an. Les mesures de mémoire du travail auditif et spatio-visuel étaient des prédicteurs contradictoires et peu fiables de la performance en lecture ou des symptômes du TDAH dans ce groupe d'âge, à la fois au début de l'étude et un an plus tard, comparativement aux mesures de la DRA. Cette recherche a contribué à une meilleure compréhension des processus sous-jacents de la DRA continue et a fourni des preuves appuyant une relation doublement dissociative entre les types de DRA, les compétences en lecture et les symptômes du TDAH. Nous encourageons l'utilisation continue de tâches variées de DRA dans le cadre des évaluations de lecture et des difficultés d'attention pour les enfants dans les premières années d'école.

Mots-clés: lecture, dénomination rapide automatisée, fluidité verbale, réalisation, TDAH, inattention, hyperactivité, impulsivité

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This long and exciting journey to the PhD at McGill University would not have been the same without the support from all those who have joined me along the way. Your encouragement and cheer has made this dissertation possible and helped me come miles closer to realizing my ambitions.

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Kirbie's Cravings Four Ingredient Nutella Mug Cake

Ingredients:

4 tbsp flour

1/4 tsp baking powder

1/4 cup Nutella

3 tbsp fat free milk

Directions:

Combine all ingredients into an oversized mug. Mix with a small whisk until batter is smooth. Cook in microwave for about 1 minute. Sharp knife inserted should come out clean and top of cake should look done rather than gooey. If cake is not cooked in one minute, add an additional 20 seconds. Let cake cool in mug completely before eating (Lee, 2013). ☺

To my Toronto friends and family near and dear to me: Thank you for being amazing and inspirational every single day, for lending your ears, and for taking an interest in my life and work. Lastly, I wish to thank my parents, Helen and Norman, as well as my brilliant brother Ben, for always being there for me. Mom and Dad, you have shown me the way to accomplishing all that I have ever wanted to do. You have taught me the valuable lessons of hard work and discipline. Mom, you've always been my steadfast #1 supporter from the day I was born. It is your hope for me that helped me pursue and finish this PhD. To Ben, thanks for listening, understanding, and being the *bestest*. I owe you one (or 2000).

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Contributions of Authors

This thesis is the combination of three draft papers (Leung & Stringer, 2014, and Leung, Rogers, & Stringer, 2014a & b). The first article is a literature review, and the second and third articles are ensuing empirical studies. The literature reviews for the two empirical articles each contain condensed and focused reviews of the literature. As primary author, my role included conceptualizing each of these studies, searching relevant literature, refining the research questions and methodology for my particular measures and variables of interest (in particular, rapid automatized naming) within the larger study context, assisting with recruiting participants, data collection, scoring, and entry, statistical analyses, condensing and interpreting the results, as well as writing the current complete dissertation. Professor Maria A. Rogers, now at the University of Ottawa, was an additional co-author on the two empirical articles and she helped extensively with primary coordination of the project, including recruiting participants, liaising with the schools, determining various project needs (e.g., testing dates, data collection, data coding, and data entry), in addition to participating in numerous discussions about the project, contributing ideas for how to make improvements, providing feedback for improvement, and reviewing the manuscripts. My supervisor, Professor Ronald W. Stringer, assisted with conceptualization of the dissertation work. Through numerous conversations, he also guided me throughout the research process, helping to clarify ideas, facilitate the collection of data, and synthesize my findings.

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Overall Introduction to the Three Manuscripts

Reading performance is negatively correlated with the speed at which people name letters, digits, colors, or objects. Rapid automatized naming tasks, known by the acronym RAN, are apparent analogues of the reading process, and likely share many cognitive similarities (Blachman, 1984; Foorman, Chen, Carlson, Moats, Francis, & Fletcher, 2003; Wolf & Bowers, 1999). In form, they typically appear in four common and standard variants identified by the types of stimuli used: letters, digits, colors, or objects. In all of these variations, sets of one stimulus type are laid out on a card arranged in rows and columns. The individual participating in the task names each stimulus in order aloud, left to right, top to bottom, as quickly as he or she can. The elapsed time and number of errors are recorded by the examiner. Like reading, RAN requires the identification of a visual stimulus, the assembly of a verbal response and its articulation, and then visual scanning to the next stimulus or line to repeat the process. Poor readers are consistently slower on RAN tasks than control groups (Denckla & Rudel, 1976b; Felton, Wood, Brown, Campbell, & Harter, 1987; Wolf, Bally, & Morris, 1986).

Performance on RAN-Letters and Digits (or alphanumeric RAN types) is a robust and significant predictor of reading ability, although RAN-Colors and Objects (or nonalphanumeric RAN) measures are less predictive (Denckla & Cutting, 1999). The predictive ability of alphanumeric versus nonalphanumeric RAN tasks appears to be directly related to the child's age when completing the RAN task (Wolf et al., 1986). Wolf et al. found that both alphanumeric and nonalphanumeric RAN tasks administered in kindergarten were predictive of second grade reading performance. However, when they examined the predictive ability of first and second grade rapid naming performance in relation to second grade reading performance, they discovered that only alphanumeric tasks predicted second grade reading measures (e.g., single word reading). Similarly, Lambrecht Smith, Scott, Roberts, and Locke (2008) found that performance on nonalphanumeric RAN-Objects and Colors assessed at the beginning of kindergarten were predictive of children's future reading, but these tasks were no longer predictive when readministered just before grade one. Thus, after approximately age 6, RAN-Letters and RAN-Numbers tasks appear to be superior to RAN-colors and RAN-objects tasks in the prediction of reading. However, some exceptions have been found. For example, Meyer, Wood, Hart, and Felton (1998) found all four types of RAN to be predictive of reading outcomes in their longitudinal study of third to eighth graders.

Performance on these RAN tasks adds unique variance to the prediction of reading skill even beyond that explained by the best individual predictor variable, phonological processing skill (Blachman, 1984; Chiappe, Stringer, Siegel, & Stanovich, 2002). Although the rapid naming of objects and colors does not consistently predict reading ability or performance (Blachman, 1984; Denckla, & Rudel, 1974; Denckla & Rudel, 1976; Wimmer, 1993; Wolf et al., 1986), RAN tasks, particularly alphanumeric RAN, seem to be specific predictors of reading problems (e.g., see Felton et al., 1987; Semrud-Clikeman, Guy, Griffin, & Hynd, 2000, as discussed below).

But what is special about RAN that predicts reading ability? Why is RAN performance related to reading? What is involved in alphanumeric or nonalphanumeric RAN performance that would show a stronger or weaker relation to reading? The answers are not clear.

Researchers have turned to clinical studies of children with extreme difficulties with reading, known as specific learning disorders in reading (SLDR) as well as behavioral symptoms of attention-deficit/hyperactivity disorder (ADHD), for clues about the processes involved in RAN performance, and to use RAN to explore the possible dissociative relations between disorders of reading and attention or hyperactivity or impulsivity. Felton et al. (1987) found that poor readers were significantly slower on all RAN tasks than children who had the attention problems of ADHD but no reading problems. They concluded that naming deficits were particular to children with reading difficulties but not children with ADHD.

Other researchers have continued to explore naming deficits in both of these clinical groups. For example, children with a specific learning disorder in reading were found to be slower on letter- and number-naming tasks and made more errors on all tasks than controls or children with ADHD, and an ADHD group performed more poorly than the control group on timed measures of color naming and object naming, but did not differ from the control group on letter and number naming (Semrud-Clikeman et al., 2000). In another example, psychostimulant medication (methylphenidate, better known by the brand name Ritalin) in children with ADHD selectively improved RAN-Colors performance in school-age children with ADHD, with or without a concurrent reading disorder. However, this improvement was not found for alphanumeric RAN performance (Tannock, Martinussen, & Frijters, 2000). Their findings challenged the tenet that naming speed deficits are specific to reading difficulties (RDs) and implicate naming-speed deficits associated with effortful semantic processing in ADHD, that are improved but not normalized by stimulant medication. In an example involving typically developing children in grades 3 and 4, performance on alphanumeric RAN was a reasonably good predictor of single-word reading scores; yet RAN-Colors showed a moderate, significant correlation with both inattentive and hyperactive behavior ratings, as well as executive functioning measures (Stringer, Toplak, & Stanovich, 2004). Stringer et al. suggested that children likely experienced increased cognitive demands when classifying and identifying colors, more so than in retrieving and articulating the color names, and thus performance on RAN-

Colors may be impacted by attention. Other evidence has suggested that variations in RAN-Colors stimuli (such as color desaturation) are more predictive of attention in adults, and that performance on a RAN task using pictures of various household objects (e.g., key, cup, house) has a unique relationship to word reading related to lexical access (Leung & Stringer, 2010).

These examples, that tie RAN performance firmly to reading performance as well as (but less consistently) to ADHD-symptoms, challenge the assumption that naming-speed deficits are specific to reading disorder (RD). The above examples also provide some support for purported processing differences underlying color naming and letter naming, and begin to weave together a coherent proposition of a *double dissociation* between alphanumeric and RAN-Colors in reading and attention difficulties.

The term *double dissociation* was introduced in 1955 by psychologist Hans-Lukas Teuber, in reference to studies on brain lesions (Van Orden, Pennington, & Stone, 2001). A double dissociation is the demonstration that two experimental manipulations each have different effects on two dependent variables. A double dissociation is shown when one manipulation affects the first variable but not the second, and the other manipulation affects the second variable but not the first. This term originated from the cognitive neurosciences in relation to studies on people with brain lesions. For example, if one can demonstrate that a lesion in brain structure A impairs function X but not Y as measured by some behavioral manipulation, and further demonstrate that a lesion to brain structure B impairs function Y but spares function X as measured by a second behavioral manipulation, one can make more specific inferences about brain function and function localization. Finding a double dissociation can demonstrate that the two functions are localized in different areas of the brain. Van Orden et al. questioned the utility and practicality of double dissociation experimental manipulations in reading, due to assumptions around modularity that may or may not exist, that is, the localization of "reading centres in the brain" from their case studies on people with traumatic brain injury. Reading is a complex task that involves many components in order to be successful in input and output.

Cognitive models are relevant for our understanding of brain activation and localization where reading and RAN processes are concerned. A meta-analysis of 36 neuroimaging studies of reading was conducted by Taylor, Rastle, and Davis (2013) to investigate reliable clusters of brain activity localized during word different types of word reading (e.g., word versus pseudoword tasks). They found convergence between cognitive models put forward of reading systems and the neural systems activated during reading tasks. Specifically, they revealed that different area clusters of the brain were activated reflecting particular types of reading processes, for example, orthographic analysis (occipitotemporal cortex), lexical and/or semantic processing (anterior fusiform, middle temporal gyrus), spelling–sound conversion (inferior parietal cortex), and phonological output resolution (inferior frontal gyrus). They were able to find a firm empirical foundation to encourage and improve the integration between cognitive and neural accounts of the reading process.

Studies with the double dissociation experimental manipulation in mind would provide a useful model by which we could better understand and illustrate the relations among RAN, reading performance, and ADHD-symptoms. Certainly we are not proposing all-or-nothing effects such as that which might be seen in people with traumatic brain injury. There likely exists an important distinction between cases where function has been lost after clear trauma and a demonstrated pattern of double dissociation, and cases such as in a typical sample of children in which there is no apparent trauma and lost function. Instead, we consider the relative strengths of associations within the guiding model of the double dissociation to be telling of significant relations among variables. These relative strengths of relations would serve to inform and illustrate important cognitive processes useful for understanding the nature of RAN, as well as reading and attention difficulties.

The present thesis posed three primary research questions in three linked papers to explore a possible double dissociation of RAN with reading and attention. The research provided further evidence for the double dissociation theory hypothesis, and supported the use of RAN in differentiating between problem behaviors, such as classroom inattention, hyperactivity, or impulsivity, and reading difficulties. Specific aims were to determine (a) if letter rapid automatized naming (RAN) task time, errors, or self-corrections predict reading fluency but not teacher-rated behavioral ADHD-symptoms (namely, inattention, hyperactivity, or impulsivity), (b) if color RAN task data predict behavioral ADHD-symptoms but not reading fluency and reading achievement, and (c) if RAN task data predict oral reading fluency, reading achievement, and behavioral ADHD-symptoms change over one year (a longitudinal component).

Although the thesis is in manuscript format, all three manuscripts are in expanded draft form. Each will eventually need to be condensed to meet typical journal length limitations. Tables and Figures are numbered for the entire thesis, and some review text is repeated. These qualities will be also revised when final publication versions are edited, and separate reference lists have been retained for each manuscript.

Manuscript 1

Rapid automatized naming (RAN) tasks are hypothesized to differentially predict behavioral ADHD-symptoms (namely, inattention, hyperactivity, and impulsivity) and reading outcomes based on RAN type, known as the *RAN double dissociation* in this review. Alphanumeric RAN tasks have been well established to correlate to measures of oral reading fluency and reading-related skills. The relations of other RAN tasks (e.g., nonalphanumeric RAN) to reading fluency and hyperactive or impulsive symptoms are less clear. The intent of this manuscript was to clearly delineate the differences between alphanumeric RAN (i.e., rapid recognition of letters and numbers) and nonalphanumeric RAN (rapid recognition of colors and shapes) and to explore the possibility that particular cognitive processes such as executive functions (e.g., attention) may be differentially related to RAN performance.

Manuscript 2

The second manuscript used a cross-sectional approach to explore naming data from RAN-Letters and RAN-Colors as predictors of ADHD-symptoms, also of oral reading fluency and single-word reading achievement (as measured by the DIBELS and Letter-Word ID), in a sample of typical English-speaking elementary schoolchildren. Statistical prediction does not necessarily imply a direct causal effect--there could be intervening variables, but the word "prediction" is used in the paper without implication of direct causality. This study also recognized that phonological processing (as measured by Elision--the ability to remove phonological segments from spoken words to form other words) is a primary predictor of reading ability in English. The objective was to link a predictor of reading performance, RAN, to English-reading achievement and behavioral symptoms of ADHD in boys and girls of elementary school age in a general school population. It was anticipated that alphanumeric RAN and phonological awareness would correlate with oral reading fluency and single-word reading achievement, whereas nonalphanumeric RAN performance would be associated with behavioral ADHD-symptoms (e.g., inattention, hyperactivity, or impulsivity) in English, which may not applicable to other languages, such as those with shallow orthographies or transparent orthographies.

Manuscript 3

The final manuscript added a longitudinal component using RAN data to predict oral reading fluency, norm-referenced reading achievement, and behavioral ratings of ADHD-symptoms after one-year. This explored a potential causal relation between RAN performance, ADHD-symptom ratings, and academic reading fluency outcomes in a typical sample of school children. Specifically, we asked how well do basic reading indicators (RAN-Letters, RAN-Colors, and phonological awareness as measured by Elision) at baseline correlate with reading outcomes (DIBELS, Letter Word ID, Reading Fluency), and attention outcomes (working memory, teacher ratings of inattention or hyperactivity or impulsivity) when tested after a period of one-year? Similarly to paper two, statistical prediction does not necessarily imply a direct causal effect--there could be intervening variables, but the word “prediction” and its associated derivatives are used in the paper without implication of direct causality.

Manuscript 1

New Insights into the Meaning of Rapid Automatized Naming (RAN) Scores: Connecting the Dots between Reading Difficulties and Inattention using RAN

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Abstract

Alphanumeric RAN tasks have been well established to correlate with measures of oral reading fluency and reading related skills. The relations of nonalphanumeric RAN tasks to reading fluency, inattention, hyperactivity, and impulsivity are less clearly established. The type of stimuli used for RAN tasks may be salient to specific types of developmental issues and suggest two contrasting patterns of group differences. Although alphanumeric RAN performance predicts reading fluency and contributes information about reading performance, nonalphanumeric RAN-Colors may more appropriately predict attention and may contribute more information about attention symptoms related to ADHD than about reading performance. The contrasting pattern of group differences in relation to RAN performance is known as the *RAN double dissociation*. The overall literature on RAN was reviewed, with specific attention paid to the nature of RAN types and the possible doubly dissociative relation to English reading fluency and ADHD-symptoms. A theoretical model applicable to RAN, reading difficulties, and inattention was outlined in light of this literature. We delineated the differences between alphanumeric RAN (i.e., rapid automatized naming of letters and numbers) and nonalphanumeric RAN (i.e., rapid automatized naming of colors and shapes) and posited that particular cognitive processes (e.g., attention, impulse control, working memory, and processing speed) may be differentially related to RAN performance.

Keywords: Reading; rapid automatized naming; fluency, attention

New Insights into the Meaning of Rapid Automatized Naming (RAN) Scores: Connecting the Dots between Reading Difficulties and Inattention using RAN

The knowledge of the link between the speed with which participants name letters, digits, colors, or objects, and their reading performance has been known for decades (Denckla, 1972; Denckla & Rudel, 1974; Wolf & Bowers, 1999). Clinically, such speeded naming tasks, known as rapid automatized naming measures or by the acronym RAN, originated as tools for probing specific neuropsychological functions related to speech-production fluency and long-term word retrieval (Denckla & Rudel, 1976b; Wolf & Bowers, 1999). Performance on RAN tasks adds unique variance to the prediction of reading performance beyond that explained by the best individual predictor variable--phonological processing or phonological awareness (Blachman, 1984; Chiappe, Stringer, Siegel, & Stanovich, 2002; Wolf, Bowers, & Biddle, 2000), particularly for typically developing and struggling students in the early stages of reading development (Allor, 2002).

Continuous or serial RAN tasks typically appear in four common and standard variants identified by the types of stimuli used: letters, digits, colors, and objects. Originally designed by Denckla (1972) and developed by Denckla and Rudel (1974, 1976a, 1976b) for clinical use, these tests involve the rapid naming of a visual array of letter, number, color, or object stimuli presented a fixed number of times in random order, organized in rows on a page or card. These tasks have been used clinically to assess basic psychological skills related to reading, such as subtests within the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999). The participant names each stimulus aloud in serial order, left to right, top to bottom, as quickly as he or she can. The elapsed time and number of errors are recorded by the examiner. This task has typically been administered as a paper-and-stopwatch task, but also has been adapted for computer use (Neuhaus, Carlson, Jeng, Post, & Swank, 2001; Howe, Arnell, Klein, Joanisse, & Tannock, 2006). RAN requires the identification of a visual stimulus, the assembly of a verbal response and its articulation, as well as visual scanning to the next stimulus or line to repeat the process. Because serial RAN tasks appear to be an analogue of the reading process, RAN and reading likely share many processes (Blachman, 1984; Foorman, Chen, Carlson, Moats, Francis, & Fletcher, 2003; Wolf & Bowers, 1999).

Performance on RAN tasks, particularly alphanumeric RAN, has been proposed to be predictive of specific reading problems, such as single-word and passage reading fluency, for a wide range of reading abilities. For example, letter and digit (alphanumeric) forms of RAN tasks were robust predictors of single-word reading in a classroom study of typically developing children in grades 3 and 4 (Stringer, Toplak, & Stanovich, 2004). Alphanumeric RAN (A-RAN) tasks were robust predictors of single-word reading for poor readers (Felton, Naylor, & Wood, 1990; Wolf & Obregón, 1992). Previous studies have also supported alphanumeric RAN as predictors of reading fluency among a majority of poor readers (Savage & Frederickson, 2005) and typically developing third and fourth graders (Pham, Fine, & Semrud-Clikeman, 2011). Denckla and Rudel (1976a) differentiated between children who were mildly learning-disabled with no reading disorder, and those with severe reading disorder using RAN tasks. Both groups were slower on RAN tasks than the control group; however, the children with the most severe reading disorder (reading scores more than two years below mental age) experienced the most difficulty and the longest times to complete RAN tasks.

Performance on RAN tasks also appears to be sensitive to age effects in the prediction of reading problems. Slow rapid naming persists as a deficit specific to poor readers across ages 5 to 10 (Wolf & Obregón, 1992) and into adulthood (Felton et al., 1990). Other studies have noted that A-RAN, as well as nonalphanumeric types of RAN (colors or objects; known as N-RAN) task performance were predictive of word-identification ability in grades 5 and 8 but only for poor readers (below the 10th percentile of a normally distributed sample) in grade 3 (Meyer, Wood, Hart, & Felton, 1998). However, another study found that, even in an adult university-educated sample, A-RAN tasks were strongly correlated with single-word identification and word-attack skills after controlling for vocabulary (Leung & Stringer, 2010).

Although performance on A-RAN tasks have been shown to predict single-word reading and passage reading fluency (Manis, Doi, & Bhadha, 2000; Meyer et al., 1998; Parrila, Kirby, & McQuarrie, 2004; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Wolf & Bowers, 1999), not all researchers have found a consistent RAN-reading link (Swanson, Trainin, Necoechea, & Hammill, 2003). For example, A-RAN tasks have not been shown to be consistent predictors of reading comprehension (Allor, 2002; Meyer et al., 1998). Meyer et al. (1998) tested the relation between RAN and passage comprehension in an impaired-reading subset of 154 randomly selected students who entered first grade in the fall of 1986. Because this was a normally distributed sample, only a small minority were poor readers. In the prediction of fifth-grade passage comprehension, neither A-RAN (consisting of RAN-Digits and RAN-Letters) nor nonalphanumeric (N-RAN, consisting of RAN-Colors and RAN-Objects) accounted for nearly as much variance in passage comprehension (less than 15%) as they did for word identification. Allor (2002), in her analysis of 16 studies investigating the relations between phonemic awareness and RAN to reading development, found that contributions of phonemic awareness and rapid naming to reading tasks other than individual word reading (e.g., reading comprehension, passage fluency, word attack) were unclear. Swanson et al. (2003), in their meta-analysis of 35 correlational studies on measures of phonological awareness, rapid naming, reading, and related abilities, found that the associations between phonological awareness and RAN performance were low and likely loaded on different factors. RAN performance was modestly correlated with real-word reading (r = .46), compared to variables such as spelling and pseudoword (r = .60 to .80), Swanson et al. suggested that the importance of RAN and phonological measures in accounting for reading performance have been overstated. Taken together, converging evidence indicates that A-RAN performance is one reliable indicator of certain reading skills such as single-word reading performance and likely not of other reading skills such as comprehension, or pseudoword decoding, although they may be sensitive to sample characteristics such as age and initial reading ability.

On the other hand, no consensus has been found about the role of nonalphanumeric RAN tasks (i.e., colors and objects) as predictors of reading ability. In fact, RAN-Colors and RAN-Objects have been inconsistent in predicting reading ability, and less predictive than alphanumeric RAN (Blachman, 1984; Denckla & Cutting, 1999; Denckla & Rudel, 1974; Wimmer, 1993; Wolf, Bally, & Morris, 1986). Savage and Frederickson (2005) found that digit, but not picture, forms of RAN predicted reading accuracy and speed in a sample of 67 children consisting mainly of poor readers with an average age of 10 years. Alphanumeric RAN (A-RAN) predicted unique variance not accounted for by phonological processing in poor reading performance, but both A-RAN and phonological processing were highly specific predictors of reading rate. Nonalphanumeric picture RAN (N-RAN) task did not predict reading rate.

However, a more recent study on a sample of 104 typical third and fourth graders found contrasting evidence, namely, that all four RAN tasks contributed significantly to reading fluency, although RAN-Letters explained the most variance and was more strongly associated with reading fluency than the other types (Pham et al., 2011). This finding corresponded with the Meyer et al. study, in which composite alphanumeric RAN as well as nonalphanumeric RAN were substantially better predictors of fifth- and eighth-grade word identification (at $p < .01$) than nonword reading and phonological segmentation (Meyer et al., 1998).

One hypothesis to explain the difference between alphanumeric and nonalphanumeric RAN in predicting reading rate and accuracy is that the types might reflect difference in cognitive sub-processes required for execution, such as vocabulary and access to lexical or semantic knowledge. For example, RAN-Objects requires access to semantic information (e.g., Humphreys, Riddoch, & Quinlan, 1988). Preliminary evidence demonstrating the difference between color and object RAN in a study of adults indicated that performance on RAN-Colors was correlated with self-rated attention measures whereas RAN-Objects performance was correlated with vocabulary (Leung & Stringer, 2010). Word-reading accuracy was associated with alphanumeric types of RAN (Digits and Letters), but not the nonalphanumeric types. This study did not examine word-reading fluency, and therefore word-reading accuracy was not controlled for in their study prior to predicting fluency from RAN. Word-reading accuracy was considered in the cited studies, even though it was controlled by Savage and Frederickson (2005) in their study of how RAN predicted word fluency.

RAN's relations to sight-word reading was reviewed in a longitudinal investigation which found that nonalphanumeric RAN performance in prereaders predicted later reading speed and subsequent alphanumeric RAN performance (Lervåg & Hulme, 2009). They speculated that these relations are mediated by a common neural mechanism that supports object recognition. Neuro-imaging studies find this area, the left mid-fusiform, is activated for both object naming and reading (Price et al., 2006). In skilled readers, proficiency in automatic word identification was correlated with increased activity in this region. The RAN literature still has not come to a conclusion about RAN-Colors or Objects performance in relation to reading. All RAN tasks are timed, but there may be additional phonological and orthographic features present in A-RAN stimuli that differ or are absent in N-RAN stimuli. The four types of RAN tasks may be differently related to distinct behavioral or performance outcomes.

Clinical Studies of RAN

Studies using RAN in clinical samples of children with reading- and attention-based difficulties have provided some clues to the nature of differences among RAN tasks in predicting reading performance and behavior. Studies in this area have begun to examine the relations among RAN stimuli type, reading skills, and behaviors in clinical samples of children with reading problems or behavioral concerns related to attention, hyperactivity, or impulsivity, known as attention-deficit/hyperactivity disorder (ADHD).

Specific learning disorder in reading (SLDR). Clinical studies of children with severe reading difficulties have been commonly referred to in the literature as “reading disabled” and with the acronym RD--representing Reading Disorder, Reading Disability, or a subtype of RD known as “dyslexia.” The standardization of operational definitions of terms related to RD may differ from one study to the next. Historically, the definition of specific learning disorder has been fraught with contention and disagreement among experts in the field (e.g., Goldstein, 2011; Hale et al., 2010). For example, many research definitions of dyslexia or RD have been based on an IQ-achievement discrepancy model in which children with RD typically have at least average intelligence, do not have general learning difficulties, and demonstrate reading problems that are not due to extraneous factors such as sensory acuity deficits, socioeconomic disadvantage, poor classroom instruction, and other environmental factors. These reading problems are manifested by extreme difficulties in acquiring basic reading subskills such as word identification and phonological (letter-sound) processing. Such difficulties have been estimated to occur in approximately 10% to 15% of school-age children (Benton & Pearl, 1978; Harris & Sipay, 1990; Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992) and tend to be accompanied by specific deficits in cognitive abilities related to reading and other literacy skills. This symptom pattern is often called "dyslexia" or "specific reading disability," and the terms are often used interchangeably (Vellutino, Fletcher, Snowling, & Scalon, 2004), or vary depending on the journal or type of researcher (e.g., educational vs. medical journal, cognitive psychologist vs. neuroscientist).

For the purposes of this paper, all references to this clinical population will henceforward be referred to as children with specific learning disorder in reading (SLDR) according to the current diagnostic criteria listed in the most recent publication of the *Diagnostic and Statistical Manual Five* (DSM-5; American Psychiatric Association, 2013a). Broadly defined, the SLD diagnosis requires "persistent difficulties in reading, writing, arithmetic, or mathematical reasoning skills during formal years of schooling" (American Psychiatric Association, 2013c, p. 1). Symptoms of SLDR may include "inaccurate or slow and effortful reading." Current academic skills must be "well below the average range of scores in culturally and linguistically appropriate tests of reading," (American Psychiatric Association, 2013c, p. 1) and the individual's difficulties must not be better explained by developmental, neurological, sensory (vision or hearing), or motor disorders, and must significantly interfere with academic achievement, occupational performance, or activities of daily living (American Psychiatric Association, 2013a).

ADHD. The essential feature of attention-deficit/hyperactivity disorder (ADHD) is a persistent pattern of inattention, or hyperactivity-impulsivity, or both, that is more frequently displayed and more severe than is typically observed in individuals at a comparable level of development (American Psychiatric Association, 2000). According to the DSM-5, ADHD is classified as a neurodevelopmental disorder consisting of three subtypes: ADHD-primarily hyperactive type, ADHD-primarily inattentive type, and ADHD-combined type. However, increasing data suggest that, for the majority of affected children, impulsivity and impaired executive functions represent core deficits (Goldstein, 2011). Conceptualization of ADHD may be seen as a cluster of different behavioral deficits, each with a specific neurosubstrate of varying severity occurring in variable constellations and sharing a common response to psychostimulant medications (Voeller, 1991). Furthermore, the frequency and severity of symptoms fluctuate across settings, activities, and caregivers (Tarver-Behring, Barkley, & Karlsson, 1985).

The inattentive subtype of ADHD in particular has been found to be related to poor academic achievement. Specifically, inattentive behavior in kindergarten children, but not hyperactive behavior, predicted poor reading outcomes in grade one and also in grade five, independent of kindergarten reading-related skills and concurrent levels of hyperactivity (Dally, 2006; Rabiner & Coie, 2000). Moreover, inattentive behavior has been found to predict poor response to evidence-based reading instruction (Fuchs, Compton, et al., 2005; Rabiner & Malone, 2004). Accordingly, the presence of some persistent inattentive behavior (e.g., distractibility, poor concentration and organization) in childhood is considered a developmental risk factor for poor academic outcomes (Warner-Rogers, Taylor, Taylor, & Sandberg, 2000).

Others have argued that the ADHD-inattentive type may be more properly understood with the context of LD more than as a variant of ADHD (e.g., Barkley, DuPaul & McMurray, 1990; Barkley, Grodzinsky & DuPaul, 1992; Cutting & Denckla, 2003) or a distinct disorder (Milich, Balentine, & Lynam, 2001; Stawicki, Nigg, & van Eye, 2006). There is evidence that medications such as Ritalin are much less effective for children with ADHD-inattentive subtype than those with hyperactivity (Barkley, 2004). The clinical picture is also dramatically different between the inattentive and hyperactive/impulsive types of ADHD that it is difficult to see how they have the same disorder. Neuropsychological profiles have also been demonstrated to differ between subtypes (Chhabildas, Pennington, & Willcutt, 2001). Clinically, children with the inattentive subtype are more likely to present with problems of staring, daydreaming, confusion, passivity, withdrawal, and sluggishness or hypoactivity and not so much with distractible and impulsive behavior and poor persistence. With all of the diagnostic considerations and controversies in the literature in mind, it would be important to consider the behavioral subtypes of ADHD separately for theoretical purposes in the consideration of linkages among RAN, reading performance, and behaviors.

Evidence for the relations among SLDR, ADHD, and RAN. RAN tasks have been used to examine the relations between SLDR and ADHD. In one study by Semrud-Clikeman et al. (2000), a sample of 71 children in three groups (13 with a specific learning disorder in reading (SLDR), 32 with ADHD without SLDR, and 26 controls) were assessed specifically on RAN deficits. Children with SLDR were slower on all alphanumeric RAN and nonalphanumeric RAN tasks compared to the control group. But in comparison with the ADHD group, the SLDR group performed more slowly than the ADHD group on both A-RAN tasks only. On the RAN-Colors task, the ADHD group performed more slowly than the control group but not the SLDR group. That is, both clinical groups were comparable for Colors. The SLDR group also made significantly more errors on the RAN-Letters task than either the ADHD or control group. No differences in errors were found between the ADHD and control group (Semrud-Clikeman et al., 2000). Overall, the ADHD group showed poorer performance than the control group on timed color- and object-naming tasks, but did not differ from the control group on letter and number naming. Other studies have challenged the claim that naming deficits are solely related to reading difficulties. For example, a study of 108 adolescents (13 to 16 years old) with ADHD (20 male and 15 female), reading disorders (6 male and 6 female), 24 ADHD+SLDR (15 male and 9 female), and 37 controls (18 male and 19 female) found that the two ADHD groups (ADHD, ADHD+SLDR) showed deficits in processing speed, RAN-Objects, RAN-Colors, and behavioral inhibition, and greater variability in reaction times. However, adolescents with SLDR (regardless of ADHD status) had poorer achievement scores, poorer verbal working memory, and were much slower on RAN-Letters. Furthermore, having both ADHD and SLDR was associated with additional cognitive deficits including slower rates of naming numbers and colors (Rucklidge & Tannock, 2002).

Poor readers are slower on RAN tasks than children with other clinical syndromes who might also be expected to have difficulty with this task, although more research is needed to assess the relation between RAN and attention. For example, poor readers were significantly slower on all RAN types than children who had attention deficit disorder (ADD) but no reading disability, in a sample of 98 children aged 8 to 12 in North Carolina (Felton, Wood, Brown, Campbell, & Harter, 1987). Children with reading disabilities, regardless of their ADD status showed significant deficits in their performance on all RAN tasks. Thus, Felton et al. found that naming-speed deficits were particular to poor readers. However, although the authors collected error and time scores, they only reported differences on time. Also, there were significant differences among the groups with ADHD and reading disabilities compared to the control group on a general intellectual-ability measure, and between the ADHD nonreading-disabled and the control group on measures of achievement. Thus, it is difficult to disentangle potential confounds that may have contributed to their findings.

We therefore have two contrasting patterns of group differences: (a) the Typical and students with ADHD are similar in A-RAN performance, but differ on N-RAN tasks, and (b) Typical and students with SLDR are similar in N-RAN performance, but differ on A-RAN tasks. Stringer et al. (2004) referred to this as the *RAN double dissociation*.

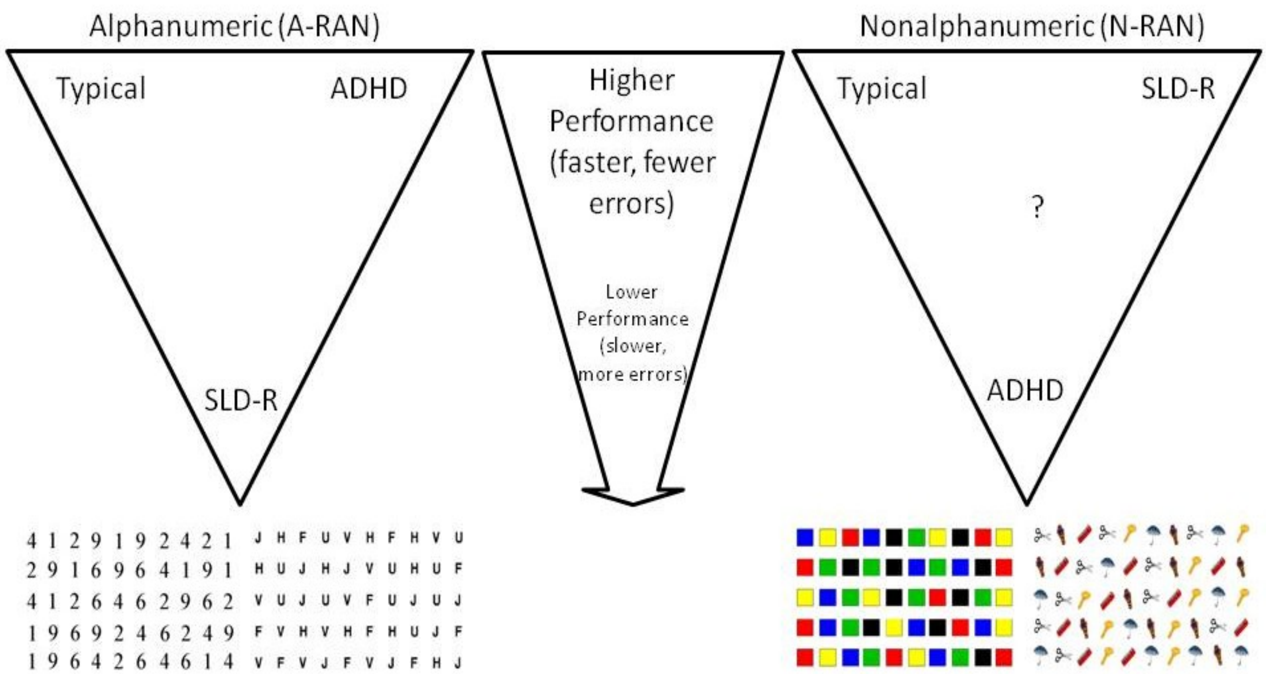

Figure 1. Schematic illustration of the RAN double dissociation hypothesis.

The relations among the populations in these figures are different or dissociated in two distinct ways: (a) Typical and ADHD groups appear to perform similarly on A-RAN tasks and the SLDR group is lower than both, however (b) ADHD group performance is lower than that of Typical students on N-RAN tasks.

The type of stimuli used for RAN tasks may be salient to specific types of developmental issues. Alphanumeric RAN performance predicts reading fluency and contributes information about reading performance, whereas nonalphanumeric RAN may more appropriately predict attention or semantic processes, or both, and RAN-Colors in particular may contribute more information about attention symptoms related to ADHD rather than about reading performance. Evidence in support of this hypothesis will have important practical implications of the double dissociation model to assessment and intervention practices for typically developing children and clinical samples of children with reading difficulties or symptoms related to ADHD.

Purpose

The purpose of this review is broadly to describe the state of evidence regarding this guiding double dissociation model and to ascertain reasonable expectations for the missing relations. In addition, it presents a theoretical context in which these relations can be further explored.

This review has three primary specific goals. First, it reviews the role of RAN in differentiating between reading and attention problems, and the overall literature on RAN with specific focus on the nature of RAN types and a possible *doubly dissociative* relation of alphanumeric RAN to reading and nonalphanumeric RAN to attention processes. Particular cognitive processes such as reading and attention may be differentiated by RAN performance, demonstrated by an in-depth review of evidence of the differential contribution of attention to reading fluency.

Our second goal is to propose a model that allows for an analysis of differences between alphanumeric RAN (i.e., letters and numbers) and nonalphanumeric RAN (i.e., colors and objects or pictures). This guiding model of the double dissociation of the RAN task in reading and attention, building on Figure 1, elucidates differences between attention-based and reading-based difficulties.

Finally, we discuss practical implications of the double dissociation model to assessment and intervention practices for typically developing children and clinical samples of children with a possible specific learning disorder in reading (SLDR) or attention-deficit/hyperactivity disorder (ADHD). Using evidence from the reading-assessment literature, we recommend strategies to address how teachers and psychologists can improve communication towards shared assessment and learning goals, and how assessment information from both can be mutually informative, yet nonrepetitive, in order to best serve students with any combination of attention or reading difficulties in the classroom setting.

What Contributes to Reading Fluency?

Reading serves two fundamental purposes: information gathering and literary experience (Mullis, Kennedy, Martin, & Sainsbury, 2006). Instruction in reading skills has been broadly divided and explicitly focused on specific areas to enhance and optimize reading achievement in young children, including phonemic awareness, phonological processing, letter-sound correspondence, phonics, fluency, vocabulary, and text comprehension (Armbruster, Lehr, & Osborne, 2001). Although these areas are listed here in a generally hierarchical order of development, most or all of these skills typically develop in parallel, can be cross-influenced by development in each other or contextually, and continue to improve into adulthood.

A few key components have been linked to the development of reading performance and reading fluency in particular. Phonological processing abilities have been well demonstrated to be crucially related to reading acquisition (e.g., Bruck, 1992; Gottardo, Stanovich, & Siegel, 1996; Stanovich, 1988, 1992, 2000; Wolf et al., 2000), although they may be orthography specific (see, for example, literature by Wimmer and colleagues in reference to German shallow orthography). Success in children's learning to read depends largely on phonemic awareness, that is, the ability to hear and manipulate sounds in words and, in a wider context, the child's phonological processing skill (Adams, 1990; Armbruster et al., 2001; Snow, Burns, & Griffin, 1998), that is, ability to use information about the sound elements of language for developing written and oral language (Wagner & Torgesen, 1987).

Although phonological processing skill (auditory detection, discrimination, and production of sounds in words) is considered to be the best individual predictor variable of reading performance even several years after being initially assessed (Adams, 1990; Vellutino, 1991; Wagner & Torgesen, 1987), other basic skills add unique variance to the prediction of reading performance beyond that explained by phonological processing, for example, rapid automatized naming (RAN), articulation rate, verbal short-term memory (Parrila et al., 2004), orthographic recognition (the ability to name, recognize, and write letters in the context of words and written language; Berninger, Abbott, Thomson, & Raskind, 2001; Olson, Forsberg, & Wise, 1994, in Neuhaus & Swank, 2002), and syntactic awareness (Gottardo et al., 1996; Plaza & Cohen, 2003). RAN has been shown to be one of the best predictors of word-reading accuracy and text-reading fluency (Wolf & Bowers, 1999; Wolf et al., 2000), particularly among poor readers, after phonological processing problems are first considered (e.g., Bowers & Newby-Clark, 2002; Bowers & Wolf, 1993; Savage & Frederickson, 2005; Wolf, 1991; Wolf et al., 2000). Also see Norton and Wolf (2012) for a review on RAN in relation to reading fluency and how RAN is unique as a cognitive measure of cognitive processes involved in reading. These findings have led to the idea of the *double-deficit hypothesis*, a two-element theory that phonological deficits and the processes underlying naming speed are separate sources of reading dysfunction, and their combined presence leads to profound reading impairment (Wolf & Bowers, 1999).

The double-deficit hypothesis led Cutting, Carlisle, and Denckla (1998, in Denckla & Cutting, 1999) to design a study that would explain RAN. Even though it is unknown if RAN is the best predictor of word reading, for example, compared to orthographic recognition or memory, it did so predict and was worthy of further exploration. A model of word reading was developed and tested on 79 typically developing readers in grades 1 to 3 who were not diagnosed with any type of learning disability or ADHD. The model attempted to test several integrated theories (e.g., Bowers, Golden, Kennedy, & Young 1994; Bowers & Wolf 1993; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993) of the relation of RAN to other predictors of word reading, such as phonological awareness (measured by phoneme deletion), memory span (measured by memory for increasingly longer series of digits), orthographic awareness (measured by a word likeness task), and also two hypothesized "behind the scenes" RAN predictors: processing speed (measured by a paper-pencil processing timed task) and articulation (measured by repetition speed of letters and numbers). RAN made a unique contribution to word reading alongside phonological awareness and orthographic awareness. Memory span did not contribute uniquely to word reading because it overlapped with phonological awareness. Processing speed was related to RAN speed, phonological awareness, memory span, and marginally to orthographic awareness. Articulation was related to only phonological awareness. RAN still contributed *uniquely* to word reading even with all the other variables included in the model. Although RAN could in large part be accounted for by processing speed, it could not fully be explained by it.

Alongside phonological processing, RAN task performance is highly correlated with reading ability (Wolf, 1991). Poor readers are consistently slower on RAN tasks than control groups (Denckla & Rudel, 1976b; Felton et al., 1987; Murphy, Pollatsek, & Well, 1988; Watson & Willows, 1995; Wolf et al., 1986). Performance on RAN tasks has been shown to be a useful clinical tool for probing reading performance both concurrently (Plaza & Cohen, 2003; Wolf & Bowers, 1999) and longitudinally (Kirby, Parrila, & Pfeiffer, 2003; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). As a concurrent example, 267 French-speaking first-grade children were examined on tasks assessing phonological processing, naming speed, and syntactic awareness--the understanding of grammar and the way words are put together to form phrases, clauses, or sentences in written language (Plaza & Cohen, 2003). Letter-naming speed was one of three separate significant predictors of reading and spelling performance (including phonological processing and syntactic awareness).

Breaking Down the RAN Task

Several studies have explored individual performance components of RAN, such as inter-item pause or articulation time, or end-of-line scanning (e.g., Georgiou, Parrila, & Kirby, 2006; 2008; 2009; Neuhaus, Foorman, & Francis, 2001) using chronometric techniques. In Neuhaus et al.'s study of 50 first- and second-grade students, RAN-Letters interarticulation pause time (i.e., the time taken in between utterances) was the most robust predictor of decoding and reading comprehension, consistently predicting all first- and second-grade measures, not the general processing speed for all RAN stimuli (2001). In Georgiou et al.'s two-year longitudinal study of 60 students from grade 3 to grade 5, pause time and articulation time on RAN tasks were highly correlated with reading fluency, although pause time shared more of its predictive variance with processing speed and lexical orthographic processing than with phonological processing, whereas articulation time's contribution was mostly independent from other cognitive processing skills (2009). Previous research also examined the impact of RAN components on reading from kindergarten until the end of grade 1 (Georgiou et al., 2006) and from grade 1 until the end of grade 3 (Georgiou et al., 2008), with somewhat similar results. That is, in their study of reading development of 62 kindergarten students through to the end of grade 1, pause time on RAN-Colors and Letters was highly stable from kindergarten to the end of grade 1, developed significantly, and was highly correlated with both reading accuracy and reading fluency measures. However, articulation time was less stable, did not develop, and was only weakly correlated with the reading measures (Georgiou et al., 2006). Similarly, in their study of 48 children grades 1, 2, and 3, pause time was highly correlated with reading fluency measures, whereas articulation time was only weakly correlated with the reading measures and was rather independent from any processing skill (Georgiou et al., 2008). Taken together, these studies show fairly consistently that variation in the pause time between named items rather than articulation time is associated with variation in reading, particularly in very early readers.

Longitudinal Studies of RAN

In longitudinal studies, RAN has also been shown to be powerful indicator of reading performance (e.g., Catts, 1993; Kirby et al., 2003; Landerl & Wimmer, 2008; Schatschneider et al., 2004; Wolf et al., 1986). Longitudinal studies of early reading development have converged to identify rapid naming in kindergarten as a major predictor--along with phonological awareness--of fourth- and seventh-grade reading skill (Badian, Duffy, Als, & McAnulty, 1991; Wolf et al., 1986; Wolf & Obregón, 1992). Kindergarten measures of RAN speed were significant predictors of word-reading ability for children in first and second grades (Catts, 1993). Longitudinal studies have also revealed an interaction between age and RAN type. For children entering first and second grades, nonalphanumeric RAN (N-RAN) stimuli lost their predictive capacity for word-reading abilities, but alphanumeric (A-RAN) stimuli continued to predict word-reading abilities (Wolf et al., 1986). Other evidence suggests a correlation between RAN and later reading (Catts, Fey, Zhang, & Tomblin, 2001; Meyer Wood, Hart, & Felton, 1998; Wolf, Bally, & Morris, 1986).

Kirby et al. (2003) determined that individual differences in RAN-Colors and Objects speeds measured on 79 children in senior kindergarten were still moderately associated with reading success five years later, despite controlling for initial general mental ability and letter knowledge. Measures of letter-name and letter-sound knowledge, RAN-Letters and Objects, and phonological awareness assessed in kindergarten were good predictors of multiple reading outcomes in 945 American children in grades 1 and 2 (Schatschneider et al., 2004). The relations between RAN tasks and reading ability change as higher order reading skills become more important. A significant relation between performance on the RAN tasks and reading comprehension was found in several longitudinal studies with this significant relation weakening as participants aged (Badian, 1998; Catts, 1993; Wolf et al., 1986).

The nature of orthographic depth in language may be important to consider in studies of RAN relations with reading performance. For example, the nature of the relations of RAN with reading performance and other reading-related skills (e.g., spelling, comprehension, letter-sound knowledge, phonological awareness) may be language dependent, and could differ in languages with more shallow orthographies, such as German, or asymmetrically transparent orthographies, such as Russian. In a group of 115 German students, the strongest specific predictor of reading fluency in grade 8 was RAN-Objects assessed in grade 1, over other predictive measures such as letter knowledge, phonological short-term memory, phonological awareness, and nonverbal IQ (Landerl & Wimmer, 2008).

Other longitudinal studies of RAN have failed to find a RAN-reading link (see Savage, 2004, for a review). Some differences in the findings may be attributed to differences in sample, such as the severity of reading difficulty (Wolf et al., 2000), or the level of reading ability the sample has already achieved at baseline (e.g. Wagner, Torgesen, & Rashotte, 1994). Evidence of a potentially causal longitudinal association is evident if RAN at time 1 predicts reading at time 2, and failure to find an effect when reading at time 1 is controlled is particularly difficult to interpret, because RAN may affect early reading to the same degree as it does later reading (Wolf et al., 2000).

Theoretical Explanations for the Relation between RAN and Reading

The reasons why RAN actually predicts reading performance are not clear. In the 1990s, it was common practice among reading researchers to subsume RAN under phonological processes whereas, in the cognitive neurosciences, RAN abilities were considered to be separate specific sources of disability (Wolf & Bowers, 1999). Thus, historically, the connection between RAN and reading has usually been attributed to the phonological processing component of RAN. Although it seems intuitive that phonological knowledge--and orthographic knowledge, not addressed in this review--are necessary for reading, the relation between rapid naming and reading is not as well understood (Neuhaus & Swank, 2002) and inconclusive (Kirby et al., 2010).

Different theoretical explanations for the relation between naming speed and reading have been proposed, based on different conceptual analyses of what is involved in naming speed and reading: phonological processing, orthographic processing, general processing speed, and executive processes or domain general automaticity deficits (Kirby et al., 2010). What these theories primarily share is that RAN and reading are treated as analogues of similar processes: Both require a sequence of eye movements across the page, that the stimulus in view be encoded and then accessed in storage, and that the associated instructions for naming the stimulus be activated. Even before the stimulus is fully articulated, the eyes move on to the next stimulus and the process is repeated. Although reading and RAN share some qualities, they differ in other ways. For example, articulation is not always required in reading, but it always is in RAN, and reading typically involves the extraction or construction of meaning, but naming speed does not. A brief summary follows of each theory that may possibly explain the predictive relation between RAN and reading fluency (Kirby et al., 2010).

Phonological processing. Speeded naming tasks such as RAN primarily assess the rate of access to and retrieval of stored phonological information in long-term memory. Reading researchers such as Torgesen and colleagues hypothesized that RAN tasks are related to reading through the more general construct of phonological processing because they measure the rate of access to stored phonological information in long-term memory (Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner & Torgesen, 1987). Previous empirical research has shown that alphanumeric RAN speed is strongly associated with reading success, particularly among poor readers, after phonological processing problems are first considered (e.g., Bowers & Newby-Clark, 2002; Bowers & Wolf, 1993; Savage & Frederickson, 2005; Wolf, 1991; Wolf et al., 2000), therefore, RAN is distinct enough from phonological awareness to make a unique contribution in predictive studies. However, the pronunciation or articulation of the stimulus names in RAN, which may be phonological in nature, has attracted attention as a possible source of naming-speed difficulty and the link to reading (e.g., Georgiou, Parrila, & Kirby, 2006; Jones, Obregón, Kelly, & Branigan, 2008). It has been suggested that the unique variance in reading ability explained by RAN, beyond that explained by phonological processing, may reflect a different phonological ability, such as phonological retrieval, that is, phonological recoding in lexical access (Wagner & Torgesen, 1987). The reader translates the visual information of the printed stimulus into a corresponding phonological representation and it is this phonological code that is then used to gain access to the stimulus's lexical entry in the neurocenter. In studies looking at reading acquisition by elementary school students in the phonologically transparent German orthography, phonological processing variables accounted for less variance in reading difficulties than RAN (e.g., Landerl & Wimmer, 2008; Wimmer, 1993; Wimmer, Mayringer, & Landerl, 2000). In a longitudinal follow-up study, RAN assessed in grade 1 was the strongest predictor of reading fluency in grade 8 and phonological awareness was the strongest predictor of correct spelling. Word-recognition speed development was more strongly influenced by early naming speed than by phonological awareness (Landerl & Wimmer, 2008). As variation in phonological processing becomes less of an impediment to reading acquisition, other processes related to RAN become the new bottleneck (Stringer et al., 2004).

In a recent study of RAN related to Russian reading skills by Rakhlin, Cardoso-Martins, and Grigorenko (2014), 96 students (with a mean age of 13) completed tests of word and pseudoword reading fluency, spelling, orthographic choice, phonological choice, phoneme awareness, and all four RAN types. They found that RAN, in particular alphanumeric RAN, accounted for variance in word and pseudoword reading fluency (rather than other reading skills such as orthographic processing). Their findings supported the idea that RAN taps into automaticity or efficiency of processing print-sound mappings.

Orthographic processing of RAN tasks. Naming-speed tasks are related to reading and distinct from phonological awareness because RAN underlies or is preliminary to orthographic processing--the mechanism by which very frequent or familiar stimuli are recognized quickly by sight (e.g., Bowers et al., 1994; Bowers & Wolf, 1993; Conrad & Levy, 2007; Manis, Seidenberg, & Doi, 1999). In reading, orthographic processing occurs when groups of letters or entire words are processed as single units rather than as a sequence of grapheme-phoneme correspondences (e.g., Stanovich & West, 1989). If letter identification is too slow or laborious, as indicated by slower RAN performance, grapheme-letter representations within words are similarly not activated quickly enough to induce sensitivity to or quick retrieval of commonly occurring orthographic patterns (Bowers & Wolf, 1993). It is also possible that RAN tasks then reflect a person's ability to form visual-verbal links in memory. In this case, RAN speed may indicate the strength of the links that are formed, or how easily they are formed.

General processing speed. Another interpretation of the RAN-reading association is that naming speed is but one manifestation of general processing speed--the speed at which cognitive processing occurs (Kail & Hall, 1994; Kail, Hall, & Caskey, 1999). Proponents of this view argue that naming and reading are linked because of the need for the rapid execution of the underlying processes involved in skilled naming and reading performance. In this interpretation, there is nothing special about the *naming* aspect of naming speed (nor with the type of stimuli). In the focus of the present review, this would imply that the stimulus type (word, number, color, object) in the RAN task would be irrelevant, but it is relevant. Despite the evidence of deficient phonological processing, disabled adult readers demonstrated faster processing speeds than reading-level adult and child controls (Chiappe et al., 2002). In a study of 50 first- and second-grade students, RAN-Letters interarticulation pause time (that is, the time taken in between utterances) was the most robust predictor of decoding and reading comprehension, consistently predicting all first- and second-grade measures, not the general processing speed for all RAN stimuli (Neuhaus et al., 2001).

Executive processing. Some researchers have argued that the relation between RAN and reading performance is due to executive processes including working memory, attention, and inhibition (e.g., Amtmann, Abbott, & Berninger, 2007). The performance of a serial task such as RAN involves classes of functions, including those that reflect inhibitory processes, those that require the shifting of set, and those that involve working memory (which also has been considered in similar, executive function terms; see Chiappe, Hasher, & Siegel, 2000, and Pennington & Ozonoff, 1996). Specifically, the brain must exert and direct attentional control and coordinate a number of actions: The eyes must be moved from stimulus to stimulus, from line to line, and in coordination with the articulation of the stimulus. Furthermore, inhibition is required to suppress pronunciation of previous items, and working memory is required to coordinate orthographic and phonological processing (Wolf & Bowers, 1999).

Domain-general automaticity deficits. Naming-speed deficits might be the outcome of cerebellar abnormality at birth leading to motor and articulatory problems, which, in turn, lead to low naming speed (Nicolson, Fawcett, & Dean 2001). This issue is peripheral to the argument being developed in this review.

Theoretical summary. These theoretical explanations suggest a number of key processes shared by RAN and reading tasks. The phonological processing interpretation implies that naming-speed tasks are at least somewhat phonological in nature, leading to the question of whether naming speed contributes anything beyond phonological processing to reading (it does). The orthographic interpretation emphasizes that RAN tasks and reading require instantaneous access to lexical representations and suggests that this may be the basis of the relation, which in turn leads to the question of whether RAN type may be differentially related to reading or if RAN types all have the same relation to reading (they do not). The processing-speed interpretation stresses the importance of speed or efficiency in responding, that is critical for some aspects of reading (e.g., reading speed or fluency), which again leads to the question of whether quick processing speed on all types of RAN predicts reading or if it does not (at this point, unlikely). Coming full circle to its origins, Denckla and Cutting (1999) suggested that RAN taps both visual-verbal (language domain) and processing speed (executive domain) contributions to reading. Wolf, Bowers, and Biddle (2000) argued that rapid-naming tasks are composed of attentional, visual, lexical, temporal, and recognition subprocesses that all contribute to naming-speed performance. Other interpretations point to the importance of executive processes to orchestrate all of these variables in synchrony for performance to be successful, which should warrant further empirical investigation into the role of processes such as working memory, attentional control, and inhibitory responses in RAN and reading performance.

The Role of Attention in Reading

An array of neuropsychological correlates such as processing speed and attention have been reported to play a role in the development and maintenance of reading skills. These same neuropsychological mechanisms are deficient in individuals with ADHD (e.g., Foy & Mann, 2013; Martinussen & Tannock, 2006; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). The core behavioral symptoms of inattention, impulsivity, and hyperactivity are associated with concurrent and later academic underachievement (e.g., Barkley, 1998; DeShazo Barry, Lyman, &

Klinger, 2002; Fergusson & Horwood, 1995; Forness & Kavale, 2001; Rapport, Scanlan & Denney, 1999; Zentall, Smith, Lee, & Wieczorek, 1994).

A body of research based on typically developing children supports the notion that inattention on its own predicts poor academic achievement. For example, in a longitudinal multisite American study of over 300 kindergarten students examining the development and prevention of conduct problems, classroom attention problems specifically predicted children's reading achievement in grades 1 and 5, but not IQ, kindergarten reading-related skills, or concurrent levels of hyperactivity (Rabiner & Coie, 2000). Moreover, inattentive behavior predicted poor response to evidence-based reading instruction (Fuchs, Compton, Fuchs, Paulsen, Bryant, & Hamlett, 2005; Rabiner, Malone, & Conduct Problems Prevention Research Group, 2004). Children who exhibit symptoms of ADHD even at levels below the clinical threshold for a diagnosis exhibit academic problems (Breslau, Miller, Breslau, Bohnert, Lucia, & Schweitzer, 2009; Currie & Stabile, 2006), typically have difficulty with paying attention to task instructions or group work, and experience significant problems with test performance, study skills, and organization of their materials and assignments (DuPaul & Stoner, 2003). Phonological awareness and rapid-naming abilities are crucial to success in subsequent word-level reading and in reading comprehension (Dally, 2006). Dally's longitudinal investigation of 132 children at 12-month intervals from kindergarten to second grade revealed that inattentive behavior had a significant and independent role in disrupting the acquisition of early reading skills, including the vital development of phonological analysis abilities. Accordingly, the presence of some persistent inattentive behavior in childhood (e.g., distractibility, poor concentration or organization) is considered a developmental risk factor for poor academic outcomes (Warner-Rogers, Taylor, Taylor, & Sandberg, 2000).

The persistence of learning difficulties in reading and problems related to symptoms of ADHD from childhood into adulthood is well documented (Barkley, Murphy, & Fischer, 2007; DuPaul & Stoner, 2003). Follow-up studies into adolescence of children with ADHD indicated that the greatest risks for this population are chronic underachievement and higher rates of school dropout (e.g., Barkley, Fischer, Edelbrock, & Smallish, 1990). Individuals with learning difficulties and clinical levels of attention problems (with or without hyperactivity or impulsivity) typically enter the workforce at lower levels and have fewer job promotions and more job changes (Barkley & Murphy, 2005; Goldstein, 2011).

At clinical levels, reading difficulties and symptoms of ADHD have been well documented in both the clinical and research literature (e.g., DuPaul & Stoner, 2003). The proportion of children with ADHD and a comorbid specific learning disorder in reading (SLDR) has been found to range from 15% to 44% (Mayes & Calhoun, 2006), or about one-third (DuPaul & Stoner, 2003). Others have estimated the co-occurrence of ADHD and SLDR to be 26% to 50% (Holborow & Berry, 1986; Lambert & Sandoval, 1980).

The high comorbidity rate between reading and attention problems suggests a strong relation between them, but the details of this relation remain unknown. Although reading has been widely studied, attention is often underestimated in the process of reading acquisition (e.g., the translation of print into speech, fluency, and comprehension; Reynolds & Besner, 2006). Although the comorbidity of reading and attention problems is generally well established, less is known about how the process of RAN, considered foundational to reading, is related to attention.

One reason why less is known about attention's role in reading acquisition might be because of the lack of differentiation and confusion in prior research between academic skills deficits (i.e., true learning disabilities) and academic performance deficits. Because a large percentage of children with ADHD display challenges with complex problem-solving (Barkley, 1990; 1998), organizational skills (Zentall, 1988), expressive language difficulties, or gross or fine motor control (Barkley, DuPaul, & McMurray, 1990; Hartsough & Lambert, 1985), the risk for educational underachievement is compounded (DuPaul & Stoner, 2003). Population challenges, such as chronic underachievement relative to intellectual capabilities and motivation, as well as research challenges, such as failure to distinguish between deficits, and inexact definitions of SLDR may have exacerbated the problem of drawing accurate conclusions about the relation between ADHD and reading problems. Skills deficits presume an actual lack of ability to learn a specific subject matter as it is taught; performance deficits presume that the requisite skills are present, but the child lacks the ability to demonstrate this knowledge consistently. Students who exhibit academic-performance deficits possess the necessary skills but do not demonstrate this knowledge on a consistent basis under typical classroom conditions, a pattern of behavior that is typically seen in children with ADHD. For example, a child with ADHD-symptoms, such as a lack of attention to academic procedures, instructions, or working materials, may demonstrate poor performance on assigned tasks even though he or she may possess the requisite skills to complete the assignment correctly. Unfortunately, empirical research has typically failed to differentiate between academic skills deficits and performance deficits (DuPaul & Stoner, 2003).

Also, most clinical ADHD and reading-problem literature has been correlational as opposed to using specific models that would be essential to explain the relations between behavior and SLDR (DuPaul & Stoner, 2003). Furthermore, professionals often disagree when defining the criteria used to define “reading problems.” Historically, the definition of a specific learning disability in reading has been fraught with contention and disagreement among experts in the field (e.g., Hale et al., 2010; Goldstein, 2011).

Causal Mechanisms of Attention and Reading Difficulties

Reading and attention. The causal mechanisms of ADHD-symptoms and reading difficulties are still not well known. Deficits, for example, in the more "basic" levels of self-regulation, response inhibition, and working memory (associated with ADHD), in relation to all types of learning problems, including reading acquisition, are still not well understood. Systematic study of the interrelations among the development of self-regulation, language, and skills in academic areas is critical in terms of understanding how reading problems may manifest differently at each age and stage of development. For example, maturation of the frontal cortex may play a critical role in developing those skills for reading comprehension (beyond what is accounted for by basic reading) that require working memory and higher order thinking (Cutting & Denckla, 2003).

Over the years, researchers have studied cognitive profiles and brain-behavior associations with different types of SLD, and most extensively of clinically diagnosed reading difficulties (e.g., Adams, 1990). Such research has yielded not only a strong understanding of the cognitive characteristics of reading disability but also strong evidence for genetic and brain bases of reading disability, although the precise genetic and brain mechanisms involved are still under exploration (Cutting & Denckla, 2003). Despite the general acceptance of neurological causality for SLDs and attention difficulties, at this time there are no clear neurological tests that distinguish individuals with learning disorders and ADHD from other types of low achieving learners or those with related psychiatric problems.

The range of intellectual functioning in groups of children with ADHD, as well as in children with reading disabilities is similar to that obtained in the general population (i.e., represented by a normal distribution from significantly below average to significantly above-average functioning; Kaplan, Crawford, Dewey, & Fisher, 2000). The extent to which ADHD is associated with delays in general intellectual functioning is controversial (DuPaul & Stoner, 2003), and may be accounted for by differences in test-taking behavior such as higher levels of inattention among children with ADHD in comparison to same-aged peers (Barkley, 1998).

Due to existing uncertainty about definitions and changing perspectives on the disorders, it will be important for practitioners to carefully evaluate their diagnostic practices of reading disorders and ADHD. Indeed, it may be of more service to any child being assessed to consider "reading difficulties" and "symptoms of inattention, hyperactivity, or impulsivity" as occurring regularly in the classroom setting in various contexts, and to focus specifically on intervention rather than labeling diagnostically for special education purposes.

RAN and attention. Rucklidge and Tannock (2002) found significant differences in performance on color and object RAN tasks between children with ADHD (with and without reading disorders) and with typically developing children. One possible explanation for this finding is that slow color and object naming may be associated with developmental delays in effortful perceptual, semantic processing, or both, typically associated with right hemisphere functioning (Tannock, Martinussen, & Frijters, 2000). Another explanation is the possibility of more than one plausible name for a given color or object, and asymmetries could exist between the labels. For example, object names may differ in word frequency leading to increased attentional demands and the necessity for more careful and detailed processing than recognizing letters or digits. Such impairments in semantic processing have been implicated in children with attention difficulties (Tannock et al., 2006).

In their review of the history and significance of RAN, Denckla and Cutting noted that the “zone of convergence” linking ADHD with RD involves the executive aspects of language. Many ADHD-related characteristics involve slowness, such as slow and variable reaction time and slow-for-age timed motor coordination (Denckla & Rudel, 1978). Characteristics such as slowness, inefficiency, and lack of fluency and automaticity demonstrated in reading performance are sometimes attributable to brain dysfunction underlying ADHD rather than to a reading disorder *per se*, suggesting that the very commonly reported comorbidity of RD and ADHD may require reanalysis (Denckla & Cutting, 1999).

The overlap between reading difficulties and attention problems in clinical and normative samples, and the presence of clinical characteristics specific to each disorder, lead to the proposal of models that suggest that, although there are overlapping mechanisms of disorders, there are distinct variables responsible for the development of disorder-specific presentations. Evidence from genetic and neuroimaging studies supports the notion of disorder-specific neurobiological mechanisms that may assist with differentiation between disorders. A double dissociation of the rapid automatized naming (RAN) task in reading and attention has been proposed to elucidate differences between attention-based and reading-based difficulties (Stringer et al., 2004). If more evidence is found to support the role of RAN-type performance in doubly dissociating between alphanumeric and RAN-Colors in reading and attention difficulties, then this challenges the assumption that naming-speed deficits are specific to reading difficulties and also will provide support for processing differences underlying color naming and letter naming. Further empirical research would provide evidence for the double dissociation theory hypothesis, and could substantiate the use of RAN as a clinical tool with a multifocused lens towards differentiating between problem behaviors such as classroom inattention, hyperactivity or impulsivity, and reading difficulties.

Evidence Supporting a RAN Double Dissociation Hypothesis

Two contrasting patterns of group differences between attention-related difficulties and reading difficulties based on RAN performance type stimuli are proposed: (a) Typical students and students with ADHD perform similarly in alphanumeric RAN performance but differ on nonalphanumeric RAN tasks, and (b) typical and students with reading disorders are similar in N-RAN performance but differ on A-RAN tasks. This is the *RAN double dissociation*.

The term *double dissociation* was introduced in 1955 by psychologist Hans-Lukas Teuber, in reference to studies on brain lesions (Van Orden, Pennington, & Stone, 2001). A double dissociation is the demonstration that two experimental manipulations each have different effects on two dependent variables. A double dissociation is shown when one manipulation affects the first variable but not the second, and the other manipulation affects the second variable but not the first. Using this type of manipulation, one can make more specific inferences about brain function and function localization.

Reading is a complex task that involves many components in order to be successful in input and output. Studies with the double dissociation experimental manipulation in mind would provide a useful *guiding* model by which we could better understand and illustrate the relations among RAN, reading performance, and ADHD-symptoms, even though reading is likely not limited to specific brain functions or localization. Certainly we are not proposing all-or-nothing effects such as that which might be seen in people with traumatic brain injury! Instead, we consider the relative strengths of associations within the guiding model of the double dissociation to be telling of relations among variables. These relative strengths of relations would serve to inform and illustrate important cognitive processes useful for understanding the nature of RAN, as well as reading and attention difficulties.

Neurologists have also suggested the possibility of theoretically dichotomizing within the executive system so that "children with RD-free-of-ADHD would show phonological-but-not-central dysexecutive features, and those with ADHD-free-of-RD would show the reverse, as yet no such splendid double dissociation has been consistently demonstrated" (Denckla & Cutting, 1999). Denckla and Cutting used the term "dysexecutive" as a parallel to "dyslexic," meaning a range of cognitive difficulties with associated with ADHD. RAN deficits may be integral for understanding the neuropsychological correlates of ADHD (Carte, Nigg, & Hinshaw, 1996; Rucklidge & Tannock, 2002; Semrud-Clikeman et al., 2000; Tannock et al., 2000; Willcutt et al., 2001). Because serial RAN performance relies on continuous responding and sustained attention to stimuli in order to perform well, RAN tasks may be more challenging for children with attention difficulties. Children with ADHD--Predominantly Inattentive Type, and reading difficulties typically share similar symptomology that may influence RAN outcomes, such as slower processing speed (Catts, Gillespie, Leonard, Kail, & Miller, 2002; Shanahan et al., 2006; Willcutt, Pennington, Olson, Chhabildas, & Huslander, 2005) and semantic processing problems (Tannock, Banaschewski, & Gold, 2006).

The cognitive demands of continuous RAN highlight why the slowness and inefficiency observed in poor readers may overlap with the executive dysfunction characteristic of children with ADHD (Denckla & Cutting, 1999). For example, RAN may heavily tax executive control of those language systems in the brain (e.g., scanning and sequencing) that lie at the "intersection" of the neurological domains hypothesized to underlie ADHD and RD (Denckla & Cutting, 1999).

Some studies have found a differential relation between RAN-type performance in clinical studies of children with reading difficulties and ADHD. Purvis and Tannock (2000) administered RAN-Letters and RAN-Digits to a clinical sample of children with ADHD only, reading disorder (SLDR) only, and comorbid ADHD+SLDR group. Children with reading disorder, both in the only and comorbid ADHD+SLDR groups performed more poorly on the RAN tasks than did children with ADHD only. No control group was included. This showed that difficulties in RAN-Digits and RAN-Letters performance are specific to children with reading disorders (Purvis & Tannock, 2000). In another study, children with an SLD in reading were slower on letter- and number-naming tasks and made more errors on all tasks than controls or children with ADHD, and the ADHD group showed poorer performance than the control group on timed measures of color naming and object naming, but they did not differ from the control group on letter and number naming (Semrud-Clikeman et al., 2000). In a study of 61 Canadian children with ADHD, 21 children with both ADHD and reading disorder, and 27 typical controls, both ADHD and ADHD with reading disorder groups were slower in performing RAN-Colors than a control group of children (Tannock et al., 2000). The ADHD+SLDR group was slower than the ADHD-only group on RAN-Letters performance. Moreover, psychostimulant medication (methylphenidate, known commonly as Ritalin) in children with ADHD was found to selectively improve performance on RAN-Colors in school-age children with ADHD (and with or without a concurrent reading disorder), but not alphanumeric RAN. Tannock et al.'s findings challenged the tenet that naming speed deficits are specific to reading difficulties and posited that certain naming speed deficits (e.g., RAN-Colors) were associated with effortful semantic processing in ADHD, which are improved but not normalized by stimulant medication. Although a control sample was used, there was no group of children with reading difficulties only.

Color-naming deficits show moderate to large effect sizes (d = 0.58-0.62) across the developmental lifespan with little evidence of age-related changes, according to a meta-analysis of 17 Stroop Color-Word task studies of cognitive deficits in 1395 children, adolescents, and young adults with ADHD (van Mourik, Oosterlaan, & Sergeant, 2005). The Stroop Color-Word task (an incongruent stimuli paradigm that generally consists of two parts: In the first trial, the written color name differs from the color ink it is printed in, and the participant must say the written word. In the second trial, the participant must name the ink color instead; Stroop, 1935) is used frequently as a measure of interference control in studies with ADHD groups and is recommended as part of a psychological test battery in clinical settings (see MacLeod, 1991, for a review) and shares characteristics with RAN tasks (such as the goal of assessing rapid naming of specific stimuli related to word or color information; Doyle, Biederman, Seidman, Weber, & Faraone, 2000).

Color perception and rapid color-naming ability were investigated in 14 children with ADHD and controls using the Stroop-Color-Word test and assessment of color vision (Banaschewski et al., 2006). Children with ADHD were slower on Stroop subtests involving color naming, although this was partially accounted for by blue–yellow and red–green discrimination abilities. They concluded that perception problems in ADHD contribute to (but do not fully explain) slower color naming.

Furthermore, alphanumeric RAN (specifically the rapid naming of digits and letters) was a reasonably good predictor of single-word reading scores in a classroom study of typically developing children in grades 3 and 4; but Colors showed a moderate, significant correlation with both inattentive and hyperactive behavior ratings, as well as executive functioning measures (Stringer et al., 2004). These results suggested that any linguistic or phonological component necessary to RAN performance is probably insignificant in terms of the overall speed of naming. That is, children likely experience increased cognitive demands when classifying and identifying colors, more so than in retrieving and articulating the color names, and thus may be impacted by attention.

Other more recent evidence indicated that variations in RAN-Colors stimuli (such as color desaturation) are predictive of attention in adults and not reading performance, and that performance on a RAN task using pictures of various household objects (e.g., key, cup, house) has a unique relation to word reading related to lexical access (Leung & Stringer, 2010). Two possible hypotheses about mechanisms were proposed: (a) that letters and digits fit a “category” structure whereas colors and objects fit a Rosch “prototype” (Rosch, 1975) indicating that variations in color or object perception may be more related to attentional or lexical processes, but a strict categorical perceptual task involving letters or digits provide no room for variability in interpretation and thus do not access attentional processes, and (b) lowered levels of dopamine may be associated with ADHD-symptoms and with problems in color perception. The Rosch approach, on the other hand, hypothesizes some categorical processing “room for error” depending on the type of stimuli, such as colors and objects. Letters and digits, however, are strict in their categorical orthography.

Pham et al. (2011) explored the concurrent relations among different measures of RAN, inattention, and reading-fluency skills in a typically developing sample of third- and fourth-grade children. Because previous studies primarily focused on comparing clinical samples of children with documented ADHD or SLD in reading with control groups, Pham et al. looked more closely at how inattentive behaviors overlap with reading skills among children with no present clinical diagnoses. This comparison provided a better understanding of the variability in attention levels among typically developing readers (Mayes, Calhoun, & Crowell, 2000). All four RAN stimuli types predicted oral reading fluency, and parent and teacher ratings of inattention predicted RAN performance after controlling for sex, working memory, and estimated IQ. Pham et al. concluded that RAN performance mediated the relation between inattention and reading fluency, and supported the notion that attentional variables should be considered when assessing reading performance among typically developing children.

On the other hand, another study failed to support the hypothesis that naming performance mediates the relation between inattention and reading outcomes. Cantor's dissertation research (2009) focused on inattention, the component of ADHD that has been shown to be most related to reading. Ninety-five children from grades 2 to 4 completed two individual testing sessions that included assessment of their phonological awareness, naming speed on RAN-Letters, RAN-Digits, RAN-colors, RAN-Objects, and reading ability, which consisted of a battery of single-word reading tasks and word attack (nonsense-word reading) measures. Inattention was assessed using both the Conners Continuous Performance Task II (CPT; Conners, 2000) and parent ratings. Consistent with previous research, performance on RAN-letters and RAN-digits, but not performance on RAN-objects and RAN-colors, was related to children's scores on reading measures. Although CPT performance was associated with phonological awareness, neither performance on the CPT nor parent ratings of attention was associated with children's performance on the RAN tasks. Oral reading fluency on passages was not assessed, nor were teacher ratings, or symptoms of hyperactivity or impulsivity related to ADHD.

Investigations that demonstrate a link between RAN-Colors and ADHD-symptoms have suggested that the relation between RAN-Colors and ADHD is such that RAN-Colors performance taps into some underlying cognitive process that is impaired in ADHD. The class of cognitive processes believed to be impaired in ADHD is referred to as executive function, and in fact, performance on some set-shifting executive function tasks, such as the Wisconsin Card Sorting Test (WCST; Heaton, 1981), and the Trailmaking Task, Part B (Reitan, 1955, 1958) have been positively associated with behavior ratings of ADHD (Riccio, Hall, Morgan, Hynd, & Gonzalez, 1994; Stringer et al., 2004). The WCST has been interpreted as a measure of the individual's ability to use external cues to guide behavior, self-monitor, and shift mindset (e.g., the tendency to perseverate or adapt quickly during changing schedules of reinforcement or feedback). These qualities may also play a role in RAN performance. Also, although this work originates in the clinical literature, it is also important to know how reading performance, behavior, and RAN are related for children at different levels of ability and difficulty (Stringer et al., 2004; Welsh, Pennington, & Groisser, 1991).

Most previous RAN studies have had limitations. Most used clinical groups, such as ADHD and specific learning disorder in reading (Purvis & Tannock, 2000; Rucklidge & Tannock, 2002). Previous ADHD studies often did not separate differences between inattentive and hyperactive-impulsive symptoms (e.g., Carte et al., 1996; Semrud-Clikeman et al, 2000). Groups of children diagnosed with ADHD in the reported studies may have exhibited either predominantly hyperactive, rather than inattentive behaviors, or a combination of both. The heterogeneous nature of the ADHD construct represents a significant limitation in studies that explore the relation between inattention and reading, especially because phenotypic studies noted that inattention is more predictive of reading difficulties than hyperactivity or impulsivity

(Willcutt et al., 2001). In addition, most studies of RAN performance in children with SLDR or ADHD have used single-word reading tasks rather than using measures of reading fluency to assess reading skills. Phonological processing was not taken into account in the most recent study (Pham et al., 2011), and this finding of superior prediction by inattention has not yet been replicated with a younger set of children in a typical classroom sample, which may or may not include children with a pre-existing diagnosis of ADHD or SLDR. The findings have not been replicated using grade-level passage reading fluency and norm-referenced single-word and reading-fluency achievement, which would be more analogous to reading skills in the classroom setting.

A doubly dissociative relation between alphanumeric and RAN-Colors in attention difficulties challenges the assumption that naming speed deficits are specific to reading difficulties and also provide some support for purported processing differences underlying color naming and letter naming. Further empirical research would provide substantive evidence for the double dissociation theory hypothesis, and could potentially substantiate the use of RAN toward differentiating between problem behaviors, such as classroom inattention, hyperactivity, or impulsivity, and reading difficulties.

The RAN Double Dissociation Hypothesis

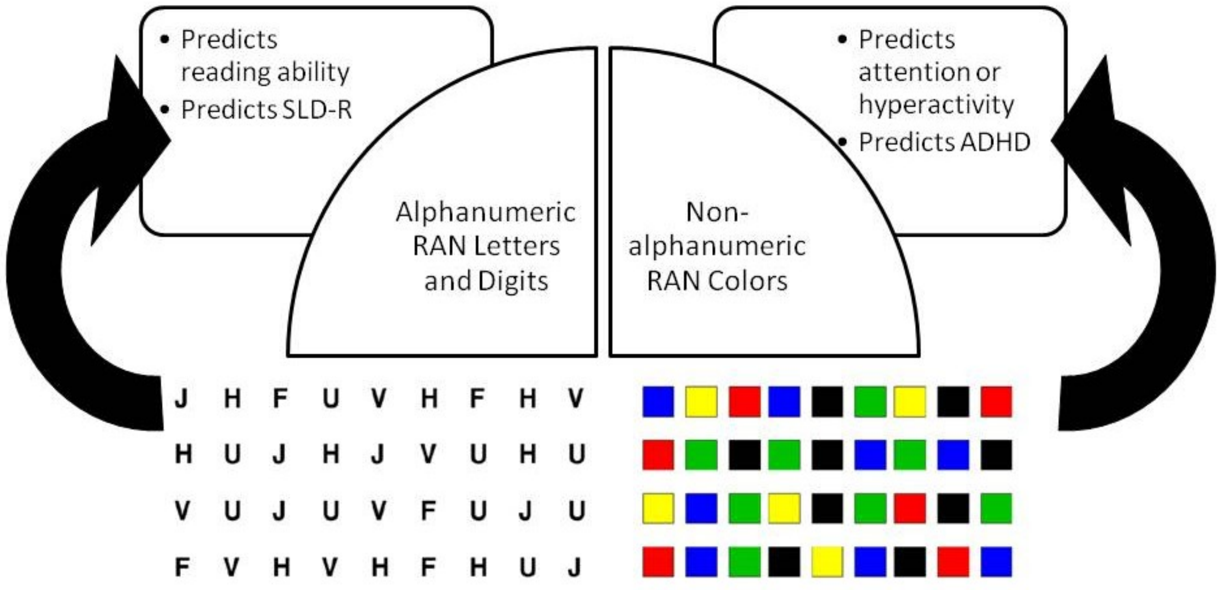

Figure 2. General illustration of the RAN double dissociation items and hypothesis.

Existing literature has set a precedent for a possible double dissociation hypothesis in RAN in relation to reading and attention (Figure 2 particularly focuses on RAN-Colors; also refer to Figure 1 for details about the dissociation and sample depictions of RAN tasks). Specifically, the serial rapid naming of familiar stimuli such as letters and digits (i.e., alphanumeric) RAN are consistently and reliably associated with reading ability, yet converging evidence suggests RAN for colors (nonalphanumeric) is more related to features of attention, especially executive functions and behavior ratings linked to ADHD (hence, the *double dissociation*).

Discussion

Interpreting the Results

The overall impression created by the literature can be illustrated as shown in Figure 3.

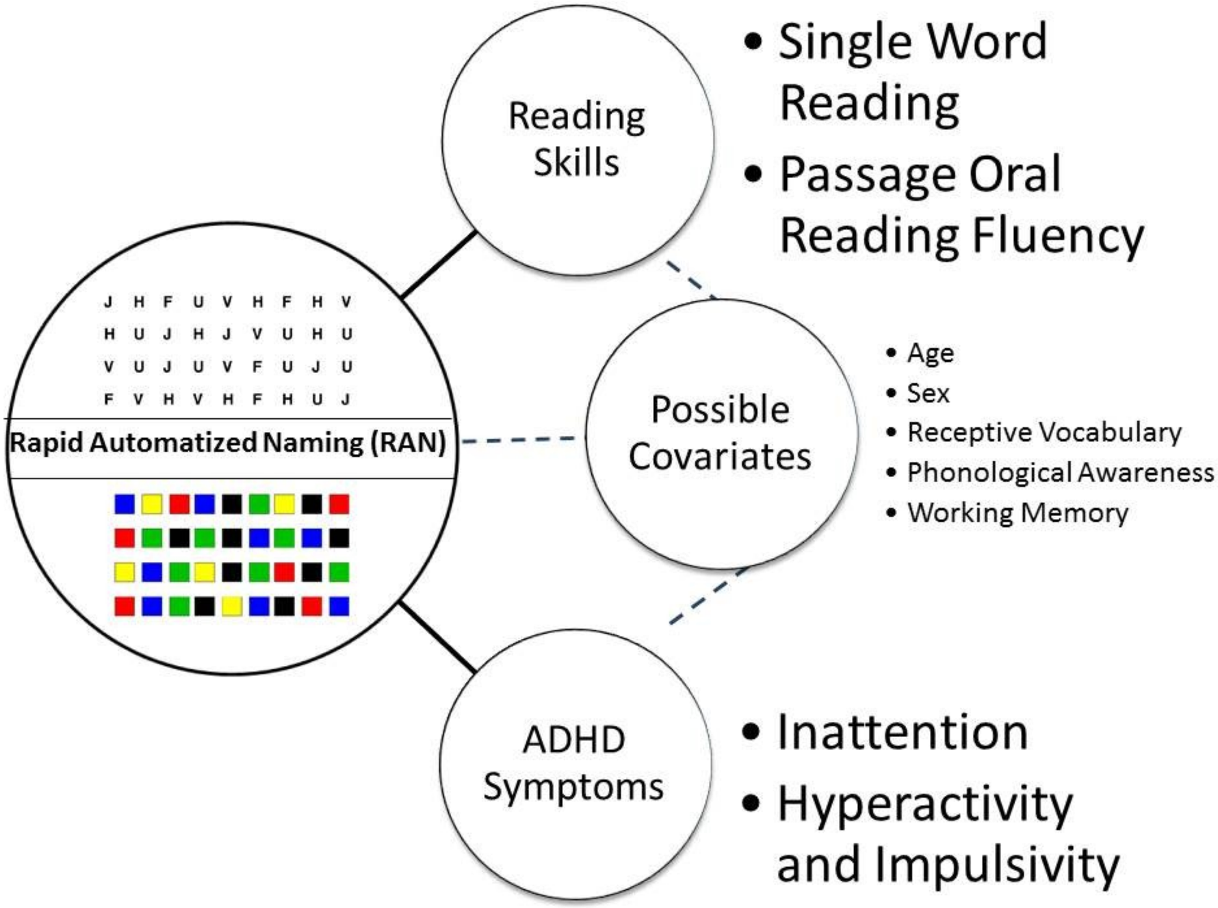

Figure 3. Illustration of the RAN double dissociation with possible covariates.

The model illustrated in Figure 3 might be incomplete, although it demonstrates the relations among the variables examined in the present study. For example, processing speed has been addressed elsewhere in relation to RAN performance (Cutting, Carlisle, & Denckla, 1998 in Denckla & Cutting, 1999). Other variables, such as expressive vocabulary, articulation rate, verbal short-term memory (Parrila et al., 2004), orthographic recognition (Berninger et al., 2001; Olson et al., 1994, in Neuhaus & Swank, 2002), and syntactic awareness (Plaza & Cohen, 2003; Gottardo et al., 1996), which have been demonstrated to predict, in part, reading fluency, may also be important variables to consider within this model.

Two main relations are proposed to exist: Performance on continuous nonalphanumeric RAN-Colors is related to attentional processes and performance on continuous alphanumeric RAN-Letters is related to reading skills. Two deficits are also noted by the above figure. Poor performance on continuous nonalphanumeric RAN-Colors (longer total time, greater frequency of errors or self-corrections) is related to attention and particularly ADHD-symptoms (inattention or hyperactivity or impulsivity), and poor performance on continuous alphanumeric RAN-Letters (longer total time, greater frequency of errors or self-corrections) is related to poor reading skills and particularly single-word reading and oral reading fluency rate and accuracy. Also, this model allows room for possible variables that may account for some variance among the relations between RAN, attention, and reading skills: phonological awareness, vocabulary as a measure of general ability, age, sex, and working memory.

Several underlying assumptions are made based on the proposed model in Figure 3. First, the two tasks, although they look quite similar in form, are not in any sense the same in terms of tapping the cognitive resources necessary for quick and accurate time performance. Nonalphanumeric RAN performance likely reflects executive function, whereas performance on alphanumeric RAN depends on highly automatized processes in which executive function (in the form of lexical decision-making) plays no role (B. M. Linn, personal communication, July 11, 2014).

Second, continuous RAN provides information about an individual's reading performance in excess of general level of automaticity. Evidence from discrete versus continuous RAN trial studies are inconsistent in demonstrating that discrete-trial RAN using letters and numbers show similar correlations with reading performance that continuous RAN tasks do (Denckla & Cutting, 1999). Discrete-trial RAN type is distinguished from continuous

RAN type by the presentation of an individual stimulus one after the other, and an average naming time is taken for all stimuli in a set. Although discrete and continuous RAN both require the same level of automaticity to perform, continuous RAN is a more reliable predictor of reading performance than discrete-trial RAN. Some researchers (e.g., Perfetti, Finger, & Hogaboam, 1978; Stanovich, 1981) have found that the discrete-trial RAN does not discriminate good and poor readers, whereas others have found the opposite (e.g., Bowers & Swanson, 1991). An additional layer of complexity is added when considering the learner's grade. For example, Walsh, Price, and Gillingham (1988) found that discrete-trial RAN correlates with reading in the earliest grades but second grade discrete-trial RAN did not predict third grade reading. Research on discrete-trial RAN has not consistently found relational differences between good and poor readers. In contrast to discrete-trial research, continuous-trial research has consistently found that the RAN discriminates between good and poor readers, even among adults (Felton et al., 1990).

The continuous RAN format may place more demands on executive functioning than the discrete format, which would explain why continuous formats are better predictors of reading than discrete formats. Discrete-trial RAN essentially eliminates the sustained processes of scanning, sequencing, and motoric requirements required to perform continuous RAN, as well as extraneous sources of variance that are likely present (Wolf, 1991), components that mimic text reading. The continuous-trial format has features, distinctly different from the discrete-trial format, that make it a more powerful discriminator of good and poor readers. Bowers and Swanson (1991) found that, even after entering discrete-trial format first in a regression equation, the continuous format RAN added uniquely to reading ability. Their study provided a key finding that continuous-format RAN involves more demands than the discrete-trial format. Thus, general orthographic knowledge or automaticity cannot explain the alphanumeric RAN deficit in reading performance because discrete and continuous RAN do not predict reading performance in the same way. The explanation must have something to do with specific demands of the continuous alphanumeric RAN task, and therefore it is the process, or processes, involved in the continuous RAN that is or are the crux of the problem for students with reading difficulties (B. M. Linn, personal communication, 2014). It is probable that a combination of phonological factors, visual-verbal connections, and executive aspects intrinsic to and within each RAN task are somehow interconnected (Denckla & Cutting, 1999).

Connections to Previous Research

Prior research supported by this synthesis. Our review of the existing literature has provided a backdrop against which a double-dissociation hypothesis in RAN in relation to reading and attention may be supported. RAN is impaired in children with specific learning disorder in reading (SLDR) as well as in those with comorbid ADHD and SLDR. Children with RD who also had elevated ratings of inattention or hyperactivity were slower in naming digits and letters than those with RD (Schuerholz et al., 1995). Slower digit-naming speed (and poorer reading comprehension) was found in children with ADHD who had good word-identification and phonological-processing skills (Brock & Knapp, 1996). RAN has also been found to not be impaired in children with ADHD who have average reading abilities (Ackerman & Dykman, 1993, 1996; Felton et al., 1987). Carte et al. (1996) found that children with ADHD demonstrated slower naming of pictured objects compared to controls but no differences in digit naming. Ackerman and Dykman, in a study of 119 children aged 7 to 12, found that a group of children with specific learning disorder in reading was distinguishably slower from an ADHD group with average reading abilities on letter and digit continuous naming speed (1993). In a study of 40 adolescents around 14 years of age, slow naming of alternating letters and digits was strongly associated with slow reading (Ackerman & Dykman, 1996).

Some studies have partially supported a double dissociation hypothesis. For example, some have demonstrated that children diagnosed with ADHD perform significantly more poorly on RAN-Objects or RAN-Colors relative to controls (e.g., Carte et al., 1996; Nigg, Hinshaw, Carte, & Treuting, 1998; Semrud-Clikeman et al., 2000). The rapid naming of pictured objects was sensitive to the presence of ADHD (Carte et al., 1996). Children with comorbid RD and ADHD were characterized by semantic retrieval problems as measured by object RAN in addition to motor-planning difficulties (Nigg et al., 1998). Children with reading disabilities were slower on letter- and number-naming tasks and made more errors on all tasks than controls or children with ADHD. The ADHD group showed poorer performance than the control group on timed measures of color naming and object naming but did not differ from the control group on letter and number naming (Semrud-Clikeman et al., 2000). Tannock et al. (2000) found that both ADHD groups (with and without concurrent specific learning disorder in reading) were significantly slower in color naming than controls, but did not differ from one another. They reported that slow color naming characterized a group of children who were diagnosed with ADHD but read well, that is, were not comorbid for reading difficulties. This was further demonstrated when children with ADHD were treated with methylphenidate (Ritalin) and the children with ADHD (but no concurrent reading disorder) improved on RAN-Colors but did not become normal in speed. Rucklidge and Tannock (2002) found significant differences in performance on color and object RAN tasks between children with ADHD (with and without reading difficulties) and with typically developing children.

Also, children with ADHD were slower on Stroop subtests involving color naming, which was partially accounted for by blue–yellow and red–green discrimination abilities but did not fully explain slowed color naming (Banaschewski et al., 2006).

Studies of typical third and fourth grade children have yielded some promising results in support of a double dissociation hypothesis (Pham et al., 2011; Stringer et al., 2004). Stringer et al. (2004) found that the rapid naming of letters and digits significantly correlated with reading, but not with executive function or behavior ratings, but the rapid naming of colors (from the Stroop task) was significantly correlated with the executive function tasks and the behavior ratings but not with reading. Pham et al. (2011) also found some data supporting a double dissociation hypothesis. They found that four RAN stimuli types, particularly RAN-Letters, were significant predictors of reading fluency. Additionally, parent and teacher ratings of inattention from the predicted RAN after controlling for gender, working memory, and estimated IQ.

The RAN study on adults (Leung & Stringer, 2010) also provided some support for a double dissociation hypothesis. RAN-Letters and Digits task performance was correlated with performance on single-word and word-attack scores, but not to a self-report of inattention or hyperactivity symptoms (as measured by the Conners Adult ADHD Rating Scales -short version); yet a desaturated version of RAN-Colors was significantly correlated to hyperactivity behavior ratings but not to reading. The regular version of RAN-Colors was not related to any of the reading or attention measures (Leung & Stringer, 2010).

Taken together, these previous research findings exist in support of a doubly dissociative relationship between alphanumeric and RAN-Colors in attention difficulties, challenging the assumption that naming speed deficits are specific to RD and also suggest processing differences underlying color naming and letter naming.

Prior research challenged by this synthesis. A key component of the proposed double dissociation model is to emphasize and strengthen the link between nonalphanumeric RAN-Colors and symptoms of inattention, hyperactivity or impulsivity related to ADHD. Although some research has shown that nonalphanumeric RAN performance may be related to executive-function processes that underlie deficits found in ADHD (e.g., Stringer et al., 2004; Tannock et al., 2000), studies that have found RAN-Colors to predict reading difficulties and not ADHD-symptoms would refute or challenge our proposal.

For example, findings from Semrud-Clikeman et al. (2000) only partially supported the synthesis. Children with reading disabilities were slower on all alphanumeric RAN and nonalphanumeric RAN tasks compared to the control group. The ADHD group showed poorer performance than the control group on timed color- and object-naming tasks, but did not differ from the control group on letter and number naming. However, on the nonalphanumeric RAN-Colors task, the ADHD group performed more slowly than the normal group but not the SLDR group.

No relation was found between RAN performance and children with ADHD (Felton et al., 1987). Poor readers were significantly slower on all RAN types than children who had attention deficit disorder (ADD) but no reading disability (Felton et al., 1987). Another previous study did not find a relation between nonalphanumeric RAN-Colors and ADHD (e.g., Cantor, 2009). Cantor hypothesized that RAN-Letters and Digits would be significant predictors of reading ability, whereas RAN-Colors and Objects were not anticipated to be significant predictors of reading. Consistent with Cantor’s prediction, the RAN-Letters and Digits composite was a significant predictor of reading after controlling for phonological ability. The RAN-Colors and Objects composite was also a significant predictor of speeded reading, but not of nonspeeded reading. However, neither parent-rated inattention nor parent-rated hyperactivity-impulsivity correlated significantly with any of the RAN measures.

Changes to the criteria used to diagnose problems of reading, inattention, hyperactivity, and impulsivity will likely be advantageous to the study of the double dissociation hypothesis in this context. In the newest iteration of the *Diagnostic and Statistical Manual* (DSM-5; American Psychiatric Association, 2013a), the highlighted changes to what is currently known as specific learning disorder in reading (SLDR), and attention deficit/hyperactivity disorder (ADHD) acknowledge and reflect evidence-based weaknesses in previous versions (Tannock, 2014).

First, the “specific learning disorder” name change, that combined the DSM-IV diagnoses of reading disorder, mathematics disorder, disorder of written expression, and learning disorders not otherwise specified reflect the finding that learning deficits in the areas of reading, written expression, and mathematics commonly occur together. Coded specifiers and severity ratings for the deficit types in each area are now included. This may have important implications for future research in RAN studies and the conceptual understanding of a learning disorder that likely has broad reaching academic implications versus a disorder limited to reading. For example, the understanding that learning deficits commonly occur together and may have an underlying basis that has broad reaching implications could result in the need to consider variables applicable to a wider range of learning contexts, rather than those specific to reading (e.g., general processing speed, fine and gross motor control, cognitive tempo).

Another important change was the replacement of the IQ-achievement discrepancy criterion with four criteria: (a) persistence of symptoms for at least six months despite focused intervention, (b) low academic achievement causing significant impairment, (c) age at onset in school-age years (but may manifest fully later in life), (d) symptoms not attributable to Intellectual Disorder, uncorrected visual or auditory acuity, other medical or neurological disorders, psychosocial adversity, lack of proficiency in the language of academic instruction, or inadequate instruction (Tannock, 2014). This shift away from the IQ-achievement discrepancy reflects what reading researchers have known for decades--that IQ is largely irrelevant to the general definition of reading disabilities and that poor readers share similar cognitive deficits, irrespective of general cognitive abilities (Fletcher, Francis, Rourke, Shaywitz, & Shaywitz, 1992; Siegel, 1992). The implicit assumption that individuals who experience reading difficulties unaccompanied by a low IQ are distinct in cognitive processing from slow or low achievers is equivocal. These groups appear to demonstrate more similarities in processing difficulties than differences (Shaywitz, Fletcher, Holahan, & Shaywitz, 1992; Stanovich & Siegel, 1994). Therefore, future RAN studies may benefit from placing less emphasis on the role of IQ, and more on the processes underlying RAN that might predict reading performance (e.g., processing speed, working memory, phonological processing, semantic processing).

The implications for the double dissociation hypothesis may likewise be meaningful to our understanding of ADHD. The diagnostic criteria for ADHD in DSM-5 remain similar to those in DSM-IV-TR, with some key exceptions. ADHD was placed in the neurodevelopmental disorders chapter to reflect brain developmental correlates with ADHD (American Psychiatric Association, 2013b). Changes were made to advantageously support diagnoses across the lifespan, especially in late adolescence or adulthood (e.g., elaborated examples of symptom manifestation relevant for older adolescents and adults, reduced symptom thresholds for individuals over 16 years of five from six, age of onset changed from age 7 to 12, specifiers for partial remission; Tannock, 2014). Other changes included the strengthening of the cross-situational requirement to "several" symptoms in each setting and a comorbid autism spectrum disorder is now allowed (American Psychiatric Association, 2013b). A shift in mindset from discrete, categorical sets of problems prompting an individual to be labeled as having ADHD or RD to a more dimensional or spectrum approach to behavioral attention, hyperactivity, impulsivity, or reading difficulties will likely have a number of positive benefits, both to individuals with these symptoms and to responsible professionals alike. Nonalphanumeric RAN performance may be related to symptoms of inattention or hyperactivity and impulsivity in a more nuanced way--that is, this evidence-based understanding of lifetime development of ADHD-symptoms will allow subthreshold levels of inattention to be important in relation to RAN performance.

Conclusions

Addressing the Specific Goals

First, we reviewed the role of RAN in differentiating between reading and attention problems, and the overall literature on RAN with a specific focus on the nature of RAN types and a possible doubly dissociative relation of alphanumeric RAN to reading and nonalphanumeric RAN to attention processes. Two contrasting patterns of differences were found based on the RAN literature: (a) Typical students and students with attention difficulties are similar in alphanumeric (A-RAN) performance but differ on nonalphanumeric (N-RAN) tasks, thus indicating that N-RAN tasks appear to be more closely associated with attentional processes (Rucklidge & Tannock, 2002; Semrud-Clikeman et al., 2000; Stringer et al., 2004), and (b) A-RAN appears to be more closely associated with reading (Manis et al., 2000; Savage & Frederickson, 2005). Students with reading difficulties only would exhibit similar N-RAN performance as shown by typical controls but would differ on A-RAN tasks. Particular cognitive processes such as reading and attention may be differentiated by RAN performance, demonstrated by an in-depth review of evidence of the differential contribution of attention to reading fluency.

Second, we set out to confirm or develop a model that allows for an analysis of differences between alphanumeric RAN (i.e., letters and numbers) and nonalphanumeric RAN (i.e., colors and shapes). The double dissociation model of the RAN task in reading and attention (Figures 2 and 3, building on Figure 1), may elucidate differences between attention-based and reading-based difficulties.

Third, we discussed the practical implications of the double dissociation model to assessment and intervention practices for typically developing children and clinical samples of children with possible specific learning disorder in reading (SLDR) or attention-deficit/hyperactivity disorder (ADHD). Using evidence from the reading-assessment literature, we recommended strategies (below) to address how teachers and psychologists can improve communication towards shared assessment and learning goals, and how assessment information from all parties can be mutually informative, yet nonrepetitive, in order to best serve students with any combination of attention or reading difficulties in the classroom setting.

Implications for Practice

Acquiring the ability to read is essential to attaining the level of literacy crucial for success in the 21st century. Learning to read represents one of the most important academic challenges that children face during their early formal school years. Educators in the primary grades have a critical role in helping their students become literate, encouraging children to become lifelong readers, and identifying those who are struggling with reading skills. The use of clinical tools such as RAN tasks provides valuable insight into basic-skills deficits that inhibit the acquisition of reading at an age appropriate level and indicate areas for intervention. Strengthened pre- and post-service training for all professionals involved with students who exhibit reading difficulties or symptoms related to behavioral inattention or hyperactivity or impulsivity is necessary to decrease fragmentation of knowledge regarding assessment, identification, and accommodation (Philpott & Cahill, 2008).

Evaluation and identification of inattention and reading difficulties at an early age allow educators and practitioners to intervene early, potentially improving the long-term academic achievement outcomes of children who may be at-risk. There is, of course, a difference between screening at-risk children early to immediately address their educational needs, versus using RAN tasks with older, already-diagnosed children who might find RAN tasks much simpler, thereby eliminating some of the potential for correlations due to possible ceiling effects on RAN performance. Brief assessments such as RAN are useful in predicting reading performance, even among children who do not exhibit reading difficulties (Kirby et al., 2010; Neuhaus & Swank, 2002; Pham et al., 2011). Slower RAN speed, particularly in RAN-Colors, suggests difficulties with control of attention, likely related to abnormal fluctuations or breakdown of neural connections (Misra, Katzir, Wolf, & Poldrack, 2004). Although these fluctuations may provide a basis for understanding levels of inattention, they may also facilitate more direct assessment of contributors to specific reading skills, particularly fluency, among typically developing children. These findings contribute to the development of a model of how the domains of reading and attention are interrelated. Researchers and practitioners may also be able to identify, and intervene early with, children who are considered at risk for developing reading or attention problems, aided by the use of RAN tasks.

In accord with other studies that have investigated typically developing children with an eye on classroom behavior and reading challenges (e.g., Pham et al., 2011; Rabiner et al., 2004; Stringer et al., 2004), this review provided additional support for the psychologist and researcher to assess attention and reading problems on a continuum, rather than determining whether they are simply present or absent in a category. Even if a student does not meet diagnostic criteria for a disorder such as SLDR or ADHD, the child may still have some degree of reading or attention reading difficulty occurring at a subthreshold level that may still warrant some type of early intervention.

Implications for Theory

Five possible theoretical explanations for the relation between naming speed and reading were reviewed in this paper based on different conceptual analyses of what is involved in naming speed and reading: phonological processing, orthographic processing, general processing speed, and executive processes or domain general automaticity deficits (Kirby et al., 2010). Because RAN and reading are treated as analogues of similar processes involving identification of a visual stimulus, assembly and articulation of a verbal response, and visual scanning to the next stiumulus (Blachman, 1984; Foorman et al., 2003; Wolf & Bowers, 1999), an explanation for the relation between RAN and reading fluency would provide key insights into the development of reading. In light of the evidence presented, each one of these theories likely contributes some insight towards the relation between RAN and reading ability.

Each theoretical explanation suggests a number of key processes shared by RAN and reading tasks. The phonological processing interpretation implies that naming-speed tasks are at least somewhat phonological in nature, leading to the question of whether naming speed contributes anything beyond phonological processing to reading. A number of studies have found that RAN does explain variance not accounted for by phonological processing (e.g., Wolf & Bowers, 1999). The orthographic interpretation emphasizes that RAN tasks and reading require instantaneous access to lexical representations and suggests that this may be the basis of the relation, which in turn leads to the question of whether RAN type may be differentially related to reading or if RAN types all have the same relation to reading. RAN types are certainly differentially related to reading (e.g., Savage & Frederickson, 2005). The general processing-speed interpretation stresses the importance of speed or efficiency in responding, that is critical for some aspects of reading (e.g., reading speed or fluency) which, again, leads to the question of whether quick processing speed on all types of RAN predicts reading. Evidence appears to the contrary: Processing speed does not predict RAN performance (Chiappe et al., 2002). Other interpretations point to the importance of executive processes to orchestrate all of these variables in synchrony for performance to be successful, which should warrant further empirical investigation into the role of processes such as working memory, attentional control, and inhibitory responses in RAN and reading performance. Other researchers have concluded that RAN taps both visual-verbal (language domain) and processing speed (executive domain) contributions to reading (Denckla & Cutting, 1999). Wolf et al. (2000) argued that rapid naming tasks are composed of attentional, visual, lexical, temporal, and recognition subprocesses that all contribute to naming speed performance.

Implications for Future Research

RAN speed is uniquely associated with a range of reading tasks across orthographies, beyond that explained by phonological processing, and early identification of children at risk for reading failure would be improved by the inclusion of variable RAN measures. Poor response to instruction of students who have slow naming speed should be considered when designing interventions. Further research is required to specify the theoretical nature of naming speed and to determine how to help students with slow naming speed (Kirby et al., 2010).

Future research should continue to examine samples of typically developing as well as clinical samples of children with ADHD and diagnosed SLD in reading. Because previous ADHD studies often do not separate differences between inattentive and hyperactive-impulsive symptoms (e.g., Carte et al., 1996; Semrud-Clikeman et al., 2000), future research could profitably sort out the differences among symptoms. Longitudinal studies of RAN performance in the prediction of reading outcomes could also be helpful to look at how RAN can be used to predict reading outcomes in each grade level.

It is also important to note that phonological processing should be considered as a key variable in order to assess the extent to which phonological components could explain RAN performance in typically developing students and to differentiate between challenges related to reading or attention symptoms. Some researchers have found no support for the assumption that a phonological system is relatively more intact for one group of poor readers when compared with another. Children with and without specific learning disorder in reading and ADHD have been found to share a common problem in phonological processing, when verbal intelligence, word recognition, and age were partialled out of the analysis (Swanson, Mink & Bocian, 1999). McGee, Williams, Moffitt, and Anderson (1989) failed to find separate effects for ADHD children on measures of verbal processing when compared with typical controls. McGee et al. studied over 1000 13-year-old boys in Dunedin, New Zealand using a battery of verbal and nonverbal neuropsychological measures, aiming to examine whether ADHD was associated with a qualitatively distinct pattern of deficits compared with reading disorder. The only deficit associated with ADHD was slightly lower IQ. However, children with reading disorder showed a pattern of memory and verbal processing deficits compared to the ADHD-only and control groups. These findings contrasted with others, for example, Douglas and Benezra (1990), who found that boys with reading disorder showed more generalized deficits across the verbal measures, suggesting problems with verbal processing, while boys with ADHD showed more deficits in self-regulatory or "executive" processes. Pennington, Groisser, and Welsh (1993), in their study of 70 school-age boys, found phonological processing differences between their groups of children with reading disorder and ADHD. Phonological processing is thus still a key component feature in RAN studies to investigate which variables differentiate between children with reading and attention-related difficulties.

Furthermore, the findings have not been replicated using grade-level passage reading fluency and norm-referenced single-word and reading-fluency achievement, which would be more analogous to reading skills taking place in the classroom setting. Because most studies of RAN performance in children with SLDR and or ADHD have used single-word reading tasks rather than using measures of reading fluency to assess reading skills, future studies should use a wide variety of reading tasks, including passage reading and single-word reading, that are classroom-based and norm-referenced.

Although ADHD research has reached the point at which a number of causal models have been proposed, it remains some distance away from empirically demonstrating the viability of such models (Coghill, Nigg, Rothenberger, Sonuga-Barke, & Tannock, 2005). Coghill et al. (2005) identified steps for future studies to establish causal models of disorders such as ADHD and SLDR, for example: the need to work across multiple levels of analysis in multidisciplinary teams; the need to recognize the existence of, and then model, causal heterogeneity; the need to integrate environmental and social processes into models of genetic and neurobiological influence; and the need to model developmental processes in a dynamic fashion. RAN tasks may be useful as a thermometer to measure the existence of phenomena such as reading difficulties or attention problems associated with ADHD and may prove to be useful for diagnostic utility, a wholly separate issue from causal models of ADHD.

Similarly, reading difficulties may be most suitably studied (e.g., in the classroom) with the assumption that these issues are situated on a normally distributed continuum rather than as discrete, categorical, sets of problems. Evidence in the literature regarding reading difficulties is converging on support for the consideration of reading as an ability that is normally distributed, with reading difficulties at the lower tail (see Snow et al., 1998; Stanovich & Siegel, 1994). This is in opposition to a more traditional categorical approach to diagnosis of a reading disorder or reading disability (or a subtype of reading disability known as “dyslexia”) based on an intelligence quotient (IQ)-achievement discrepancy model.

It is important for clinicians and educators to recognize that dimensional approaches to the diagnosis, education, and treatment of children with ADHD better predict life outcomes (Fergusson & Horwood, 1992), in contrast to a categorical approach. Therefore, in this light, SLDR and ADHD are typically determined by an arbitrary cutoff at the low end of each of their respective continua (Pennington et al., 2009). The dimensional approach involves the study of a normal range of activity assuming that ADHD is at one end of the continuum or trait, and the categorical approach is based on studying children of families who meet diagnostic criteria and assuming that ADHD is a discrete disorder (Faraone et al., 1992). Alphanumeric RAN is a sensitive predictor of reading ability for children with varying levels of reading problems (Denckla & Rudel, 1976a), and typical children (Pham et al., 2011). Given the evidence that supports the assessment of attention and reading difficulties on a continuum or broader scale, RAN studies in these populations should be investigated as continuous and not categorical dimensions. This implies that future empirical studies should make use of regression analyses to better understand patterns of behavior.

Linking Text: Manuscript 1 to Manuscript 2

Manuscript 1 was a review of the rapid automatized naming (RAN) literature in relation to reading and ADHD-symptoms and a guiding model for the RAN double dissociation was presented within. Manuscript 2 is a cross-sectional, correlational, and exploratory study that builds directly on the foundation and recommendations for further research set forth in the review.

Manuscript 2 is situated within a developmental framework that draws upon constructs from educational and cognitive psychology, and seeks to answer questions regarding the use of RAN, reading assessment measures, and behavioral indicators of inattention and hyperactivity or impulsivity. Because it follows directly from the extensive literature review regarding the RAN double dissociation hypothesis, Manuscript 2 does not contain an extensive literature review. Rather, the literature addressed in this second manuscript focused more on specific research about RAN and its relations to reading development in the early grades and symptoms of ADHD (inattention, hyperactivity, and impulsivity). Nevertheless, there will be some redundancy. Although the paper is in manuscript format intended for publication, a reduction will be undertaken after the dissertation has been defended.

The primary objective of Manuscript 2 was to link a key predictor of reading performance, namely RAN, with reading achievement and behavioral symptoms of inattention, hyperactivity, or impulsivity in elementary school-age pupils in the general school population. Manuscript 2 examined the proposed RAN double dissociation hypothesis wherein two main relations are proposed to exist: Performance on continuous alphanumeric RAN-Letters is related to reading skills, and performance on continuous nonalphanumeric RAN-Colors is related to attentional processes as noted by behavioral ratings of ADHD. Specifically, poor performance on continuous alphanumeric RAN-Letters (longer total time, greater frequency of errors or self-corrections) should be related to poor reading skills and particularly single-word reading and oral reading fluency rate, and poor performance on continuous nonalphanumeric RAN-Colors (longer total time, greater frequency of errors or self-corrections) should be related to ADHD-symptoms (inattention or hyperactivity or impulsivity), and not, or less so, to reading skills.

This study shed light on the role of cognitive processing in both reading problems and ADHD-symptoms (e.g., using working memory, rapid naming, phonological processing, and oral reading-fluency tasks), contributed to the theoretical understanding of how attention difficulties contribute to reading performance, and to a practical understanding for education professionals responsible for governing students with attention difficulties in the classroom context. Most importantly, it provided further clues to sorting out the cognitive similarities and differences between children with attention difficulties and reading problems, which, in isolation or in combination, may lead to being at risk for poor academic outcomes, decreased motivation at school, and drop out.

Manuscript 2

Stumbling over RAN-Color and Letter Blocks: New Uses for the Rapid Automatized Naming (RAN) task to Differentiate between Reading and Attention Difficulties in the Classroom

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Abstract

Interrelations between rapid automatized naming (RAN), attention, and reading fluency among typically developing children were examined in order to investigate the possibly doubly dissociative relation of RAN in reading and attention skills. Ninety-six students, 6 to 9 years old, completed continuous RAN measures consisting of two stimuli (letter and color) and reading tasks (measures of oral reading fluency and single-word reading). Teacher, parent, and examiner-ratings of behaviors related to attention-deficit/hyperactivity disorder (ADHD) were collected on each participant. Correlational and multiple regression analyses revealed that RAN-Letters total time was the only significant predictor of reading fluency, after controlling for children's sex, age, phonological processing skill, and working memory. RAN-Colors total time was not associated with reading performance nor teacher or parent ratings of ADHD-symptoms, but it was associated with naïve examiner ratings of behaviors after controlling for child's sex, age, phonological processing skill, and working memory. Furthermore, errors and self-corrections on RAN-Colors were associated with both teacher ratings from the SWAN scale and examiner ratings of inattentive or hyperactive and impulsive behaviors, whereas errors and self-corrections on RAN-Letters were associated with reading outcomes (oral passage reading and single-word reading) only. The study supported a double dissociation of the RAN tasks in reading outcomes and attention skills in typically developing children.

Keywords: Reading; rapid automatized naming; fluency, attention, attention deficit/hyperactivity disorder

Stumbling over RAN Blocks: New Uses for the Rapid Automatized Naming (RAN) task to Differentiate between Reading and Attention Difficulties in the Classroom

The finding that the speed with which participants can name letters, digits, colors, or objects, correlates with their reading performance has been known for decades (Denckla, 1972; Denckla & Rudel, 1974; Wolf & Bowers, 1999). Performance on RAN tasks adds unique variance to the prediction of reading performance beyond that explained by the best individual predictor variable--phonological processing or phonological awareness (Blachman, 1984; Chiappe, Stringer, Siegel, & Stanovich, 2002; Wolf, Bowers, & Biddle, 2000), particularly for typically developing and struggling students in the early stages of reading development (Allor, 2002). The word “prediction” and its associated derivatives are used in this paper in their statistical sense and without implication of direct causality. RAN is predictive of a variety of reading abilities including word identification (e.g., Bowers, Steffy, & Tate, 1988; Bowey, Storey, & Ferguson, 2004; Compton, 2003; Mann, 1984; Meyer, Wood, Hart, & Felton, 1998; Miller et al., 2006; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Torgesen, Wagner, Simmons, & Laughon, 1990) and reading fluency (e.g., Georgiou, Parrila & Kirby, 2006; Katzir et al., 2006; Savage & Frederickson, 2005; Schatschneider et al., 2002). Some studies have found relations between RAN performance and reading comprehension (e.g., Katzir et al., 2006; Murphy, Pollatsek, & Well, 1988) and spelling (Plaza & Cohen, 2004), but others have not (e.g., Allor, 2002; Meyer et al., 1998). Converging evidence indicates that A-RAN performance is a reliable indicator of certain reading skills such as single-word reading performance and not a reliable predictor for other reading skills such as comprehension.

There is some evidence that the type of stimuli used for the RAN task may be salient to specific types of developmental issues such as reading difficulties and behavioral symptoms of classroom inattention, hyperactivity, and impulsivity. Clinical studies have investigated RAN performance within special populations of children with severe reading difficulties--commonly referred to in the literature as "reading disabled" and with the acronym RD--representing Reading Disorder or Reading Disability. Within this paper, all references to this clinical population will henceforward be referred to as children with specific learning disorder in reading (SLDR) according to the current diagnostic criteria listed in the recent publication of the *Diagnostic and Statistical Manual Five* (DSM-5; American Psychiatric Association, 2013a). Clinical studies have also investigated RAN performance within special populations of children with severe symptoms of behavioral inattention, hyperactivity, or impulsivity, or a combination of the three--referred to as attention deficit/hyperactivity disorder (ADHD). The co-occurrence between ADHD and SLDR, whether defined as diagnostic categories or quantitative traits, is well documented (e.g., August & Garfinkel, 1990; Dykman & Ackerman, 1991) yet poorly understood in terms of etiology, developmental mechanisms, and implications for remediation. The rates of prevalence of reading problems in children with ADHD range between 15% and 50% depending on the diagnostic criteria for either of the disorders (DuPaul & Stoner, 2003; Holborow & Berry, 1986; Lambert & Sandoval, 1980; Mayes & Calhoun, 2006), higher than estimates in typically developing children. RAN tasks could likely be a strong candidate for understanding the relation between SLDR and ADHD.

RAN tasks are capable of differentiating between children with and without SLDR (Badian, McAnulty, Duffy, & Als, 1990; Badian, Duffy, Als, & McAnulty, 1991; Denckla & Rudel, 1976b; Spring & Capps, 1974) as well as between groups of skilled versus less skilled (e.g., Ackerman, Dykman, & Gardner, 1990) and poor versus average readers (e.g., Bowers & Swanson, 1991).

Some researchers have demonstrated that children diagnosed with ADHD perform poorly on RAN-Objects or RAN-Colors relative to controls (e.g., Carte, Nigg, & Hinshaw, 1996; Nigg, Hinshaw, Carte, & Treuting, 1998; Semrud-Clikeman, Guy, Griffin, & Hynd, 2000). In a study of 71 children in three groups (reading disabilities, ADHD without reading disabilities, and typical controls), the ADHD group showed poorer performance than the control group on timed measures of color naming and object naming but did not differ from the control group on letter and number naming (Semrud-Clikeman et al., 2000). In an investigation of RAN and effects of stimulant medication in school-age children with attention-deficit/hyperactivity disorder (ADHD) with and without concurrent specific learning disorder in reading (SLDR), Tannock, Martinussen, and Frijters (2000) found that both ADHD groups (with and without SLDR) were significantly slower in color naming than controls, but did not differ from one another. Tannock and her group reported that slow color naming characterized a group of children who were diagnosed with ADHD but who read well, that is, were not comorbid for RD. When treated with methylphenidate (Ritalin), these children with ADHD (but no RD) became somewhat faster on RAN-Colors but did not become normal in speed. Rucklidge and Tannock (2002) found significant differences in performance on color and object RAN tasks between children with ADHD (with and without reading difficulties) and with typically developing children.

RAN performance is impaired in children with a specific learning disorder in reading (SLDR) as well as in those with comorbid ADHD and SLDR. Children with SLDR who also had elevated ratings of inattention or hyperactivity were slower in naming digits and letters than those with SLDR (Schuerholz et al., 1995). Slower digit-naming speed (and poorer reading comprehension) was found in children with ADHD who had good word identification and phonological processing skills (Brock & Knapp, 1996). RAN has also been found to not be impaired in children with ADHD who have average reading abilities (Ackerman & Dykman, 1993; Felton, Naylor, & Wood, 1990; Felton, Wood, Brown, Campbell, & Harter, 1987). Carte et al. (1996) found that children with ADHD had slower naming of pictured objects compared to controls but no differences in digit naming. Also, children with ADHD were slower on Stroop subtests involving color naming, which was partially accounted for by blue–yellow and red–green discrimination abilities but did not fully explain slowed color naming (Banaschewski et al., 2006).

RAN studies of typical children have also yielded some interesting results (Pham, Fine, & Semrud-Clikeman, 2011; Stringer, Toplak, & Stanovich, 2004). Stringer et al. (2004) found that the rapid naming of Letters and Digits significantly correlated with reading, but not with executive function or behavior ratings, and the rapid naming of colors (from the Stroop task) was significantly correlated with the executive function tasks and the behavior ratings but not with reading. Pham et al. (2011) found that four RAN stimuli types, particularly RAN-Letters, were significant predictors of reading fluency. Additionally, parent and teacher ratings of inattention predicted RAN performance after controlling for gender, working memory, and estimated IQ. Preliminary research on adults also provided support for a double dissociation hypothesis. Letter and Digit RAN-task performance was correlated with performance on single word and word attack scores, but not with a self-report of inattention or hyperactivity symptoms (as measured by the Conners Adult ADHD Rating Scales--short version). Interestingly, a desaturated version of RAN-Colors was significantly correlated to hyperactivity behavior ratings but not to reading (Leung & Stringer, 2010).

Two contrasting patterns of differences were found based on the RAN literature: (a) A-RAN appears to be more closely associated with reading (Manis, Doi, & Bhada, 2000; Savage & Frederickson, 2005) and (b) typical students and students with attention difficulties are similar in alphanumeric (A-RAN) performance but differ on nonalphanumeric (N-RAN) tasks, thus indicating that N-RAN tasks appear to be more closely associated with attentional processes (Rucklidge & Tannock, 2002; Semrud-Clikeman et al., 2000; Stringer et al., 2004). It would be expected that students with reading difficulties only would exhibit similar N-RAN performance as shown by typical controls but would differ on A-RAN tasks. Stringer et al. (2004) referred to this as the *RAN double dissociation*. Particular cognitive processes such as reading and attention may be differentiated by RAN performance. These findings suggest that naming speed deficits are not specific to RD and also suggest processing differences underlying color naming and letter naming.

Two corollaries arise from this dissociative relation: poor performance on continuous nonalphanumeric RAN-Colors (longer total time, greater frequency of errors or self-corrections) is related to attention and particularly ADHD-symptoms (inattention or hyperactivity or impulsivity), and poor performance on continuous alphanumeric RAN-Letters (longer total time, greater frequency of errors or self-corrections) is related to poor reading skills and particularly single-word reading and oral reading fluency rate and accuracy.

Purpose

The goal was to explore a RAN double dissociation hypothesis in which two main relations are proposed to exist, primarily in English-language speaking elementary schoolchildren: performance on continuous nonalphanumeric RAN-Colors is related to attentional processes and performance on continuous alphanumeric RAN-Letters is related to reading skills. We examined RAN-Letters and RAN-Colors data as predictors of oral reading fluency, single-word reading, and ADHD-symptoms in an exploratory cross-sectional, and correlational, study.

Specifically, poor performance (longer total time, greater frequency of errors and self-corrections) on continuous nonalphanumeric RAN-Colors is proposed to be related to attention and particularly ADHD-symptoms (inattention or hyperactivity or impulsivity), and poor performance on continuous alphanumeric RAN-Letters (longer total time, greater frequency of errors or self-corrections) should be related to poor reading skills and particularly single-word reading and oral reading fluency rate and accuracy. These expectations also allow room for other possible variables that may account for variance among the relations between RAN, attention, and reading skills such as phonological awareness, vocabulary as a measure of general ability, age, sex, and working memory.

Background

RAN

Continuous or serial RAN tasks typically appear in four common and standard variants identified by the types of stimuli used: letters, digits, colors, and objects. RAN types can be subdivided into two groups based on type of stimuli used: Alphanumeric (letters or numbers) and nonalphanumeric (colors or objects). Originally designed by Denckla (1972) and developed by Denckla and Rudel for clinical use (1974, 1976a, 1976b), these tests involve the rapid naming of a visual array of stimuli presented a fixed number of times in random order. RAN has been adapted for use in clinical settings by psychologists to assess basic skills related to reading, as subtests within the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999). In the CTOPP, 36 stimuli--letters, digits, colors, or objects--are laid out in four rows of nine stimuli. The CTOPP RAN-Letters task uses a randomly ordered set of six lowercase consonants and vowels (a, c, k, s, t, n) repeated six times each. The CTOPP RAN-Colors task uses a randomly ordered set of six common color blocks (black, blue, brown, red, yellow, green). [See Figure 1 in Leung & Stringer, 2014--Manuscript 1 for a sample illustration of these tasks.] The Digits task, not addressed in this study, uses six numbers, and the Objects task, also not used, uses six simplified graphics of identifiable common household objects. We omitted the Digits and Objects tasks in order to focus on the RAN tasks which have been found to demonstrate relations with reading performance and behavioral ADHD-symptoms. The participant names each stimulus in serial order, left to right, top to bottom, as quickly as he or she can. The elapsed time and number of errors are recorded by the examiner. Because serial RAN tasks appear to be an apparent analogue of the reading process, RAN and reading likely share many processes, such as the identification of a visual stimulus, the assembly of a verbal response and its articulation, as well as visual scanning to the next stimulus or line to repeat the process (Blachman, 1984; Foorman et al., 2003; Wolf & Bowers, 1999).

Oral Reading Fluency

Reading fluency is the ability to read a text quickly and accurately. In young children as well as adults, variation in reading fluency is common. Fluency is a key component of the reading process because it bridges word recognition and comprehension. Because fluent readers likely expend fewer conscious cognitive resources on word decoding, they can focus their attention on what the text means. Thus, fluent readers can efficiently make connections among the ideas in the text and between the text and their own background knowledge (Armbruster, Lehr, & Osborne, 2001). However, less fluent readers must focus their attention on figuring out the words, leaving little attention for text comprehension. RAN, particularly alphanumeric RAN, has been found to be predictive of passage oral reading fluency in typical students (e.g., Cantor, 2009; Pham et al., 2011) and children with extreme reading difficulties (e.g., Cornwall, 1992).

Single-Word Reading

RAN is predictive of a variety of reading abilities including word identification (e.g., Bowers et al., 1988; Bowey et al., 2004; Compton, 2003; Cornwall, 1992; Mann, 1984; Meyer et al., 1998; Miller et al., 2006; Schatschneider et al., 2002; Schatschneider et al., 2004; Torgesen et al., 1990). Letter and digit (alphanumeric) forms of RAN tasks were robust predictors of single-word reading (Stringer et al., 2004) in a classroom study of typically developing children in grades 3 and 4. Other studies have found that alphanumeric RAN (A-RAN) tasks were robust predictors of single-word reading for poor readers (Felton et al., 1990; Meyer et al., 1998; Wolf & Obregón, 1992).

Behavioral Inattention, Hyperactivity, and Impulsivity

An array of neuropsychological correlates such as processing speed and attention have been reported to play a role in the development and maintenance of reading skills. These same neuropsychological mechanisms have been reported to be deficient in individuals with ADHD (e.g., Foy & Mann, 2013; Martinussen & Tannock, 2006; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). The core behavioral symptoms of inattention, impulsivity, and hyperactivity, are associated with concurrent and later academic underachievement (e.g., Barkley, 1998; DeShazo Barry, Lyman, & Klinger, 2002; Fergusson & Horwood, 1995; Forness & Kavale, 2001; Rapport, Scanlan & Denney, 1999; Zentall, Smith, Lee, & Wieczorek, 1994). Furthermore, a body of research based on typically developing children supports the notion that inattention on its own predicts poor academic achievement. For example, in a longitudinal multisite American study of 387 kindergarten students examining the development and prevention of conduct problems, it was specifically classroom-attention problems that predicted children's reading achievement in grades 1 and 5, and not IQ, kindergarten reading-related skills, or concurrent levels of hyperactivity (Rabiner & Coie, 2000). Moreover, inattentive behavior has been found to predict poor response to evidence-based reading instruction (Fuchs et al., 2005; Rabiner, Malone, & Conduct Problems Prevention Research Group, 2004). Children who exhibit symptoms of ADHD even at levels below the clinical threshold for a diagnosis exhibit academic problems (Breslau et al., 2009; Currie & Stabile, 2006), and typically have difficulty with paying attention to task instructions or group work, and experience significant problems with test performance, study skills, and organization of their materials and assignments (DuPaul & Stoner, 2003). Accordingly, the presence of some persistent inattentive behavior in childhood (e.g., distractibility, poor concentration and organization) is considered a developmental risk factor for poor academic outcomes (Warner-Rogers, Taylor, Taylor, & Sandberg, 2000).

Ratings of behavior. Behavior-assessment approaches are typically used in ADHD evaluations, wherein multiple methods of data collection are utilized across informants and settings (Anastopoulos & Shelton, 2001; Barkley, 1998). Rating scales are important in identifying children with behavior problems, predicting future socioemotional and behavioral adjustment, and discriminating among clinical types (McKim & Cowen, 1987; Vaughn, Riccio, Hynd, & Hall, 1997). Previous research reported that parent and teacher ratings of ADHD-symptoms were internally consistent, stable across time, and highly related to criterion measures of classroom performance (DuPaul, 1991). Although the use of rating scales and interviews from multiple informants is considered essential for the assessment of ADHD and disorder symptoms, a number of studies have found low or no association between teacher and parent ratings of

ADHD (Antrop, Roeyers, Oosterlaan, & Oost, 2002; Mitsis, McKay, Schulz, Newcorn, & Halperin, 2000; Wolraich et al., 2004).

Teachers. Teacher perceptions of student functioning have been found to be strong predictors of academic achievement (e.g., Breslau et al., 2009; DuPaul et al., 2004). For example, teacher ratings of attention, internalizing behaviors, and externalizing problems at age six significantly predicted math and reading achievement at age 17. Attention problems especially predicted mathematics and reading achievement with little diminishing of effect, even when types of problems were examined simultaneously (Breslau et al., 2009).

Gathering ratings from teachers is standard practice both for researchers and clinicians, and numerous studies show that teacher ratings are an important component of identifying children with possible disorders related to behavior, for example, ADHD (Andrade et al., 2005; Barkley, 1998; DuPaul & Stoner, 2003; Semrud-Clikeman, Hynd, Lorys, & Lahey, 1993). Teachers have a number of advantages in reporting student behaviors, such as specific training in typical and atypical child development. Because rating scales typically require the informant to compare the target child to other children, teachers' knowledge in typical and atypical domains is essential. Parents or other reporters of childhood functioning may not be able to draw the same necessary comparisons (Andrade et al., 2005). In addition, teachers, unlike parents, do not share genetic or other familial characteristics with their students that may bias their ratings. Teachers spend a great deal of time with students and have a wealth of experience about how children behave across time, setting, and situation, particularly when demands on student attention and behavior may be greatly increased or challenged. Thus, teachers play a vital role in detecting, reporting, and identifying children with possible classroom-related difficulties related to reading and behavior.

Parents. Parents can provide additional valuable information about their child's behaviors. For example, they can provide details about the presence and frequency of behavior control difficulties at home, information regarding the child's early childhood development in terms of onset and chronicity over time, as well as a family history of behavioral, emotional, and learning problems (DuPaul & Stoner, 2003).

Several studies have found low concordance between teacher and parent ratings of ADHD-symptoms, whether by interviews or behavioral rating measures (Antrop et al., 2002; Mitsis et al., 2000; Wolraich et al., 2004). Low levels of agreement between parent and teacher ratings of ADHD-symptoms may be influenced by different perceptions of the problem behavior by parents and teachers or situation specificity of children's behavior. Antrop et al. (2002), using a sample of 55 children in the age range of 6 to 12 years with clinically diagnosed ADHD, found no association between parent and teacher ratings of inattention and hyperactivity or impulsivity. In a direct examination of the concordance between parent and teacher reports of 74 clinically referred children for ADHD, the agreement between parents and teachers was found to be relatively poor, with virtually no agreement for individual ADHD subtypes (Mitsis et al., 2000). Parent reports of in-school behavior were more highly correlated with their own reports of their child's behavior at home than with teacher reports of their child's behavior in school. Also, diagnoses made from either only parent or only teacher data resulted in over representation of either inattentive or hyperactive subtypes. The diagnosis of ADHD inattentive or hyperactive-impulsive subtypes based on data from a single informant may be of questionable validity, stressing the importance of using multiple informants when diagnosing in clinically referred samples.

Parent and teacher agreement was low concerning ADHD-symptoms and performance in another study. In a screening of 6171 elementary school children, 1573 children were identified with a high risk for ADHD according to teacher ratings (Wolraich et al., 2004). Follow-up parent interviews and information from teachers were subsequently collected, and the researchers found low agreement between the parent and teacher reports of ADHD-symptoms according to DSM-IV-based questionnaires, with *r* values ranging from .27 for hyperactive and Impulsive symptoms, to .34 for inattentive symptoms.

Examiner observations (global clinical impressions). Direct observations of student behaviors by a relatively impartial observer can be useful in addressing possible limitations, including inherent biases presented with the use of teacher and parent rating measures (DuPaul & Stoner, 2003). Repeated observations in the school setting, during individual seatwork, typically provide data that are better at discriminating children with ADHD from controls. Three categories of behavior were found to consistently discriminate between ADHD and non-ADHD samples: off-task behavior, excessive gross motor activity, and negative vocalizations (e.g., refusal to obey task requests; Platzman et al., 1992). The need for systematic, impartial, direct observation could point to a weakness in standard procedures and diagnostic structure, for example, diagnoses relying solely on parent and teacher reports, rather than a multistep assessment model including classroom screening, psychometrically sound teacher questionnaires, followed by systematic behavioral observations and parent ratings (DuPaul & Stoner, 2003).

Sex Differences

Boys are much more likely to be diagnosed with specific learning disorders in reading (Willcutt & Pennington, 2000) and ADHD (DuPaul & Stoner, 2003). In a community sample of 494 twins with a reading disability (223 girls, 271 boys) and 373 twins without a reading disability (189 girls, 184 boys) to assess the relation between reading disability (RD) and attention-deficit/hyperactivity disorder (ADHD), specific learning disorder in reading (SLDR) was significantly associated with inattention in both girls and boys, but associated with hyperactivity and impulsivity only in boys (Willcutt & Pennington, 2000). This difference may provide a partial explanation for the discrepancy between the sex ratio obtained in referred (approximately 4 boys to 1 girl) and nonreferred (1.2 to 1.5 boys to 1 girl) samples of individuals with SLDR. Specifically, the hyperactive and impulsive behaviors exhibited by boys with SLDR may be more disruptive than the inattentive behaviors exhibited by girls and may therefore lead to more frequent referrals for clinical attention.

More males than females are diagnosed with ADHD (3:1; DuPaul & Stoner, 2003). Symptoms in girls are less noticeable than in boys, because girls with ADHD are less likely than boys with ADHD to exhibit observable behaviors in the classroom, including interference behaviors (such as clowning around, interrupting others, talking during work), gross motor behaviors (such as standing up, running, skipping) or physically aggressive behaviors (such as punching, hitting, kicking). However, girls with ADHD are more likely than boys with ADHD to exhibit verbal aggression (such as teasing, name-calling, and taunting) towards peers. Boys and girls with ADHD do not differ from each other in off-task behaviors, minor motor movements (such as rocking movements), and cognitive function and academic achievement (Abikoff et al., 2002). Despite these differences in the manifestation of the overt behavioral symptoms, girls with ADHD are as impaired as boys with ADHD in a number of domains, including academic and social skills. However, girls with ADHD are more likely than boys with ADHD to be overlooked and under-diagnosed. Although the prevalence of ADHD tends to be higher in boys than in girls, there is no evidence for substantial sex differences in the relative importance of genetic or environmental influences (Derks, Hudziak, & Boomsma, 2007). RAN studies have usually found no sex differences in performance (e.g., Scarborough, 1998), and thus could be an important tool for assessing attention-based difficulties.

Age

Studies that have demonstrated superior predictive power of reading ability for alphanumeric versus nonalphanumeric RAN tasks (e.g., Bowers et al., 1988; Compton, 2003; Cornwall, 1992; Spring & Capps, 1974) have utilized populations of children ranging from 7 to 13 years of age (Cantor, 2009). Studies of RAN conducted in kindergarten have generally shown predictive ability of all RAN types to future and concurrent reading performance (Lambrecht Smith et al., 2008; Wolf, Bally, & Morris, 1986). Wolf et al. (1986) found that both alphanumeric and nonalphanumeric RAN tasks administered in kindergarten were predictive of second-grade reading performance. However, the predictive ability of nonalphanumeric RAN in the first grade diminished significantly in relation to second-grade reading performance, and only alphanumeric RAN predicted single-word reading, connected oral reading, and comprehension. Similarly, Lambrecht Smith et al. (2008) determined that, although RAN-Objects and RAN-Colors assessed at the beginning of kindergarten were predictive of children's future reading, these tasks were no longer predictive when re-administered just prior to grade 1. After approximately age 6, alphanumeric RAN tasks consistently predict reading performance, whereas nonalphanumeric RAN tasks do not. However, some have found all four types of RAN to be predictive of reading outcomes, such as in a longitudinal study of third to eighth graders (Meyer et al., 1998), and a cross-sectional study of third and fourth graders (Pham et al., 2011).

Phonological Processing

The most powerful predictor of reading performance has repeatedly been shown to be phonological processing, that is, the ability to recognize and play with the sound components of spoken and auditory language (Bruck, 1992; Bruck & Treiman, 1990; Fox & Routh, 1984; Liberman, Shankweiler, Fischer, & Carter, 1974; Pennington, Van Orden, Smith, Green, & Haith, 1990; Siegel & Ryan, 1988; Stanovich, 1988; Stanovich, Nathan, & Vala-Rossi, 1986). Phonological processing refers to the use of phonological information (the sounds of a language) in processing written and oral language (Adams, 1990; Stanovich, 1992) and is a primary predictor of reading ability. It is the ability to notice and work with the individual sounds in spoken words. Before children learn to read print, they need to become aware of how the sounds in words work. They must understand that words are made up of small speech sounds, or phonemes, that can change the word's meaning with slight variations.

Phonological processing skill is considered to be the best individual predictor variable of reading performance even several years after being initially assessed (Adams, 1990; Vellutino, 1991; Wagner & Torgesen, 1987). Other basic skills add unique variance to the prediction of reading performance beyond that explained by phonological processing, for example, RAN, articulation rate, verbal short-term memory (Parrila, Kirby, & McQuarrie, 2004), orthographic recognition (Berninger, Abbott, Thomson, & Raskind, 2001; Olson, Forsberg, & Wise, 1994), and syntactic awareness (Gottardo, Stanovich, & Siegel, 1996; Plaza & Cohen, 2003). Alphanumeric RAN is strongly associated with reading success, particularly among poor readers, after phonological processing problems are first considered (e.g., Bowers & Newby-Clark, 2002; Bowers & Wolf, 1993; Savage & Frederickson, 2005; Wolf, 1991; Wolf et al., 2000). These findings have led to the idea of the *double deficit hypothesis*, a two-element theory that phonological deficits and the processes underlying naming speed are separate sources of reading dysfunction, and their combined presence leads to profound reading impairment (Wolf & Bowers, 1999). The speed of processing is the critical component tapped in rapid naming tasks, and such tasks contribute specific variance to orthographic processing skills in reading development (Bowers, 1995).

Phonological components could explain RAN performance in typically-developing students and differentiate between challenges related to reading or attention symptoms. Some researchers have found no support for the assumption that a phonological system is relatively more intact for one group of poor readers when compared with another, such as children with ADHD. Children with and without specific learning disorder in reading and ADHD were found to share a common problem in phonological processing, when verbal intelligence, word recognition, and age were partialled out of the analysis (Swanson, Mink, & Bocian, 1999; McGee, Williams, Moffitt, & Anderson, 1989).

These findings were in contrast to others, for example, those of Douglas and Benezra (1990), who found that boys with reading disorder showed more generalized deficits across the verbal measures, suggesting problems with verbal processing, whereas boys with ADHD showed more deficits in self-regulatory or “executive” processes. Pennington, Groisser, and Welsh (1993) in their study of seventy school-age boys, found phonological processing differences between their groups of children with reading disorder and ADHD. Phonological processing is thus still a key component feature in RAN studies to investigate which variables differentiate between children with reading and attention-related difficulties.

Working Memory

Working memory refers to structures and processes used for temporarily storing and manipulating information, such as holding several facts or thoughts in memory temporarily while solving a problem or performing a task (Sattler, 2008). The major components of working memory include the control of attention and the ability to inhibit irrelevant associations (Geary, 2005). Working-memory tasks measure short-term memory, rote learning, and sequential processing. Tasks in this area, such as Digit Span or Finger Windows forward, wherein the child is asked to recall a string of numbers or visual-spatial sequences and repeat them aloud or visually in proper sequence, assess the ability to retain several elements that have no logical relation to each other. Related inverse forms, such as Digit Span and Finger Windows backward, involves these abilities with the additional complication of planning and the ability to transform the input before responding. High scores on the backward forms may indicate "flexibility, tolerance for stress, and excellent concentration," and both forms may be considered separately (Sattler, 2008, p. 326).

Nonoverlapping deficits may provide clues to the differentiation and underlying mechanisms between the two disorders. For example, de Jong et al. (2009) found that visuospatial working-memory deficits were specific to children with only ADHD. In a meta-analytic study of working-memory deficits in children with ADHD, Martinussen, Hayden, Hogg-Johnson, and Tannock, (2005) found that children with ADHD exhibited deficits in multiple components of working memory that were independent of comorbidity with language learning disorders and weaknesses in general intellectual ability. They argued that evidence of working-memory impairments particular to children with ADHD support recent theoretical models implicating working-memory processes in ADHD.

Others have found contrasting evidence in relation to working memory in children with attention or reading problems. Adolescents with specific learning disorder in reading (regardless of ADHD status) had poorer achievement scores, poorer verbal working-memory, and were much slower with RAN-Letters. Having both ADHD and SLDR produced additional cognitive deficits including slower rates of naming numbers and colors (Rucklidge & Tannock, 2002). Siegel and Ryan (1989) studied working memory and phonological skills in 138 typical students, 65 children with learning disorders in reading, 63 children with learning disorders in mathematics, and 15 children with ADHD-hyperactive subtype, from 7 to 14 years old. Short-term memory was significantly correlated with a variety of reading skills. Children with a reading disability showed a significant lag in short-term memory and an even greater deficit in phonological skills. Children with ADHD-hyperactive subtype who also had normal achievement scores did not have any major difficulties except on an aurally presented sentence-completion and working-memory task that required significant memory and attention demands.

Another study that investigated the possible discriminant validity of working-memory deficits in 120 children with ADHD and SLDR found that a test of memory and learning, the *Wide Range Assessment of Learning and Memory* (*WRAML*; Sheslow & Adams, 1009), provided little distinguishing information for ADHD and LD children (Phelps, 1996). Including working-memory tasks that require reconfiguration of material, problem solving, and more complexity may be more beneficial in identifying processing weaknesses with suspected ADHD and LD youngsters.

Some researchers have argued that the relation between RAN and reading performance is due to executive processes including working memory, attention, and inhibition (e.g., Amtmann, Abbott, & Berninger, 2007). Performance on a serial task such as RAN involves classes of functions, including those that reflect inhibitory processes, those that require the shifting of set, and those that involve working memory (which also has been considered in similar, executive function terms--see Chiappe, Hasher, & Siegel, 2000; Pennington & Ozonoff, 1996). Specifically in RAN the brain must exert and direct attentional control and coordinate a number of actions: The eyes must be moved from stimulus to stimulus, from line to line, and in coordination with the articulation of the stimulus. Inhibition is required to suppress pronunciation of previous items, and working memory is required to coordinate orthographic and phonological processing (Wolf & Bowers, 1999).

All in all, future investigations of RAN using working-memory variables, auditory and visual-spatial, could provide valuable insight into the differentiation of reading and attention problems. The working model illustrated in Figure 3 (below) shows some possible relations among variables examined in this study. Some other processes that are not under current consideration may play a role in RAN performance. For example, processing speed has been addressed elsewhere in relation to RAN performance (Cutting, Carlisle, & Denckla, 1998 in Denckla & Cutting, 1999). Other variables, such as expressive vocabulary, articulation rate, verbal short-term memory (Parrila et al., 2004), orthographic recognition (Berninger et al., 2001; Olson et al., 1994), and syntactic awareness (Plaza & Cohen, 2003; Gottardo et al., 1996), which have been demonstrated to predict, in part, reading fluency, may also be important variables to consider within this model and could very well be in the future iterations of this working depiction.

Subselection of Students with Reading Difficulties and ADHD-Symptoms

Some studies have found that RAN has predictive power for poor readers but not for average readers (Meyer et al., 1998). This finding is interpreted as suggesting that impaired readers are qualitatively different from the normal-reading population and are not simply the "tail" of a normal distribution of reading ability. Other studies have found that RAN, particularly alphanumeric RAN, is a robust predictor of reading ability for elementary school students in grades 3 and 4 (Pham et al., 2011; Stringer et al., 2004).

Reading difficulties associated with specific learning disorder in reading have been estimated to occur in approximately 10% to 15% of school age children (Benton & Pearl, 1978; Harris & Sipay, 1990; Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992). Several literature reviews have reported highly variable rates of ADHD worldwide, ranging from as low as 1% to as high as nearly 20% among school-age children (Bird, 2002; Faraone, Sergeant, Gillberg, & Biederman, 2003). A world-wide meta-analysis of 102 studies comprising 171,756 participants from all world regions found that the ADHD prevalence was 5.29% (Polanczyk, Silva de Lima, Horta, Biederman, & Rohde, 2007). A subselection sample of 10% of children demonstrating reading difficulties and, separately, with ADHD-related symptoms, could provide additional information regarding the predictive ability of RAN to discriminate between children who have symptoms and those who do not. We selected 10% based on a conservative average estimated figure in prevalence studies of ADHD and SLDR.

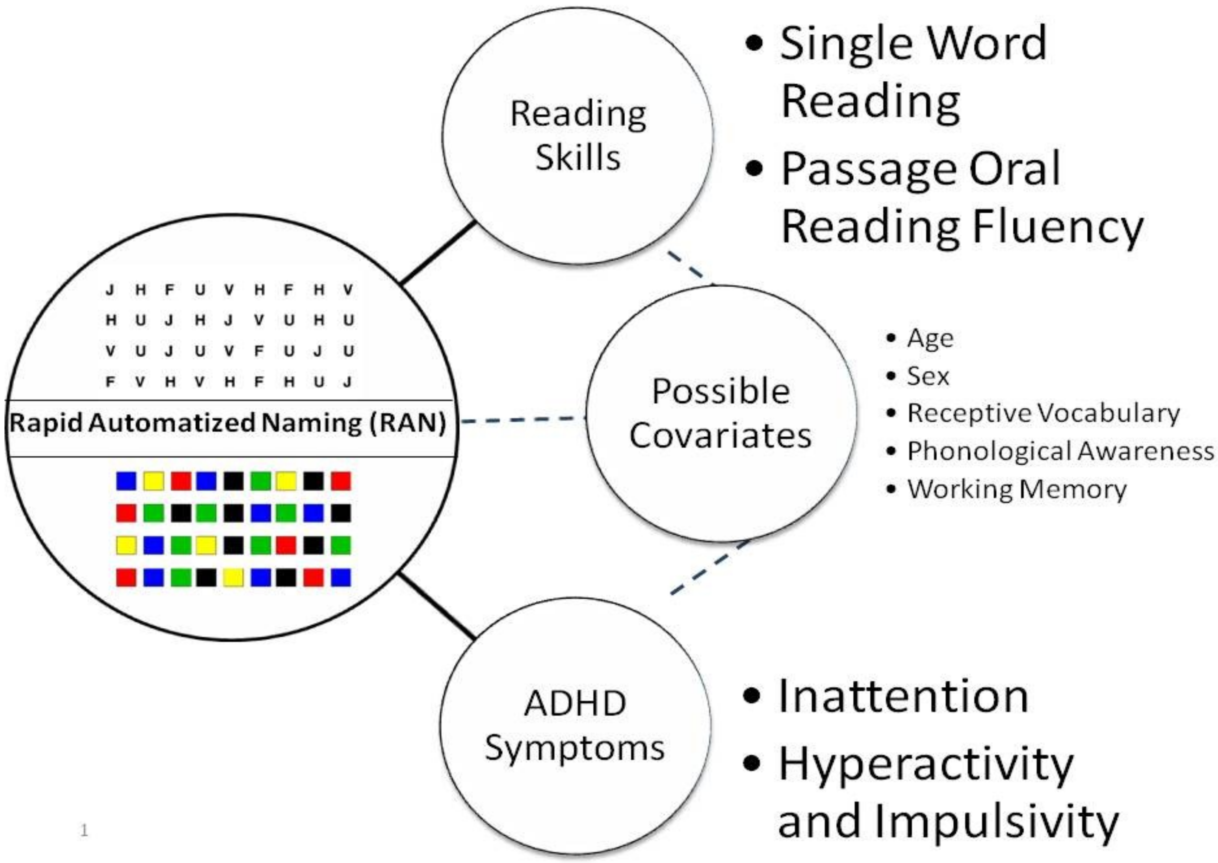

Figure 3. *Illustration of the RAN double dissociation with possible covariates (from Leung & Stringer, 2014*--Manuscript 1*)*

Central Research Questions

We sought to answer some exploratory questions to demonstrate the links among RAN, reading skills, and behavioral symptoms of ADHD (Figure 3). The central questions sought to explore the relations between RAN task total time, behavioral ratings of inattention and hyperactivity from three sources (teacher, parent, and examiner), and reading outcomes (single word and passage oral reading fluency).

1. Does the type of rapid automatized naming (RAN) task differentially predict reading skills and behavioral ADHD-symptoms (namely, inattention and hyperactivity or impulsivity)? That is, does RAN-Letters total time correlate with oral reading fluency and single-word

reading performance? Does RAN-Colors total time correlate with teacher-rated symptoms of inattention, hyperactivity, or impulsivity? We anticipated that the slower rapid naming of letters is associated with poorer reading fluency (fewer words read and more errors or self-corrections) but not symptoms of inattention as rated by the teacher, parent, or examiner. Our second expectation was that the slower rapid naming of colors would be associated with symptoms of hyperactivity or impulsivity as rated by the teacher, parent, or examiner, but not reading fluency, after phonological processing had been taken into account.

2. Are other variables, such as phonological processing, working memory, sex, or age associated with the relations amongst RAN task total time and type, reading skills (oral reading fluency, single-word reading), and behavioral ADHD-symptoms?

Secondary Research Questions (Errors and Self-Corrections)

The secondary research questions sought to explore the relations among RAN task errors and self-corrections, reading outcomes (single-word and passage oral reading fluency), and behavioral ratings of inattention and hyperactivity from three sources (teacher, parent, and examiner). Specifically, we asked:

1. Do error-makers or self-correctors on the RAN tasks differ from nonerror-makers or self-correctors in oral reading fluency or reading achievement scores (single-word reading)? We anticipated that students who made errors or self-corrections on RAN-Letters are more likely to have lower oral reading fluency and single-word reading scores. Are there sex differences?
2. Do error-makers or self-correctors on the RAN tasks differ from non-error-makers or self-correctors in behavioral ratings of inattention or hyperactivity? We anticipated that students who made errors or self-corrections on RAN-Colors may be more likely to have been rated

as "less attentive" or "more hyperactive or impulsive" than students who did not make errors or self-corrections on RAN-Colors. Are there sex differences?

3. Does removing 10% of participants with the lowest oral reading fluency scores or the 10% with the lowest teacher-rated ADHD-symptoms affect the predictive ability of RAN measures? We chose 10% as a rough research-based conservative estimate of children with reading difficulties and attention problems and in a typical classroom sample. The rationale for this was to investigate the ability of RAN measures to discriminate differences in reading and attention for average readers and attenders (in separate analyses).

Anticipated Outcomes in Relation to the Literature

The results of this study are expected to align with recent literature about the predictive validity of measures such as RAN to differentially dissociate reading skills difficulties and ADHD-symptoms in school-aged children (Stringer et al., 2004). It will be interesting to note any differences in predictive ability of RAN and inattentive symptom data in measures of single-word reading achievement as compared to passage oral reading-fluency measures. Rapid automatized naming (RAN) tasks are anticipated to differentially predict behavioral ADHD-symptoms (i.e., inattention, hyperactivity, or impulsivity), with RAN-Letters task performance correlating with measures of oral reading fluency and RAN-Colors performance correlating with inattentive, hyperactive, or impulsive symptoms. Furthermore, inattentive and hyperactivity or impulsivity symptoms and RAN data are anticipated to differentially predict reading fluency and measures of reading achievement, particularly in boys. Therefore, sex is expected to be a covariate in the analyses.

Methodology

Participants

A community sample of children was recruited through two English-language public elementary schools in suburban Montreal. All students in mainstream classrooms from grades 1 to 3 were eligible to participate. Students in segregated settings (classrooms or schools) were excluded because the standardized tests could not accommodate their special language needs. A brief five- to ten-minute presentation was given to each class to outline the study and information and consent packages were sent home to families (see Appendix A for a copy of the parent consent form and child assent form). Out of the 224 information and consent packets distributed, 124 yielded parental consent. Two students transferred schools prior to data collection, and one child was absent during the testing period. Therefore, data from 121 participants were collected and analyzed. Teacher-rating data were missing for three participants, although the child data were collected. The total participating sample of the entire project consisted of 118 students; this group completed a portion of measures on at least one occasion. However, due to time constraints and limited resources, the primary measures of interest, the RAN tasks, were considered to be the limiting factor in subsequent analyses and were administered to 96 participating students at only one of the two schools. The other remaining 22 students attended the second school, none of whom was included in this particular study. Thus, for the purposes of this manuscript, the total sample consisted of 96 students, a convenience sample of students from one school, due to geographical limitations of the data collection. No other systematic reasons were evident for attrition, and thus we were unable to ascertain if missing data were truly random, or if the 96 are representative of the 118 or if there could have been some other systematic differences. A priori power analysis (Cohen, 1988; 1992) indicated that a minimum of 91 participants was required to address the primary hypotheses of the study. According to Cohen (1992), a statistical power ($1 - \beta$) approaching .80 is considered adequate for rejecting the null hypothesis if it were false, and thus represents a convention proposed for general use. For multiple linear regression procedures with five independent variables, given a significance criterion, α, of 0.05, assuming a medium effect size (0.15), and statistical power level of .80, the total recommended sample size was at least 91 participants (Cohen, 1992).

The sample included 43 males (45%) and 53 females (55%) in grades 1 to 3 at one school. Their ages ranged from 6 years, 7 months to 9 years, 6 months ($M = 7.72$, $SD = .90$). Participating children spoke English (81.3%), French (6.6%), or another language (12.1%) at home; however, all participants were proficient in English because this was the primary language of instruction at the recruited schools. Fifteen participants (15.6%) were identified for special education, 21 (21.9%) had an individual education plan (IEP) which entitled children to receive either a modified curriculum (one student), or a regular curriculum with accommodations (20 participants). An additional three participants were reported to be receiving regular curriculum with accommodations. One student had a previously documented ADHD diagnosis. This manuscript uses the term "typically developing" throughout to describe the participating sample in reference or comparison to a non-referred, or non-clinical sample of students (i.e., none of these children were clinically identified). However, some of these participants may or may not be "typically developing" in the truest sense. Rather, these children are likely representative of what might be considered a typical school sample of children in the regular classroom setting, particularly in the early grades prior to possible later identification and intensive support for those children who may benefit.

Participants in the study received either one (screening measures only) or two (screening plus more in-depth) phases of testing during the school year. Sixty-five students participated in two phases of testing during the school year.

Design

The study employed a combined cross-sectional design. The data were collected as part of a two-year prospective study investigating the interrelations among behavioral symptoms of inattention, cognitive measures of attention, and academic outcomes in elementary school children [the results of the longitudinal component involving RAN are reported in Leung, Rogers, & Stringer, 2014b--Manuscript 3]. Participants received either one (screening measures only) or two (screening plus more in-depth) phases of testing during the school year.

The study was approved by the Research Ethics Board of McGill University, the participating school boards' Ethics Review Committees, as well as by the school administrations and parent associations.

Procedure

Consent forms and information sheets were sent home by the teachers to all parents of children in grades 1 through 3 (N = 224 in total) in the spring of the school year (March-April), following brief classroom presentations describing the study. Families that agreed to participate (N = 124) completed consent forms and the demographic sheets and returned them to their children's teacher. We have no way of knowing if the nonrespondents differed in any systematic way, but the 55% parental response rate was good for a mail-in survey and provided some informal confidence. The researchers then collected the forms and compiled a list of students with permission to participate. Teachers were then given a set of measures to complete for each of the participating students in their class, during paid leave time during the normal school day. This payment of regular salary was paid from research funds as an incentive to participate, and was approved in the ethics certification. Concurrently, arrangements were made with the teachers and principal of the school to allow the participating sample of children time to work with the researcher during their normal school day. Family packages with participant-number coded measures and a self-addressed, stamped envelope were also sent home from the schools for parents or guardians to complete for their child. Parents were given the option to return the forms by either mail or to the school for pick-up by the researchers.

To ensure confidentiality, participant names were removed from all data forms prior to data entry, and participants' data were identified only by a number code. Parents, school personnel, and all others involved in the project were told that no information would be released about individual participants, unless specifically requested by the child's parents. De-identified participant data files were kept in a locked filing cabinet in a locked office at the university campus.

Participating students were tested individually in a quiet room in each school in late spring (May and June). All measures were given in English, by a trained university-level research assistant, a trained school/applied child psychology graduate student, or a registered psychologist. Participants were provided as much time as necessary and were encouraged to ask questions about instructions, procedures, or content. Confidentiality of their responses was emphasized. Upon completion of the testing session, participating children were given a small reward for their participation (e.g., a colored gel pen, page of stickers). Measures at this stage of testing included oral reading fluency passage (*Dynamic Indicators of Basic Early Literacy Skills*; DIBELS) and basic reading (Elision and RAN) tasks. Testing took approximately 20 minutes per child.

A subsample (n = 54, 56% male) of the total 96 participants participated in further in-depth (second phase) testing of their skills related to verbal comprehension ability, reading, working memory, and attention. In the entire project of 118 participants, a subsample (n = 65, 55% male) completed further in-depth (second phase) testing of their skills related to verbal comprehension ability, reading, working memory, and attention. The decision to select only a subsample of participants for further in-depth testing was made prior to the commencement of data collection, in order to reduce the burden on teachers and students, and to minimize disruption to the classrooms. This subsample was selected based on the procedures described below in *Screening for ADHD-symptoms*. Upon completion of this second phase of testing, participating children were awarded an additional small reward for their participation (e.g., a colored gel pen, page of stickers). This second session of testing session occurred either in the same or following week of the first session and took approximately 30 minutes per child.

Measures

Most of the proposed measures have been employed in previous research and have good psychometric properties that have been well documented in the literature.

Teacher ratings of student behavior.

Classroom information. Teachers completed a short background form providing information about each participating student, including his or her reading achievement in class, in comparison to classroom peers, and any special education resources. This measure took approximately three to five minutes for each teacher to complete for each participating student.

Screening for ADHD-symptoms. The teacher form of the *Strengths and Weaknesses of ADHD-Symptoms and Normal Behavior Scale–Teacher Form* (SWAN-T; Swanson et al., 2006) was used to screen for classroom ADHD-symptoms and the selection of a subsample of participants to receive in-depth measures. The SWAN-T asks teachers to rate each student relative to others of the same age on a seven-point scale (0 = far below average, 1 = below average, 2 = slightly below average, 3 = average, 4 = slightly above average, 5 = above average, 6 = far above average). The scale contains 18 items and each item is inversely worded for symptoms of inattention and hyperactivity or impulsivity, based directly on criteria from the DSM. The first nine SWAN items assess attention (e.g., "Gives close attention to detail and avoids careless mistakes"), whereas the last nine items assess regulated behaviors associated with less hyperactivity and impulsivity (e.g., "Modulates motor activity" and "Reflects on questions"). Thus, lower scores reflect more ADHD-symptoms that the teacher rated for the child. The sum of the first nine items was used as the Inattention Subscale score in the main analyses. The sum of the latter nine items was used as the Hyperactivity and Impulsivity Subscale score in the main analyses. That is, although the items are positively worded, low scores will reflect increased symptoms of inattention, hyperactivity, or impulsivity. One missing value was found and was resolved by prorating the score (taking the average of the remaining eight items on the relevant subscale and replacing the missing value with the average). The total SWAN-T score was used to estimate the selection of the subsample of participants for a second phase of more in-depth assessment. This scale took approximately three to five minutes for each teacher to complete for each participating student.

After screening the 96 participants, the SWAN-T data were examined in order to stratify the sample. Participants scoring in the high, middle, and low ranges of the SWAN-T were selected for additional testing. Participants were selected based on a visual inspection of data to identify natural breaks in the data range of the total SWAN-T score that allowed the three groups to be designated. That is, after the teachers had submitted their completed questionnaires, the post-doctoral fellow leading the project chose participants with approximations of high, medium, and low average total scores on the SWAN-T. For example, participants with 14 to 18 scores of 0 or 6 out of 18 items would likely be picked to represent "low" or "high" attenders.

Psychometric properties. The inattentiveness, hyperactivity, and impulsivity items on the SWAN forms have strong cohesiveness (Young, Levy, Martin, & Hay, 2009). A key advantage of the SWAN scale is that, based on subscale total scores on the SWAN scale, it generates a normal distribution of the data and avoids potential psychometric flaws that are associated with skewed or kurtotic distributions (Cornish et al., 2008; Hay et al., 2007; Polderman et al., 2007; Robaey et al., 2007). The scales have also been used extensively as a screening tool for inattentive behaviors in population-based samples and validated for use in both home and school settings (Polderman et al., 2007; Cornish et al., 2005; Cornish et al., 2008; Hay et al., 2007; Lui & Tannock, 2007).

The psychometric properties and clinical utility of the SWAN scale have been demonstrated and described in multiple journal articles since its initial introduction in 2000 (Swanson et al., 2012), and reconfirmed in recent clinical studies (Arnett et al., 2013; Lakes, Swanson, & Riggs, 2012). Internal consistency for parent ratings was high ($\alpha = .88$) and similar to another ADHD questionnaire, the Disruptive Behavior Rating Scale (DBRS; Barkley & Murphy, 2005 in Arnett et al., 2013). Reliability for the SWAN ranged from .72 to .90. Lakes et al. (2012), in their evaluation of the reliability and validity of the English and Spanish versions of the SWAN rating scale, found strong internal consistency ($\alpha = .95$) and acceptable test-retest coefficient magnitude for Inattention ($r = .76$) and Hyperactivity ($r = .72$) in the English forms.

Parent ratings of student behavior and demographic measure (*n* = 66).

Medical history and demographic information. Parents completed a short background form providing demographic information about their child's family, specifically, their child's age, parental education levels, documented medical or psychological diagnoses of the child, languages spoken at home, and family ethnicity.

Screening for ADHD-Symptoms. The parent form of the *Strengths and Weaknesses of ADHD-Symptoms and Normal Behavior Scale–Parent Form* (SWAN-P; Swanson et al., 2006) was used to as a cross-comparison for the teacher-rated classroom ADHD symptoms (as described above). Similar to teacher form, the scale for parent's assessment of their child's ADHD-symptoms contains 18 items. Each item is inversely worded for symptoms of inattention and hyperactivity or impulsivity, and each item is worded exactly the same as the teacher form. Subscales are also scored exactly the same as the teacher form.

Eight of the parent responses had missing data. Seven of the eight had one missing value for "ignores extraneous stimuli" on the inattention subscale and the remaining one was missing an item on the hyperactivity subscale. The missing data issue was resolved by replacing the missing value with the rounded average of the individual's score on the remaining eight items within the subscale. **Individual tasks completed with all participating students.**

Rapid automatized naming (RAN) tasks. Two RAN tasks were used, one with letters as stimuli and the other with colors as stimuli. In the letter version of this task (RAN-Letter), adapted for use from the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner et al., 1999), participants named six monosyllabic lowercase consonant or vowel letters. Participants were each given a practice card with individual letter stimuli and asked to name each letter aloud. When participants identified all six letters successfully without assistance, participants were then shown a card (8.5" × 11") of 36 letters presented in a matrix of nine columns and four rows. The order of the letters was random. Participants named the letters from left to right out loud, starting with the top row and ending on the bottom. The total naming time was recorded by the experimenter, using a stopwatch. The dependent variables of the continuous version of the RAN-Letters task were the total naming time, total number of errors, and total number of self-corrections. Total errors were determined by counting instances when the participant skipped or misarticulated a stimulus. Total self-corrections were determined by counting instances when the participant misarticulated then correctly articulated the stimulus. In the color version of this task (RAN-Colors), participants named six colors based on the CTOPP. The stimulus presentation and procedure were the same as for the RAN-Letters. Again, the dependent variables were total naming time, total number of errors, and total number of self-corrections. An aggregate score for each subtest was obtained by doubling the total naming time and converting to an age-appropriate scaled score based on the CTOPP norms, which provided an estimate of the individual's efficient retrieval of information from long-term or permanent memory compared to same age peers. The RAN-Letters and Colors tasks were counterbalanced--that is, half of the participants began with RAN-Letters and the other half began with RAN-Colors. Raw scores were used in the main analyses. Reliability coefficients for the RAN subtests on the CTOPP are 0.82 for both Color and Letter subtests (Wagner, et al., 1999). This measure took about two to three minutes to administer.

Phonological processing. The Elision subtest from the CTOPP (Wagner et al., 1999) was used to obtain an estimate of the participants' awareness of the phonological structure of oral language, essential to the development of reading skill. This task required participants to aurally delete single phonemes from the initial, final, or middle positions in words to form another word. Task directions were, "Let's play a word game." An example of a phoneme deletion task for the child could be to say "pie" and then to say "pie" without the "p" sound" (sounds that were to be deleted were pronounced in phoneme form). Participants deleted phonemes from blends, in the initial or final position, or internal to the blend. Elision provided a measure of an individual's awareness and access to the phonological structure of oral language, essential to the development of reading skill. The maximum possible score was 20. Raw scores were converted to an age-appropriate scaled score based on the CTOPP norms, which provided an estimate of the individual's phonological processing ability compared to same age peers. Raw scores were used in the main analyses. This measure took about two to three minutes to administer.

Psychometric properties of the CTOPP. The CTOPP assess phonological awareness, phonological memory, and rapid naming, and was normed on a stratified sample of 1656 individuals, reflecting the demographic status of the US population in 1997. In the study of test-retest reliability, all test-retest reliability coefficients were greater than or equal to .70. Test-retest reliability over time ranged from .70 to .97 for individual subtests. The error attributable to interscorer differences was minimal, with reliability coefficients equal to or greater than .96 (Wagner et al., 1999). Validity coefficients for seven to 24 year olds in the normative sample between the CTOPP and the Test of Word Reading Efficiency (TOWRE; Torgeson, Wagner, & Rashotte, 1999) indicated moderate associations ranging from .47 to .57 for the Elision subtest, .50 to .56 for RAN-Letters, and .48 to .53 for Alternate Rapid Naming (a composite score consisting of RAN-Colors and RAN-Objects).

Oral reading fluency. Participants' oral reading skills were obtained through the use of the Oral Reading Fluency (ORF) subtest from the *Dynamic Indicators of Basic Early Reading Skills* (DIBELS; Good & Kaminski, 2002), a set of standardized, individually administered curriculum-based measures (CBMs) of early literacy development. Participants were presented with three grade-level passages to read aloud and instructed to try to read each word accurately and to read as many words of the passage as they could in one minute. Median numbers of errors and total median words read correctly across the three passages were scored. CBMs can be used to monitor students' educational progress through direct assessment of academic skills (e.g., in reading, mathematics), using academic material from the school curriculum under standardized conditions. The raw total of median words read correctly was used in the main analyses. This measure took about five minutes to administer.

The DIBELS is a widely used instrument to assess fluency on a range of reading-related tasks in the United States. Extensive research has demonstrated that oral reading fluency is a good indicator of children's overall reading skills development (e.g., Yovanoff, Duesbery, Alonzo, & Tindal, 2005). Many reliability and validity estimates have been produced from a number of sources (Stoolmiller, Biancarosa, & Fien, 2012). The average correlation among the three passage scores at a benchmark assessment is typically between .90 and .95 (Baker et al., 2008; Biancarosa, Bryk, & Dexter, 2010; Dynamic Measurement Group, 2008). The validity of DIBELS ORF is also very good, the typical concurrent correlation in Grades 1 through 3 is about .60 to .85 with norm-referenced tests of reading achievement (Baker et al., 2008; Biancarosa et al., 2010; Roberts et al., 2005; Roehrig, Petscher, Nettles, Hudson, & Torgesen, 2008; Schilling, Carlisle, Scott, & Zeng, 2007) and the typical predictive correlation with end-of-year comprehensive tests of reading proficiency is about .60 to .75 (Baker et al., 2008; Roehrig et al., 2008; Schilling et al., 2007). Although brief in duration, CBM reading scores (like the DIBELS ORF) have also been found to correlate well with traditional (i.e., norm-referenced) measures of decoding and comprehension. Further, they also appear to be one of the most valid measures available for monitoring reading competence (Fuchs & Fuchs, 1999; Hintze, Owen, Shapiro, & Daly, 2000).

However, the evidence regarding DIBELS ORF usefulness in documenting reading progress and predicting success on standardized tests is mixed. One study found no connection between the DIBELS ORF outcome measure and students' oral reading fluency and comprehension of authentic literature, and the researchers questioned the utility of DIBELS in grouping and leveling students for intervention and instruction (Shelton, Altwerger, & Jordan, 2009). Stoolmiller et al. (2012) found evidence of nonlinear relations among passage scores within each grade level that indicated passage equating was necessary in order to control for issues such as passage effects and non-equivalence of passage difficulty.

Individual tasks completed with the subset of participating students (*n* = 54). After screening all 96 participants (118 participants in the full sample), the SWAN-T data were examined in order to stratify the sample. Participants scoring in the high, middle, and low ranges of the SWAN-T were selected for additional testing (*n* = 54, *n* = 65 in the full sample).

Norm-referenced, single-word reading achievement. We employed the Letter-Word Identification (ID) subtest from the *Woodcock-Johnson- III Tests of Achievement with Normative Update* (WJ-III; Woodcock, McGrew, & Mather, 2001) to measure standardized reading achievement. The Letter-Word Identification subtest assesses single-word reading skills. This subtest has been used by other researchers as a measure of early reading ability (Rabiner & Coie, 2000; Wood & Felton, 1994). Raw scores on this subtest were converted to an age-appropriate standard score based on the WJ-III norms, which provided an estimate of the individual's early reading achievement, although raw scores were used in the main analyses. The WJ-III is a widely used, individualized, norm-referenced achievement test that can be used throughout the academic trajectory and taps reading, mathematics, and writing abilities, and demonstrates exemplary psychometric properties (DuPaul et al., 2003). The median test reliability statistic was .94 for Letter-Word Identification and 3.81 for the standard error of measuresment (McGrew & Woodcock, 2001). Raw scores were used in the main analyses. This subtest took approximately three to five minutes to complete.

Assessment of auditory and visual-spatial working-memory. For the assessment of auditory working-memory, we employed the *Digit Span Task* (from the *Wechsler Intelligence Scale for Children-III*; Wechsler, 1991) that required participants to listen to and recall a series of digits of increasing length from two to nine digits (two trials for each digit length). Participants were asked to repeat a series of digits in increasing length from two to eight digits (two trials for each digit length) in reverse order. Total raw scores on this subtest were converted to an age-appropriate scaled score based on the WISC-III norms, in order to obtain an estimate of the individual's working-memory skills compared to same age peers. Individual raw scores from Digit Span forward and backward tasks were used in the main analyses. The Digit Span task took about five to ten minutes to administer. One rationale for this task choice is that poor verbal short-term memory measured by tasks such as Digit Span predicted poor academic outcomes particularly in boys, in a longitudinal and epidemiological study conducted in Australia (Rowe, Pollard, & Rowe, 2004). Studies that correlate the WISC with other individual tests intended to measure intelligence indicated that the WISC has satisfactory criterion validity (Sattler, 2008).

In addition, we used the *Finger Windows Task* (adapted from the *Wide Range Assessment of Memory and Learning*; WRAML; Sheslow & Adams, 1990), which required participants to watch and repeat visual-spatial sequences of increasing length from two to nine, in order to assess visual-spatial working-memory. Trials increased in sequence length gradually, from three trials per sequence length to six trials, and then decreasing in trials per sequence length as the sequences became longer. The Finger Windows task requires the participant to recall the sequential placement by the examiner of a pencil into a series of randomly placed holes in a card (8.5" × 11") by putting their own finger through the same holes, in the same order. Then participants were asked to repeat a series of visual-spatial sequences of increasing length from two to nine holes (two trials for each digit length) in reverse order. Poor verbal short-term memory predicted poor academic outcomes, particularly in boys (Rowe, Pollard, & Rowe 2004). Total raw scores on the Finger Windows forward subtest were converted to an age-appropriate scaled score based on the WRAML norms, in order to obtain an estimate of the individual's visual-spatial working-memory skills compared to same-age peers. Separate raw scores from Finger Windows forward and backward tasks were used in the main analyses. The Finger Windows task took about 10 to 15 minutes to administer.

Psychometric properties. Both types of working memory tasks have excellent psychometric properties, including high internal-consistency reliability (Digit Span = 0.87, Wechsler, 2003; Finger Windows = .99, Adams & Sheslow, 2004; Normand & Tannock, 2014). Internal consistency measures were in the high to excellent range (.86 - .93) for the majority of subtests on the WRAML2, the updated version of the WRAML. In addition, subtests of the WRAML2, such as Finger Windows, demonstrated an acceptable degree of correlation with other instruments designed for the measurement of memory, including the Wechsler Memory Scale-III (r = .60), Children's Memory Scale (r = .49), Test of Memory and Learning (r = .69).

Verbal comprehension ability. The *Peabody Picture Vocabulary Test* (PPVT-III; Dunn & Dunn, 1997), an untimed test of receptive vocabulary for Standard American English, provided an estimate of a person's verbal ability or scholastic aptitude. Participants' pointing or verbal responses were recorded. Raw scores were converted to standard scores in order to provide a general estimate of the sample's level of receptive vocabulary as an indicator of intellectual ability. These scores were not used in the present analyses due to the small sample size of participants who received the task, and are beyond the scope of the current study. The PPVT-III took about five to ten minutes to administer.

Semrud-Clikeman et al. (2000) found that there were no differences between groups of children with RD, ADHD with no RD, and normal controls on receptive vocabulary. This finding contrasted with Felton et al., (1987), who found that the children with ADHD performed more poorly on the PPVT-R (used as a measure of general ability) than the control group.

Psychometric properties. According to the examiner's manual of the PPVT-IIIA (Dunn & Dunn, 1997), internal consistency alphas for the age groups from 2 to 90 range from .92 to .98 (median: .95), and split-half reliability ranges from .86 to .96 (median: .94). The test-retest coefficients range from .91 to .94.

The PPVT has been widely used for decades as a receptive vocabulary or verbal ability measure by clinicians, educators, and researchers for children (e.g., Campbell, Bell, & Keith, 2001; Gerde & Powell, 2009; Walker, Givens, Cranford, Holbert, & Walker, 2006; Washington & Craig, 1999). PPVT scores have also been useful as proxy scores of verbal intelligence in the clinical setting (Carvajal, Nowark, & Fraas, 2000), and as indicators of receptive vocabulary knowledge in research (Gerde & Powell, 2009), although construct validity was not found to fully support its use as a useful measure of receptive vocabulary for struggling adult readers who were African American (Pae, Greenberg, & Morris, 2012).

Examiner ratings of behaviors during computerized cognitive attention tasks. Participants were observed and rated on their behaviors during their performance on two individualized computerized tasks (Vigilance and Visearch). The Vigilance and Visearch tasks were developed for use assess a subset of participating students on their cognitive attentional abilities (Cornish et al., 2008; Wilding, 2003; Wilding, Munir, & Cornish, 2001). For the purposes of this study, only the sum of the experimenter rated task behaviors during the Vigilance and Visearch tasks were examined. Participants were observed for 16 total behaviors:

1. fidgety, inappropriate body posture,
2. off-task, inattentive behavior,
3. verbal frustration with task,
4. physical frustration with task,
5. verbal frustration with performance,
6. physical frustration with performance,
7. hyper or excessive pressing,
8. task-related singing or shouting,
9. task-unrelated singing or shouting,
10. task-related private speech,
11. task-unrelated private speech,
12. related social speech,
13. unrelated social speech,
14. defiance,
15. strategic play, and
16. off-task play.

Examiners rated each student on a four-point scale (0 = not at all, 1 = a little bit, 2 = pretty much, 3 = very much). Sum-total behaviors for each of the two cognitive attention tasks were used in subsequent analyses as an indicator of examiner-rated task-related behaviors. Some of the rated behaviors could be interpreted as prosocial, and helpful behaviors that improve task performance (e.g., task-related private or social speech), rather than inattentive or hyperactive behaviors which could be detrimental to a participant's task performance (e.g., off-task play, excessive pressing, task-unrelated singing or shouting). To date, there have been no studies published using this exploratory rating measure. However, for the purposes of this study as an exploratory measure comparison to parent and teacher ratings of ADHD-symptom behaviors, sum-total examiner ratings were used. Also, splitting the total ratings into subscales would be a challenge in our analyses due to low frequencies of noted behaviors. Future analyses could consider subsets of behaviors, for example, with a large enough sample using exploratory factor analysis to assess possible subscales of behaviors indicating inattention or positive behaviors improving cognitive task performance. Descriptions of the two cognitive attention tasks are presented below. Because these ratings were newly used for this purpose of comparison with parent and teacher reports, published reports of reliability statistics were not found.

Vigilance. A display was presented on a laptop computer screen, similar to that of the Visearch task. Participants were told that, from time to time, a yellow line would appear around one of the black vertical ellipses, showing that a monster was at home, and as soon as they saw this, they should click on the hole and the monster would appear. They were again told that they were looking for the king and must continue until he appeared. The child clicked on a hole that was lit with a yellow outline within seven seconds to produce a monster face. If the child missed the lit target and did not click on it within seven seconds, it disappeared on its own and a “miss” was recorded. The king appeared on the 16th target (even if the child did not click on it), and then the task ended. The Vigilance task took about three to five minutes to administer.

Visual search (Visearch). A display was presented on a laptop computer screen, consisting of a river, trees, and eight different kinds of holes, varying in shape, size, and color, on a light green background. There were two versions of the single-target search, one with a vertical black ellipse as target, and the other with a pinkish brown horizontal ellipse as target. There were 25 targets randomly placed among 100 shapes in all. Participants were instructed that they had to find the king of the monsters hiding in either the black or pinkish brown holes by clicking on holes with their computer mouse. In the dual-target search, there were 15 targets of each type among 100 shapes in all, and participants were required to alternate between the black vertical and pinkish brown horizontal targets to record "hits." In total, there were five search tasks plus a practice session for each task. Performance times varied for each task, depending on how quickly the participant was able to click on correct targets. The Visearch task took about 10 to 15 minutes to administer.

Data-Analysis Procedures

Distributions of all variables were examined, and log transformations were used for several variables showing excessive skewness (i.e., examiner-rated behavior sums for Visearch and Vigilance, RAN-Letters total time, and RAN-Colors total time). Preliminary analyses were performed to confirm scale reliability in the sample and to ensure that characteristics of the measures did not violate statistical test assumptions. Descriptive statistics were performed on all main variables of interest. Correlations were calculated to investigate the relations between RAN, reading, and attention measures. Methodological considerations justified keeping inattentive and hyperactive and impulsive subscales on the teacher and parent ratings separate in all analyses, although they were highly correlated with each other. Multiple regression analyses were conducted to examine the relations between RAN performance, reading skills, and ratings of attention, while controlling for variables such as age, sex, working memory, and phonological processing. Separate multiple-regression analyses were applied to determine the predictive relation of RAN measures on reading and attention ratings. Independent *t* tests and Cohen's *d* effect-size statistics were calculated to investigate the significance and size of differences between error-makers and self-correctors on the RAN-Letters and RAN-Colors task on reading and attention rating outcomes.

Results

Reliability and Validity

SWAN-T. The inattentiveness and hyperactivity and impulsivity items on the SWAN have strong cohesiveness (Young et al., 2009). Cronbach's alpha values were calculated to determine the scale reliability (internal consistency) for the teacher ratings of behaviors. In our sample, the Inattention subscale of the SWAN-T showed very good internal consistency, $\alpha = .99$. The Hyperactivity and Impulsivity subscale of the SWAN-T also demonstrated high internal consistency, $\alpha = .98$.

Preliminary sample analysis presented here was taken from a currently unpublished manuscript (Rogers, 2012), in order to investigate within sample differences based on the SWAN-T rating scale. In preliminary analyses of the SWAN data, the rough estimate represented the top and bottom quartiles. The ADHD Symptom subgroup ($n = 32$, 75% male) was created by selecting participants whose average SWAN-T score was below 2.5 (indicating most teacher responses in the “slightly below average” to “far below average” range). Lower scores reflect more severe ADHD-symptoms that the parent or teacher rated for the child.

The non-ADHD subgroup ($n = 34$, 37% male) was created by selecting those participants whose average SWAN-T score was above 4.5 (indicating teacher responses mostly in the “slightly above average” to “far above average” range). Therefore, the ADHD symptom group had significantly higher SWAN-T scores than the non-ADHD symptom group ($t(65) = 23.57$, $p < .01$).

According to preliminary analyses conducted on the same sample by Rogers (2012), the groups did not differ significantly on child age ($t(65) = 1.42$, $p = .31$) or family socioeconomic status as defined by highest of mothers' or fathers' education ($t(35) = 1.79$, $p = .09$). There were no significant differences between the groups on family ethnicity (Caucasian, other: $\chi^2(1) = .05$, $p = .81$) or languages spoken in the home (English, French, other: $\chi^2(2) = .03$, $p = .98$). The ADHD symptom group contained significantly more boys than girls (male, female: $\chi^2(1) = 10.27$, $p < .01$) and was more likely to be accessing special-education services in the school setting (yes, no: $\chi^2(1) = 11.37$, $p < .01$). Although the groups did not differ on previous psychological or medical diagnoses (yes, no: $\chi^2(1) = 1.12$, $p = .42$), one child in the ADHD-symptom group had a previous diagnosis of ADHD and one had a previous diagnosis of Learning Disability.

SWAN-P. Cronbach's alpha values were calculated to determine the scale reliability for the parent ratings of behaviors. The Inattention subscale of the SWAN-P appeared to have good internal consistency, $\alpha = .94$. The Hyperactivity and Impulsivity subscale of the SWAN-P also appeared to have good internal consistency, $\alpha = .92$.

Examiner ratings of behaviors during computerized cognitive attention tasks. Cronbach's alpha values were calculated to determine the scale reliability for the examiner ratings of behaviors. Examiner ratings of student behaviors during the Vigilance computer task appeared to have moderate internal consistency, $\alpha = .76$. Similarly, examiner ratings of student behaviors during the Visearch task appeared to have moderate internal consistency, $\alpha = .73$.

Interrater reliability. An intercorrelation matrix of the attention ratings provided by teachers, parents, and the study examiner was constructed (Table 1). See Appendix B for a full intercorrelation matrix of the attention ratings provided by teachers, parents, and the study examiners for the entire sample of 118 participants in the project.

Table 1

Intercorrelations among teacher, parent, and examiner ratings of inattention, hyperactivity, and impulsivity

Variable/measure	2	3	4	5	6
1. SWAN-T inattention	**.88*****	**.50*****	**.37****	-.22	**-.28***
	n = 93	n = 65	n = 65	n = 54	n = 54
2. SWAN-T hyperactivity and impulsivity		**.29***	**.35****	**-.28***	**-.33***
		n = 65	n = 65	n = 54	n = 54
3. SWAN-P inattention			**.63*****	-.02	-.02
			n = 66	n = 37	n = 37
4. SWAN-P hyperactivity and impulsivity				-.02	-.06
				n = 37	n = 37
5. Examiner-rated behaviors during vigilance task					**.72*****
					n = 54
6. Examiner-rated behaviors during search task					

Note. SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (T = Teacher or P = Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

SWAN-T Inattention was strongly correlated with SWAN-T Hyperactivity and Impulsivity, $r(93) = .88$, $p < .001$. SWAN-P Inattention was correlated with SWAN-P Hyperactivity and Impulsivity, $r(66) = .63$, $p < .001$. The examiner-rated behaviours during the computer tasks were also significantly correlated, $r(54) = .72$, $p < .001$. SWAN-T Inattention was significantly associated with SWAN-P Inattention, $r(65) = .50$, $p < .001$. SWAN-T Hyperactivity and Impulsivity was significantly associated with parent SWAN-P Hyperactivity and Impulsivity, $r(65) = .35$, $p < .01$.

Given the similarity of the teacher and parent measures, we would expect high correlations between the same subscales for each measure (SWAN-T Inattention with SWAN-P Inattention; SWAN-P Hyperactivity with SWAN-P Hyperactivity). The significance of the difference between correlation coefficients was assessed using a series of Fisher r-to-z transformations. The correlation between teacher and parent ratings of inattention was not significantly different from the correlation between teacher and parent ratings of hyperactivity and impulsivity, $Z = 1.02$, $p = .31$ (two-tailed), indicating some consistency between raters on the SWAN measures for each subscale. The correlation between teacher subscale ratings on the SWAN was significantly higher than the correlation between parent subscale ratings on the SWAN, $Z = 3.86$, $p < .001$ (two-tailed). The correlation between teacher subscale ratings on the SWAN was significantly higher than the correlation between examiner ratings, $Z = 2.67$, $p < .001$ (two-tailed). The correlation between parent subscale ratings on the SWAN was not significantly lower than the correlation between examiner ratings, $Z = -.88$, $p = .38$ (two-tailed).

In general, there were stronger and more significant correlations between teacher and parent ratings than either had with the examiner observations. For example, the correlation between teacher and parent inattention ratings was significantly higher than the correlations between teacher inattention ratings with either of the two examiner ratings (Vigilance) $Z = 4.09$, $p < .001$ (two-tailed), and (Visearch) $Z = 4.43$, $p < .001$ (two-tailed), respectively. Similarly, the correlation between teacher and parent hyperactivity and impulsivity ratings was significantly higher than the correlations between teacher hyperactivity and impulsivity ratings with either of the two examiner ratings (Vigilance) $Z = 4.09$, $p < .001$ (two-tailed), and (Visearch) $Z = 3.75$, $p < .001$ (two-tailed), respectively. The correlation between teacher and parent inattention ratings was significantly higher than the correlations between parent inattention ratings with either of the two examiner ratings (Vigilance or Visearch) $Z = 3.58$, $p < .001$ (two-tailed). The correlation between parent and parent inattention ratings was significantly higher than the correlations between parent hyperactivity and impulsivity ratings with either of the two examiner ratings (Vigilance) $Z = 3.58$, $p < .001$ (two-tailed), and (Visearch) $Z = 3.77$, $p < .001$ (two-tailed), respectively.

Demographics and Descriptive Statistics

Descriptive statistics of the experimental measures of inattention, RAN, and reading measures are presented in Table 2.

Table 2

Descriptive statistics

Variable/measure	*n*	Mean	*SD*	Range
Age	96	7.72	.90	6.07 to 9.06
Grade	96	1.97	.80	1 to 3
Parent's highest education	60	5.72 (College graduate)	1.97	2 to 8 (Completed Grade 11 to Postgraduate Degree)
Race	57			
Caucasian	29	51%		
Italian	16	28%		
Latin American	4	7%		
Middle Eastern	6	11%		
Other	1	1.5%		
Declined to Answer	1	1.5%		
Receptive vocabulary[a]	43	94.58 (Average)	12.64	73 to 137 (Borderline to Very Superior)
Digit Span total[b]	54	10.44	2.77	6 to 16

		(Average)		(Low Average to Very Superior)
Finger Windows forward[b]	54	9.96 (Average)	2.53	3 to 14 (Very Low to High Average)
CTOPP				
Elision raw	96	11.72	4.80	2 to 19
Elision scaled score[b]	96	10.48 (Average)	2.58	5 to 16 (Borderline to Very Superior)
RAN-Letters total time	96	43.08	12.16	28 to 100
Errors	96	.24	.61	0 to 3
Self-corrections	96	.18	.44	0 to 2
Scaled score[b]	96	10.87 (Average)	2.13	7 to 15 (Low Average to Superior)
RAN-Colors total time	96	69.86	17.66	46 – 156
Errors	96	.14	.37	0 to 2
Self-corrections	96	.16	.39	0 to 2
Scaled score[b]	96	9.65 (Average)	2.48	3 to 16 (Very Low to Very Superior)
Reading measures				
DIBELS ORF median words correct	96	82.97	40.56	8 to 194
WJ-III Letter-Word Identification raw score	54	44.28	8.98	21 to 64
WJ-III Letter-Word Identification[a]	54	108.33 (Average)	9.17	83 to 128 (Low Average to Superior)
SWAN-T				
Inattention[c]	93	30.43	13.05	4 to 54
Hyperactivity and Impulsivity[c]	93	32.90	11.64	1 to 54

Total score	93	63.33	23.96	7 to 108
SWAN-P				
Inattention[c]	66	34.27	9.21	15 to 53
Hyperactivity and Impulsivity[c]	66	33.20	8.64	15 to 54
Total score	66	67.46	16.12	33 to 107
Examiner ratings of behaviors				
Vigilance[d]	54	2.19	3.13	0 to 19
Visearch[d]	54	2.22	3.25	0 to 18

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN-T/P = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher/Parent form).

[a]Scores from these measures are based on a standard score, mean = 100, *SD* = ± 15.

[b]Scores from these measures are based on a scaled score, mean = 10, *SD* = ± 3.

[c]Scores from these measures are based on a raw score: 0 (Far below average) to 6 (Far above average).

[d]Scores from these measures are based on a raw score: 0 (Not at all) to 3 (Very much).

In general, participants in this sample performed in the average range on all measures as expected. The data reported in Table 2 suggest that the tasks had adequate psychometric characteristics for the age ranges included in this study. Values were in the acceptable range, and performance was free from floor and ceiling effects on all tasks.

See Appendix C for the descriptive statistics for the whole project sample for both schools. In comparison with the sample used in this study (n = 96), the participants in the entire project sample also performed in the average range on all measures as expected. Thus, there was no reason to believe that there was a selection bias for the smaller group or that the schools differed significantly in terms of parent background, child receptive vocabulary, or measures of reading or behavioral ratings.

Relations among Primary Variables of Interest

An intercorrelation matrix of the primary variables of interest was also constructed (Table 3). A summary of the major intercorrelations is presented below. See Appendices D and E for intercorrelation matrices of the primary variables of interest for the entire sample of the project.

Table 3

Full intercorrelation matrix of variables

		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Sex	*r* =	.04	-.16	-.11	-.14	.18	.07	**.35***	.09	.16	-.09	**.37*****	**.34****	.16	**.25***	-.12	-.17
	p =	.68	.11	.29	.18	.07	.60	.01	.52	.25	.54	.00	.00	.21	.04	.41	.22
	n =	96	96	96	96	96	54	54	54	54	53	93	93	66	66	54	54
2. Age	*r* =	--	**.34****	**-.31****	**-.29****	**.60*****	**.66*****	**.41****	**.30***	**.45****	**.28***	.13	.16	-.09	.04	.00	-.12
	p =		.00	.00	.00	.00	.00	.00	.03	.00	.05	.23	.12	.50	.76	.10	.40
	n =		96	96	96	96	54	54	54	54	53	93	93	66	66	54	54
3. CTOPP Elision[1,2]	*r* =		--	**-.37****	**-.24***	**.54****	**.64****	.19	.25	.15	**.32***	.19	.09	.12	-.02	-.17	-.09
	p =			.00	.02	.00	.00	.16	.07	.27	.02	.08	.38	.32	.85	.22	.50
	n =			96	96	96	54	54	54	54	53	93	93	66	66	54	54
4. CTOPP RAN-LETTERS Time[3]	*r* =			--	**.45*****	**-.66*****	**-.65****	-.25	-.26	**-.48*****	**-.41****	**-.23***	-.10	-.08	.11	.11	.13
	p =				.00	.00	.00	.07	.06	.00	.00	.03	.36	.55	.36	.43	.35
	n =				96	96	54	54	54	54	53	93	93	66	66	54	54
5. CTOPP RAN-COLORS Time[3]	*r* =				--	**-.47*****	**-.43****	-.26	-.07	-.17	-.13	**-.22***	-.07	-.22	.03	**.37****	**.38****
	p =					.00	.00	.05	.64	.23	.36	.04	.54	.07	.82	.01	.01
	n =					96	54	54	54	54	53	93	93	66	66	54	54

6. DIBELS ORF correct median	r =						--	**.85*****	**.44****	**.40****	**.43****	**.44****	**.49*****	**.39*****	.21	.21	-.24	-.23
	p =							.00	.00	.00	.00	.00	.00	.00	.09	.09	.08	.10
	n =							54	54	54	54	53	93	93	66	66	54	54
7. WJ-III Letter Word ID[1]	r =							--	**.43****	**.41****	**.41****	**.40****	**.48****	**.47****	.20	.17	-.26	**-.32***
	p =								.00	.00	.00	.00	.00	.00	.24	.31	.06	.02
	n =								54	54	54	53	54	54	37	37	54	54
8. WISC-III Digit Span forward[1,4]	r =								--	**.50****	.23	.27	**.43****	**.37****	**.38***	.17	.09	.01
	p =									.00	.09	.05	.00	.01	.02	.32	.51	.95
	n =									54	54	53	54	54	37	37	54	54
9. WISC-III Digit Span backward[1,4]	r =									--	.12	**.29***	**.41****	**.34***	.21	.03	.04	.01
	p =										.38	.04	.00	.01	.21	.84	.76	.97
	n =										54	53	54	54	37	37	54	54
10. WRAML Finger Windows forward[1,5]	r =										--	**.50*****	.23	.18	-.22	-.31	-.05	-.06
	p =											.00	.10	.19	.20	.07	.71	.65
	n =											53	54	54	37	37	54	54
11. WRAML Finger Windows backward[1,5]	r =											--	.18	.09	.17	-.04	.05	.17
	p =												.21	.51	.32	.84	.72	.24
	n =												53	53	36	36	53	53

12. SWAN-T Inattention	*r* =	--	**.88*****	**.50*****	**.37****	-.22	**-.28***
	p =		.00	.00	.02	.11	.04
	n =		93	65	65	54	54
13. SWAN-T Hyperactivity and Impulsivity	*r* =		--	**.29***	**.35****	**-.28***	**-.33***
	p =			.02	.00	.04	.01
	n =			65	65	54	54
14. SWAN-P Inattention	*r* =			--	**.63****	-.02	-.02
	p =				.00	.92	.89
	n =				66	37	37
15. SWAN-P Hyperactivity and Impulsivity	*r* =				--	-.02	-.06
	p =					.93	.71
	n =					37	37
16. Examiner-rated behaviors during vigilance task	*r* =					--	**.72*****
	p =						.00
	n =						54
16. Examiner-rated behaviors during visearch task							--

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Weschler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed).

p and *r* values are rounded to the nearest hundredth decimal place.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

[4] Measure of auditory working-memory

[5] Measure of visual-spatial working-memory

Sex differences. Being female significantly and moderately correlated positively with teacher ratings of attention (higher ratings mean positive behaviors), $r(93) = .37$, $p < .001$ (meaning that boys were rated as less attentive than girls), and hyperactive and impulsive control, $r(93) = .34$, $p < .01$ (meaning that boys were more hyperactive and impulsive as rated by teacher and parent, $r(66) = .25$, $p < .05$). Girls performed significantly better than boys on Digit Span forward, $r(54) = .35$, $p < .05$. Also, there were no significant differences between boys and girls on examiner-rated problematic behaviors on the computerized cognitive tasks. No other sex differences were found.

Age. The age of participants was significantly correlated with scores on all performance measures (that is, phonological processing, working memory, and reading). There were no correlations between age and SWAN ratings by either the teacher or parent, nor with examiner ratings of behaviors. Age correlated positively with Elision (phonological processing), $r(96) = .34$, $p < .01$, oral reading fluency, $r(96) = .60$, $p < .001$, single-word reading, $r(54) = .66$, $p < 0.001$, and working memory (forward Digit Span, $r(54) = .41$, $p < .01$, backward Digit Span, $r(54) = .30$, $p < .05$, forward Finger Windows, $r(54) = .45$, $p < .01$, and backward Finger Windows, $r(53) = .28$, $p < .01$).

Older participants were faster on RAN tasks, as shown by negative correlations with RAN-Letters total time, $r(96) = -.31$, $p < .01$ and RAN-Colors total time, $r(96) = -.29$, $p < .01$.

Phonological processing (Elision). Elision, a subtest of the CTOPP, correlated positively with passage oral-reading fluency, $r(96) = .54$, $p < .01$, single-word reading, $r(54) = .64$, $p < .01$, and backward Finger Windows, $r(53) = .32$, $p < .05$, meaning that higher scores on phonological processing were associated higher scores in oral reading fluency, single-word reading, and backward visual-spatial working-memory (the more challenging of the two parts).

Elision was negatively correlated with total time taken for both RAN-Letters, $r(96) = -.37$, $p < .01$, and RAN-Colors, $r(96) = -.23$, $p < .05$, meaning that participants with higher scores on phonological processing were faster on the RAN tasks. Elision was not significantly correlated with either of the teacher-rated ADHD symptom subscales (inattention or hyperactivity), or working memory (with the exception of visual-spatial working-memory).

RAN.

Letters. RAN-Letters total time was positively correlated with RAN-Color total time, $r(96) = .45$, $p < .001$, meaning that participants who were slower on the RAN-Letters task also took longer on the RAN-Colors task. RAN-Letters total time was negatively correlated with passage oral-reading fluency, $r(96) = -.66$, $p < .001$, single-word reading, $r(54) = -.65$, $p < .01$, forward Finger Windows, $r(54) = -.48$, $p < .001$, backward Finger Windows, $r(53) = -.41$, $p < .01$, and teacher-rated attention, $r(93) = -.23$, $p < .05$ (but not hyperactive and impulse control), meaning that participants who were slower on the RAN-Letters task had lower scores in oral reading fluency and single-word reading, and visual-spatial working-memory (both forward and backward), and were more likely to be rated as having below average scores of attention based on the teacher ratings.

Colors. RAN-Colors total time was negatively correlated with passage oral reading fluency, $r(96) = -.47$, $p < .001$, single-word reading, $r(54) = -.43$, $p < .01$, and teacher-rated attention, $r(92) = -.22$, $p < .05$, and examiner-rated behaviors, $r(54) = .37$, $p < .01$, $r(54) = .38$, $p < .01$, meaning that longer times taken on the RAN-Colors task were associated with lower oral reading fluency, single-word reading scores, teacher-rated attention, and examiner-rated behavior scores. RAN-Colors total time was not correlated significantly with working memory or teacher-rated hyperactivity scores.

Reading measures.

Passage oral-reading fluency (DIBELS Correct Median). Passage oral-reading fluency was positively correlated with single-word reading, $r(54) = .85$, $p < .001$, all working-memory tasks, (forward Digit Span, $r(54) = .44$, $p < .01$, backward Digit Span, $r(54) = .40$, $p < .01$, forward Finger Windows, $r(54) = .43$, $p < .01$, backward Finger Windows, $r(53) = .44$, $p < .01$), and teacher ratings of positive attention and hyperactivity behaviors (SWAN-T Inattention, $r(93) = .49$, $p < .001$, SWAN-T Hyperactivity and Impulsivity, $r(93) = .39$, $p < .001$, but not with parent or examiner ratings. Passage oral-reading fluency was significantly associated with most of the other variables, with the exception of sex.

Single-word reading (Letter-Word Identification). Single-word reading was associated with all working-memory tasks (forward Digit Span, $r(54) = .43$, $p < .01$, backward Digit Span, $r(54) = .41$, $p < .01$, forward Finger Windows, $r(54) = .41$, $p < .01$, backward Finger Windows, $r(53) = .40$, $p < .01$), teacher-rated symptoms of ADHD (SWAN-T Inattention, $r(54) = .48$, $p < .01$, SWAN-T Hyperactive Impulsive, $r(54) = .47$, $p < .01$), and examiner-ratings on the Visearch, $r(54) = -.32$, $p < .05$, but not with sex.

Behavioral ADHD-symptom ratings.

Teacher-rated student ADHD-symptoms (SWAN-T). Inattentive behavior was not significantly correlated with age or phonological processing, but it was correlated with both RAN-Letters and RAN-Colors total time, $r(93) = -.23$, $p < .05$ and $r(93) = -.22$, $p < .05$, respectively. Hyperactive or impulsive behavior was significantly strongly correlated with reading measures (passage oral-reading fluency, $r(93) = .39$, $p < .001$, single-word reading, $r(54) = .47$, $p < .01$) as well as with auditory working-memory (Digit Span forward, $r(54) = .37$, $p < .01$, Digit Span backward, $r(54) = .34$, $p < .05$). Hyperactive or impulsive behavior was not significantly correlated with phonological processing, RAN-Letters or RAN-Colors total time, or visual-spatial working-memory (Finger Windows).

Parent-rated student ADHD-symptoms (SWAN-P). Parent-rated inattention was not significantly correlated with most performance measures. Parent-rated inattentive behavior was significantly correlated with forward Digit Span, $r(37) = .38$, $p < .05$. Hyperactive or impulsive behavior was significantly correlated with sex, $r(66) = .25$, $p < .05$, meaning that boys were rated more likely to be rated as hyperactive than girls.

Examiner ratings of behavior. Examiner-rated behaviors from both the Vigilance and Visearch computer cognitive attention tasks correlated with RAN-Colors total time, for Vigilance, $r(54) = .37$, $p < .01$, and Visearch, $r(54) = .38$, $p < .01$, respectively. Examiner-rated behaviors on the Visearch task also correlated with single-word reading, as described above. No other significant correlations with performance measures were found.

Working-memory measures on a subset of participants with high, low, and moderate levels of inattention.

Auditory working-memory (Digit Span). Forward Digit Span was moderately positively correlated with backward Digit Span, $r(54) = .50$, $p < .01$, teacher-rated attention, $r(54) = .43$, $p < .01$, teacher-rated hyperactivity and impulsivity , $r(54) = .37$, $p < .01$, and parent-rated attention, $r(37) = .38$, $p < .05$. Digit Span backward was moderately correlated with Finger Windows backward, $r(53) = .29$, $p < .05$, teacher-rated attention, $r(54) = .41$, $p < .01$, and teacher-rated hyperactivity and impulsivity, $r(54) = .34$, $p < .05$.

Visual-spatial working-memory (Finger Windows). Forward Finger Windows was correlated with backward Finger Windows, $r(53) = .50$, $p < .001$. Backward Finger Windows was not correlated with teacher-rated attention or with teacher-rated hyperactive and impulsive behavior.

Although visual-spatial working-memory correlated significantly with RAN-Letters, auditory working-memory did not. Also, auditory working-memory showed stronger correlations with teacher-rated inattention and hyperactivity than visual-spatial working-memory. Thus, auditory working-memory (Digit Span) revealed a different correlational pattern than visual-spatial working-memory, justifying keeping all of these variables separately, and including them in the regression model.

Relations among RAN, reading skills, and ADHD-symptom ratings. Individual regression analyses (β) predicting reading fluency and attention ratings from RAN performance are presented in Table 4 (4a without working memory, 4b with working memory). See Appendices F through M for the complete regression models with detailed statistical values.

Table 4a

Individual linear regression models (working-memory measures excluded)--Beta coefficients

		Dependent variables							
		Reading		Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms		Examiner-rated problem behaviors during cognitive attention tasks	
		DIBELS ORF median correct (*n* = 96)	WJ-III Letter-Word ID (*n* = 54)	SWAN Inattention (*n* = 93)	SWAN Hyperactivity and Impulsivity (*n* = 93)	SWAN Inattention (*n* = 66)	SWAN Hyperactivity and Impulsivity (*n* = 66)	Visearch (*n* = 54)	Vigilance (*n* = 54)
Predictor variables	Sex	**.15***	.08	**.39*****	**.37****	.19	**.27***	-.09	-.06
	Age	**.35*****	**.43*****	.02	.14	-.21	.08	-.05	.10
	CTOPP Elision^{1,2}	**.28*****	**.39*****	.21	.13	.19	.09	-.02	-.14
	RAN-Letters^{3}	**-.38*****	**-.28****	-.06	.02	.05	.18	-.07	-.09
	RAN-Colors^{3}	-.11	.09	-.08	.04	-.25	-.00	**.37***	**.38***

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative

Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Table 4b

Individual regression models (working memory included)--Beta coefficients

			Dependent variables						
			Reading		Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms		Examiner-rated problem behaviors during cognitive attention tasks
			DIBELS ORF median correct (n = 53)	WJ-III Letter-Word ID (n = 53)	SWAN Inattention (n = 53)	SWAN Hyperactivity and Impulsivity (n = 53)	SWAN Inattention (n = 36)	SWAN Hyperactivity and Impulsivity (n = 36)	Visearch (n = 53)	Vigilance (n = 53)
Predictor variables	Sex		**.19***	.06	**.40****	**.41****	.10	.34	-.11	-.11
	Age		**.19***	**.40*****	-.19	-.04	-.15	.33	-.09	.04
	CTOPP Elision[1,2]		**.25****	**.35*****	.21	.22	-.02	-.10	-.08	-.19
	Working memory	Digit Span forward[1,4]	.04	.03	.11	.09	.26	.01	.18	.26
		Digit Span backward[1,4]	.09	.10	**.30***	.21	.02	-.11	-.08	-.06
		Finger Windows	-.03	-.02	.13	.07	-.32	**-.70***	-.11	-.11

Forward[1,5]								
Finger Windows Backward[1,5]	.10	.02	.00	-.07	.31	.34	.27	.10
RAN-Letters[3]	**-.45*****	**-.27****	.00	-.05	-.02	-.24	-.03	-.10
RAN-Colors[3]	-.13	-.14	-.14	.02	-.17	.19	**.38***	**.39***

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

[4] Measure of auditory working-memory

[5] Measure of visual-spatial working-memory

As expected, RAN-Letters total time significantly contributed to the variance on both reading tasks (passage oral-reading fluency and single-word reading). Age and phonological processing were significant predictors of both reading tasks, although the effect was stronger for single-word reading. RAN-Colors total time did not significantly predict student performance on either of the reading measures or teacher ratings of ADHD-symptoms. Separate regression models were conducted on parent ratings of attention as well as examiner observations of behaviors during the computerized cognitive attention tasks, and RAN-Colors total time significantly predicted the examiner ratings of behaviors, but not parent ratings. Sex was also a significant predictor of oral reading fluency, teacher-rated ADHD-symptoms, and parent-rated hyperactivity or impulsivity. When working-memory variables were considered, auditory working-memory (Digit Span backward) was significantly associated with teacher-rated inattention symptoms. Visual-spatial working-memory (Finger Windows forward) was significantly associated with parent-rated hyperactivity or impulsivity.

RAN-Letters Errors and Self-Corrections Analyses

Results of the independent *t* test analyses and Cohen's *d* effect-size statistics were calculated to investigate the significance of differences between error-makers (Table 5a) and self-correctors (Table 5b) on the RAN-Letters task on reading and attention rating outcomes. Due to low error rates and self-corrections in this sample as a whole, participants with any number of errors on the RAN task were placed in the group of "error-makers" and participants with any self-corrections were placed in the "self-correctors" category.

Table 5a

Individual t tests on RAN-letters errors, reading measures, and attention ratings

	RAN-Letters					
	Non-error-makers *Mean (SD)*	Error-makers (Range = 1-3) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
RAN tasks						
Letters total time	3.68 (.22) *n* = 81	3.98 (.26) *n* = 15	**-4.79*****	94	.000	-1.36
Colors total time	4.20 (.21) *n* = 81	4.32 (.27) *n* = 15	-1.85	94	.06	-.53
Reading measures						
DIBELS ORF correct	87.03 (38.97) *n* = 81	61.07 (43.28) *n* = 15	**2.33***	94	.02	0.66
WJ-III Letter-Word ID	45.86 (7.68) *n* = 44	37.30 (11.26) *n* = 10	**2.29***	10.98	.04	1.78
CTOPP Elision	11.98 (4.75) *n* = 81	10.33 (4.97) *n* = 15	1.22	94	.23	0.35
Attention measures						
SWAN-T Inattention	30.56 (12.94) *n* = 78	29.73 (14.09) *n* = 15	.23	91	.82	0.06

SWAN-T Hyperactivity and Impulsivity	32.90 (11.62) *n* = 78	32.93 (12.14) *n* = 15	-.01	91	.99	0.00
SWAN-P Inattention	33.81 (9.02) *n* = 48	34.20 (10.52) *n* = 10	-.61	64	.54	-0.20
SWAN-P Hyperactivity and Impulsivity	32.44 (8.41) *n* = 52	36.00 (9.24) *n* = 14	-1.38	64	.17	-0.42
Examiner-rated behaviors (during Visearch)	.81 (.80) *n* = 44	.87 (.92) *n* = 10	-.23	52	.82	-0.08
Examiner-rated behaviors (during Vigilance)	.85 (.78) *n* = 44	.84 (.74) *n* = 10	.04	52	.97	0.01

Note. Standard deviations appear in parentheses next to means.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Effect size estimates: Small = <.20; medium = .50; large = >.80.

Table 5b.

Individual t tests on RAN-letters self-corrections, reading measures, and attention ratings

	RAN-Letters					
	Non-self-correctors *Mean (SD)*	Self-correctors (Range = 1-2) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
RAN tasks						
Letters total time	3.69 (.22) $n = 81$	3.94 (.28) $n = 15$	**-3.83*****	94	.016	-1.09
Colors total time	4.21 (.23) $n = 81$	4.28 (.21) $n = 15$	-1.17	94	.33	-0.33
Reading measures						
DIBELS ORF correct	87.10 (40.98) $n = 81$	60.67 (30.54) $n = 15$	**2.38***	94	.02	0.67
WJ-III Letter-Word ID	45.30 (8.49) $n = 44$	39.80 (10.15) $n = 10$	1.78	52	.08	0.64
CTOPP Elision	12.05 (4.89) $n = 81$	9.93 (3.97) $n = 15$	1.82	22.63	.08	1.05
Attention measures						
SWAN-T Inattention	30.97 (13.22) $n = 78$	27.60 (12.18) $n = 15$	.92	91	.36	0.26

SWAN-T Hyperactivity and Impulsivity	33.47 (11.81) *n* = 78	29.93 (10.60) *n* = 15	1.08	91	.28	0.31
SWAN-P Inattention	34.31 (9.43) *n* = 55	34.05 (8.41) *n* = 11	.09	64	.93	0.03
SWAN-P Hyperactivity and Impulsivity	33.02 (8.90) *n* = 55	34.09 (7.54) *n* = 11	-.37	64	.71	-0.12
Examiner-rated behaviors (during Visearch)	.80 (.73) *n* = 44	.89 (1.13) *n* = 10	-.23	10.78	.82	-0.18
Examiner-rated behaviors (during Vigilance)	.81 (.69) *n* = 44	.99 (1.06) *n* = 10	-.65	52	.52	-0.23

Note. Standard deviations appear in parentheses next to means.

$^{*} = p < .05$, $^{**} = p < .01$, $^{***} = p < .001$.

Effect size estimates: Small = <.20; medium = .50; large = >.80.

RAN-letters errors analysis. Sex of the child, age, or grade was not significantly different between error-makers and nonerror-makers on the RAN-Letters task. There was no significant effect for sex, $t(94) = 1.29$, $p = .20$, age, $t(94) = 1.62$, $p = .11$, or grade, $t(94) = 1.97$, $p = .05$. RAN-Letters error-makers read statistically significantly more slowly than nonerror-makers on the RAN-Letters task. The group of participants who made errors on the RAN-Letters task had statistically lower scores on the single-word reading (Letter Word Identification) and oral-reading fluency measures. Cohen's effect size value ($d = .66$ for Oral Reading Fluency, and $d = 1.78$ for Letter-Word Identification) suggested a moderate to high practical significance.

Groups were not significantly different on teacher ratings of inattention or hyperactivity or impulsivity (i.e., RAN-Letters error-makers were not considered more inattentive and hyperactive or impulsive) by their teachers, parents, or examiner. This finding supports the anticipated outcome as posited by the RAN double dissociation (the RAN-Letters task is associated with reading and not inattention and hyperactivity). There were no differences between groups based on the parent ratings of inattention and hyperactivity or impulsivity as well as the examiner ratings.

RAN-letters self-corrections analysis. Sex of the child, age, or grade were not significantly different between self-correctors and nonself-correctors on the RAN-Letters task. There was no significant effect for sex, $t(94) = .70$, $p = .47$, age, $t(94) = 1.20$, $p = .23$, or grade, $t(94) = 1.24$, $p = .22$. Self-correctors on the RAN-Letters task read statistically more slowly than nonself-correctors (i.e., took more time) on the RAN-Letters only. This may be due to increased variability on the total times for RAN-Colors task, so slight differences on RAN-Letters were more likely to be significant. Participants who made self-corrections on the RAN-Letters task had statistically lower scores on oral reading fluency but not single-word reading. Cohen's effect size value (*d* = .67) suggested a moderate practical importance. Self-correctors and nonself-correctors on RAN-Letters were not significantly different on teacher ratings of inattention, hyperactivity, impulsivity (i.e., RAN-Letters self-correctors were not considered more inattentive and hyperactive or impulsive) by their teachers, parents, or examiner. This finding also supports the RAN double dissociation (RAN-Letters task is associated with reading and not inattention or hyperactivity, with the addition that self-corrections for the RAN-Letters task are again important to consider in this context).

RAN-Colors Errors and Self-Correction Analyses

Results of the independent *t*-test analyses and Cohen's *d* effect-size statistics were calculated to investigate the significant differences between error-makers (Table 6a) and self-correctors (Table 6b) on the RAN-Colors task on reading and attention rating outcomes.

Table 6a

Individual t tests on RAN-colors errors, reading measures, and attention ratings

	RAN-Colors					
	Non-error-makers *Mean (SD)*	Error-makers (Range = 1-2) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
RAN tasks						
Letters total time	3.74 (.25) $n = 84$	3.67 (.22) $n = 12$	.98	94	.35	.31
Colors total time	4.22 (.22) $n = 84$	4.19 (.26) $n = 12$	.42	94	.78	.13
Reading measures						
DIBELS ORF correct	83.08 (41.65) $n = 84$	82.25 (33.42) $n = 12$	.07	94	.95	.02
WJ-III Letter-Word ID	44.67 (9.20) $n = 49$	40.40 (5.60) $n = 5$	1.01	52	.32	.48
CTOPP Elision	11.37 (4.86) $n = 84$	14.17 (3.61) $n = 12$	**-2.39***	17.27	.03	1.74
Attention measures						
SWAN-T Inattention	30.77 (13.53) $n = 81$	28.17 (9.39) $n = 12$	.84	18.56	.41	.58

SWAN-T Hyperactivity and Impulsivity	33.83 (11.93) *n* = 81	26.67 (7.04) *n* = 12	**2.95****	21.82	.01	1.88
SWAN-P Inattention	33.89 (9.50) *n* = 57	36.67 (7.04) *n* = 9	-.84	64	.40	-.31
SWAN-P Hyperactivity and Impulsivity	33.40 (8.43) *n* = 57	31.89 (10.39) *n* = 9	.49	64	.63	.18
Examiner-rated behaviors (during Visearch)	.73 (.77) *n* = 49	1.69 (.73) *n* = 5	**-3.08****	52	.01	-1.47
Examiner-rated behaviors (during Vigilance)	.75 (.71) *n* = 49	1.78 (.73) *n* = 5	**-2.64***	52	.00	-1.26

Note. Standard deviations appear in parentheses next to means.

[*] = $p < .05$, [**] = $p < .01$.

Effect size estimates: Small = <.20; medium = .50; large = >.80.

Table 6b

Individual t tests on RAN-colors self-corrections, reading measures, attention ratings

	RAN-Colors		*t*	*df*	*p*	*Cohen's d*
	Non-self-correctors *Mean (SD)*	Self-correctors (1 or 2) *Mean (SD)*				
RAN tasks						
Letters total time	3.71 (.23) $n = 82$	3.86 (.32) $n = 14$	**-2.13***	94	.13	-.62
Colors total time	4.19 (.21) $n = 82$	4.39 (.24) $n = 14$	**-3.27***	94	.002	-.96
Reading measures						
DIBELS ORF correct	86.77 (39.76) $n = 82$	60.71 (39.35) $n = 14$	**2.27***	94	.03	.66
WJ-III Letter-Word ID	45.34 (8.68) $n = 44$	39.60 (9.23) $n = 10$	1.87	52	.07	.67
CTOPP Elision	11.89 (4.73) $n = 82$	10.71 (5.28) $n = 14$	.85	94	.40	.25
Attention measures						
SWAN-T Inattention	31.70 (13.07) $n = 79$	23.29 (10.79) $n = 14$	**2.27***	91	.02	.67

SWAN-T Hyperactivity and Impulsivity	34.08 (11.65) $n = 79$	23.29 (10.79) $n = 14$	**2.37***	91	.02	.69
SWAN-P Inattention	34.14 (9.13) $n = 56$	34.95 (10.08) $n = 10$	-.25	64	.80	-.09
SWAN-P Hyperactivity and Impulsivity	33.07 (8.31) $n = 56$	33.90 (10.80) $n = 10$	-.28	64	.78	-.10
Examiner-rated behaviors (during Visearch)	.75 (.74) $n = 44$	1.12 (1.06) $n = 10$	-1.29	52	.20	-.46
Examiner-rated behaviors (during Vigilance)	.76 (.70) $n = 44$	1.23 (.96) $n = 10$	-1.81	52	.08	-.65

Note. Standard deviations appear in parentheses next to means.

* = $p < .05$, ** = $p < .01$.

Effect-size estimates: Small = <.20; medium = .50; large = >.80.

RAN-colors errors analysis. Sex of the child, age, or grade were not significantly different between error-makers and nonerror-makers on the RAN-Colors task. There was no significant effect for sex, $t(94) = .38$, $p = .70$, age, $t(94) = .68$, $p = .50$, or grade, $t(94) = 1.01$, $p = .31$. Did participants who made errors on RAN complete the task faster than nonerror-makers, thus sacrificing accuracy for speed? No.

Participants who made errors on the RAN-Colors task had statistically lower ratings of hyperactivity or impulsivity (i.e., were considered more hyperactive or impulsive) by their teachers, with high practical significance ($d = 1.88$). Also, error-makers on the RAN-Colors task had higher ratings of behaviors from their examiner from observations on two cognitive attention tasks, with high practical significance ($d = -1.47, -1.26$, respectively). There were no significant differences between groups on any of the reading measures. This finding also supports the RAN double dissociation (RAN-Colors task is associated with inattention and hyperactivity, and not reliably with reading measures). Error-makers on RAN-Colors had higher scores on phonological processing, which was an unexpected finding. There were no significant differences between groups based on the parent ratings of inattention and hyperactivity or impulsivity. Parent ratings generally did not contribute new information about the analyses conducted.

RAN-colors self-corrections analysis. Sex, age, and grade were not significantly different between groups. That is, there was no significant effect for sex, $t(94) = 1.59$, $p = .115$, age, $t(94) = 1.06$, $p = .29$, or grade, $t(94) = 1.29$, $p = .20$. Self-correctors on the RAN-Colors task were slower than nonself-correctors (i.e., took more time) on both the letter and RAN-Colors tasks.

Participants who made self-corrections on the RAN-Colors task had statistically lower ratings of attention and were considered to be more inattentive and hyperactive or impulsive by their teachers. Self-correctors also had significantly lower median scores on passage oral-reading fluency. Similarly to the results for RAN-Color errors, the self-correction results also are in line with the RAN double dissociation. That is, the RAN-Colors task is associated with inattention and hyperactivity rather than reading measures, although there were no significant differences between groups based on the parent ratings of inattention and hyperactivity or impulsivity as well as the examiner ratings.

Additional analyses on sex and working memory (errors and self-corrections). A series of one-way between-subjects analyses of variance (ANOVAs) was conducted to compare sex effects on making either RAN-errors or self-corrections on reading outcomes and teacher ratings of ADHD-symptoms. When only boys were selected for the analysis, neither RAN-Letters or RAN-Colors errors were significant for any outcome measures in boys only. RAN-Letters differences between self-correctors and nonself-correctors were not significant for any outcome measures. However, RAN-Colors self-correctors and nonself-correctors were significantly different on their SWAN-Teacher hyperactive and impulsive ratings, $F(1, 41) = 4.29$, $p = .05$. This meant that boys who made self-corrections were rated significantly lower (on average) on hyperactive and impulse control, that is, more hyperactive and impulsive on average, by their teachers.

In girls, the pattern held for errors but not for self-corrections. RAN-Letters errors were associated with all reading-outcome measures, DIBELS, $F(1, 51) = 13.06$, $p = .00$, and Letter-Word Identification, $F(1, 22) = 13.07$, $p = .00$. RAN-Colors errors was associated with SWAN-T hyperactive ratings, $F(1, 48) = 7.12$, $p = .01$, but not inattentive ratings, $F(1, 48) = 2.24$, $p = .14$, nor reading measures, $F(1, 51) = .37$, $p = .54$ for ORF, $F(1, 22) = .04$, $p = .84$ for Letter-Word. No significant differences were found for girls' self-corrections on either RAN-Letters or RAN-Colors.

In terms of working-memory associations with RAN errors or self-corrections, RAN-Letters errors were associated only with Finger Windows backward, $F(1, 51) = 4.95$, $p = .03$, with participants who made no errors receiving higher scores. Self-corrections on RAN-Letters was only associated with Finger Windows forward, $F(1, 52) = 19.80$, $p = .00$. However, neither RAN-Colors errors nor self-corrections was associated with any working-memory variables. The group of participants who made errors or self-corrections on RAN-Letters significantly differed in their performance on visual-spatial working-memory, but not on auditory working-memory.

Further analyses were done to assess if there were differences between errors and self-corrections on RAN tasks when: (a) the participants with the lowest 10% reading scores on passage reading fluency were excluded (which translated to less than 25 DIBELS median words correct), and (b) all participants with documented ADHD as well as the top 10% of participants with behavioral symptoms of ADHD were excluded (which translated to less than a total score of 98 on the SWAN-T). This would essentially test the sensitivity of the RAN tasks on average or good readers and attenders, and the ability of RAN tasks to differentiate between attention or reading concerns on average or good readers. If RAN measures can be used to predict reading performance and attention concerns in typically developing participants, we would expect that when poor readers are excluded from the analysis, both RAN-Letters and RAN-Colors differences would remain intact. Similarly, if RAN measures can be useful to differentiate between participants with reading concerns in typically developing participants with average attention concerns, we would expect that when participants with symptoms of ADHD are excluded from the analysis, RAN-Letters differences would stay intact on reading measures. RAN-Colors differences would likely disappear or wash out, unless RAN-Colors errors or self-corrections were sensitive enough to detect subtle differences in ADHD-symptoms among typically developing participants.

Ten percent of participants with severe reading symptoms excluded. A one-way ANOVA was conducted. Participants who made errors on RAN-Letters were not significantly different on any of the reading or teacher-rated attention measures. RAN-Letters self-corrections were not significant on teacher ratings on any of attention measures, nor reading measures. RAN-Colors errors showed significant differences on SWAN-T Hyperactivity and Impulsivity, $F(1, 82) = 4.67$, $p = .03$, and examiner ratings, Vigilance, $F(1, 47) = 10.35$, $p = .00$, and Visearch, $F(1, 47) = 8.59$, $p = .01$. Color self-corrections did not reveal any significant differences on any measures after the participants with the most reading difficulties were excluded. This result implied that RAN-Letters errors and self-corrections were more sensitive in differentiating between poor and good readers, rather than detecting differences in average to good readers. However, the relation between RAN-Colors errors performance and reading difficulties remained intact, indicating that, in a sample of average to good readers, RAN performance was still related to ADHD-symptoms.

Ten percent of participants with ADHD-symptoms excluded. RAN-Letters errors were still significantly different on DIBELS, $F(1, 85) = 6.88$, $p = .01$ and Letter-Word Identification, $F(1, 47) = 10.73$, $p = .00$). RAN-Letters self-corrections showed no significant differences between groups on any of the outcome variables. RAN-Colors errors revealed significant differences on Elision, $F(1, 85) = 5.01$, $p = .03$, and SWAN-T Hyperactivity and Impulsivity, $F(1, 85) = 5.20$, $p = .03$. RAN-Colors self-corrections revealed significant differences on SWAN-T

Inattention, $F(1, 85) = 4.52$, $p = .04$, and SWAN-T Hyperactivity and Impulsivity, $F(1, 85) = 5.13$, $p = .03$, but none of the reading measures. This result suggested that, in typical classroom sample of children, RAN performance in a typical population remains sensitive when participants with higher ratings of dysfunctional behaviors related to ADHD were excluded from the analysis. The relation between RAN errors and self-corrections performance, reading difficulties, and ADHD-symptoms still remains intact in participants with average to above average attention, as well as hyperactive or impulsive control.

A summary of the significant associations from the multiple linear regression analyses and *t* tests is presented in Table 7.

Table 7

Summary of significant cross-sectional associations

	Dependent variables							
	Reading		Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms		Examiner-rated behaviors	
Predictor variables	DIBELS Oral Reading Fluency	WJ-III Letter Word ID	Inattention	Hyperactivity and Impulsivity	Inattention	Hyperactivity and Impulsivity	Vi-search	Vigil-ance
Sex	√		√	√		√		
Age	√	√						
Elision	√	√						
RAN-Letters time	√	√						
RAN-Letters errors	√	√						
RAN-Letters self-corrections	√							
RAN-Colors time							√	√
RAN-Colors errors				√			√	√
RAN-Colors self-corrections	√		√	√				
Digit Span forward								
Digit Span backward			√					
Finger Windows forward						√		
Finger Windows backward								

Conclusions

Answers to the Specific Research Questions

1. Does the type of rapid automatized naming (RAN) task differentially predict reading skills and behavioral ADHD-symptoms (namely, inattention and hyperactivity or impulsivity)? Does RAN-Letters total time correlate with oral reading fluency and single-word reading performance? Does RAN-Colors total time correlate with teacher-rated symptoms of inattention, hyperactivity, or impulsivity? Based on the regression analyses, RAN-Letters total time significantly contributed to the variance on reading tasks (passage oral-reading fluency and single-word reading), but RAN-Colors total time did not for any of the reading measures, parent or teacher ratings of ADHD-symptoms. Therefore, the slower rapid naming of letters was also associated with poorer reading fluency (fewer words read) but not with symptoms of inattention as rated by the teacher, parent, or examiner. The slower rapid naming of colors was associated with behavioral symptoms as rated by the naïve examiner, but not with reading measures. These results support a RAN double dissociation.

2. Is working memory associated with the relations amongst RAN task total time and type, reading skills (oral reading fluency, single-word reading), and behavioral ADHD-symptoms? Auditory and verbal working-memory were individually correlated with RAN total task time but, in the regression analyses (not stepwise), these did not account for significant proportions of RAN variability. These findings were similar to those of Pham et al. (2011) who also found that working-memory measures did not account for a significant amount of variance in their regression models of RAN predicting reading outcomes and attention, and also Phelps (1996) who found that tasks on the WRAML did not discriminate well between students with ADHD and reading difficulties. Are there working-memory differences for errors and self-

corrections? RAN-Letters errors and self-corrections were associated with visual-spatial but not auditory working-memory. No working-memory differences were found for RAN-Colors errors and self-corrections.

3. Is the sex of the child associated with the relations amongst RAN task total time and type, reading skills (oral reading fluency, single-word reading, and behavioral ADHD-symptoms? No, it is not.

4. Is age associated with the relations amongst RAN task total time and type, reading skills (oral reading fluency, single-word reading, and behavioral ADHD-symptoms? Yes, it is.

Answers to Secondary Research Questions (Errors and Self-Corrections)

1. Do error-makers or self-correctors on the RAN tasks differ from nonerror-makers in oral reading fluency or reading achievement scores (single-word reading)? Yes, they do differ, and in the direction supporting a double dissociation. Are there sex differences? Girls who did not make errors or self-corrections on RAN-Letters had higher reading scores on average than girls who did.

2. Do error-makers or self-correctors on the RAN tasks differ from nonerror-makers in behavioral ratings of inattention or hyperactivity? Students who made errors or self-corrections on RAN-Colors may be more likely to have been rated as “less attentive” or “more hyperactive” than students who did not make errors on RAN-Colors. Yes, they differ, and in the direction supporting a double dissociation. Are there sex differences? Girls who did not make errors or self-corrections on RAN-Colors had more positive ratings (fewer symptoms) of hyperactivity and impulsivity than girls who did. Boys who made self-corrections were more likely to be rated as hyperactive or impulsive by their teacher.

Performance on RAN-Letters predicted reading outcomes on single word and passage oral-fluency scores in a typical classroom sample of children in grades 1 to 3. Also, performance on the RAN-Colors task predicted teacher hyperactivity and impulsivity ratings as well as examiner global clinical impressions during the computerized cognitive-attention measures. This dual relation of RAN task to differential behavioral outcomes is the RAN double dissociation.

3. Does removing 10% of participants with the lowest oral reading fluency scores or the 10% with the lowest teacher-rated ADHD-symptoms affect the predictive ability of RAN measures? When the participants with the lowest oral reading fluency scores were excluded from the analyses, the pattern of results changed for RAN-Letters Errors and Self-Corrections, as well as RAN-Colors Self-Corrections. That is, when the poorest readers were excluded, RAN-Letters errors and self-corrections were no longer found to be significantly different from nonerrors or nonself-corrections on any of the reading measures, and RAN-Colors self-corrections were no longer different from nonself-corrections on attention measures. However, RAN-Colors errors still showed significant differences from nonerrors on multiple behavior ratings (teacher and examiner). Thus, RAN-Colors error performance in a typical population with no reading difficulties remains sensitive when poor readers were excluded from the analysis. RAN-Letters errors or self-corrections performance in a typical population with no reading difficulties did not remain sensitive when poor readers were excluded from the analysis. This finding supported the notion that RAN-Letters errors or self-corrections may do a better job at discriminating between poor and good readers rather than detecting subtle reading performance differences among average or good readers.

When participants with severe ADHD-symptoms were excluded, the general pattern of associations between RAN-Letters with reading measures, and RAN-Colors with attention measures remained intact. That is, the group of participants with errors on RAN-Letters was still significantly different on all reading outcomes. RAN-Colors errors still revealed significant differences on Elision, and teacher-rated hyperactivity or impulsivity. RAN-Colors self-corrections still revealed significant differences on teacher ratings of inattention, hyperactivity, and impulsivity. These outcomes implied that, in a typical classroom sample of participants, RAN performance remains sensitive when participants with higher ratings of dysfunctional behaviors related to ADHD were excluded from the analysis. The relation between RAN-Letters errors performance and reading difficulties remained intact. RAN-Colors errors and self-corrections appeared to still be sensitive to teacher ratings. This finding supported the notion that RAN-Colors errors and self-corrections may both discriminate between good and poor attenders as well as detect subtle differences in ADHD-symptoms among average and good attenders.

The double dissociation model as described in this paper is presented as a useful guide, or measuring device of RAN associations with reading performance and symptoms of ADHD, namely, inattention, hyperactivity, and impulsivity. The relative strengths of associations as described and summarized in this paper signal clues of which clinicians or researchers could use specific types of RAN to be essentially a thermometer or barometer to measure the existence of attention or reading phenomena in children.

Discussion

Rapid automatized naming (RAN) tasks are differentially correlated with reading outcomes as well as behavioral ADHD-symptoms (namely, inattention, hyperactivity, or impulsivity), with the RAN-Letters task correlating primarily with measures of oral reading fluency and single-word reading outcomes, but not attention-ratings, and the RAN-Colors task correlating with experimenter-rated behaviors but not reading outcomes. Slower rapid naming of letters was associated with poorer reading fluency and single-word reading scores. Slower rapid naming of colors was associated with examiner-rated behaviors, but not with teacher or parent ratings of inattention, hyperactivity, impulsivity, or reading measures. Errors and self-corrections on the RAN tasks predicted reading and attention-ratings in the direction supported by the double dissociation hypothesis. See Table 7 for a summary table of the main results. These results indicate relative strengths of associations, and not true double dissociation per se, yet the model presents a useful tool to understand the nature of RAN associations with reading performance and symptoms of ADHD.

These findings extend and complement the findings of Cantor (2009), who found no evidence of a relation between nonalphanumeric RAN performance and behavioral outcomes of inattention, as measured by the Continuous Performance Test and parent ratings. We also found no relation among nonalphanumeric RAN performance and behavioral outcomes of inattention as measured from parent ratings, however, evidence supporting this relation was found by comparing multiple informants (teacher, examiner). Furthermore, our main findings agreed with Pham et al. (2011), who also found relations among nonalphanumeric RAN performance and behavioral outcomes of inattention as measured by teacher ratings, and no evidence of strong relations between working-memory variables in their regression models. However, our findings also contrasted with their findings with regard to nonalphanumeric RAN's association with reading. We found that nonalphanumeric RAN performance was not associated with reading ability after phonological processing, sex, age, and working memory were accounted for in the equation.

A few interesting discussion points arise based on these main findings. First, the two RAN tasks, although they appear to be quite similar in form, do not behave similarly in terms of tapping the cognitive resources necessary for quick and accurate time performance--hence the dissociation. Nonalphanumeric RAN performance may reflect processes not tapped by alphanumeric RAN, such as executive function, whereas performance on alphanumeric RAN depends on highly automatized processes in which executive function (in the form of lexical decision-making) plays no role. Second, continuous RAN provides information about an individual's reading performance beyond general level of automaticity. Alphanumeric forms of RAN reliably predict reading performance after phonological processing has been accounted for, but nonalphanumeric and discrete-trial formats do not (e.g., Perfetti, Finger, & Hogaboam 1978; Stanovich 1981). General level of automaticity does not explain why continuous RAN performance predicts reading. The continuous RAN format may place more demands on executive functioning than the discrete format, and executive functioning is disrupted in ADHD. The type of stimuli used in nonalphanumeric RAN tasks may also place more demands on executive functioning than alphanumeric RAN tasks, even in the early primary grades. This could explain why continuous formats are better predictors of reading than discrete formats, and why letters are better than colors in doing so. The continuous-trial format has features, distinctly different from the discrete-trial format, that make it a more powerful discriminator of good and poor readers.

General orthographic knowledge or automaticity cannot explain the alphanumeric RAN deficit in reading performance simply due to the fact that discrete and continuous RAN do not predict reading performance in the same way. The explanation must have something to do with specific demands of the continuous alphanumeric RAN task, and therefore it is the process, or processes involved in the continuous RAN that is the crux of the problem for students with reading difficulties (B. M. Linn, personal communication, 2014). For example, the processes involved in executive function likely provide some clues in regard to RAN performance. It is probable that a combination of phonological factors, visual-verbal connections, and executive aspects intrinsic to and within each RAN task are somehow interconnected (Denckla & Cutting, 1999). These theoretical explanations could shed light on how errors and self-corrections play a role also in the predictive ability of RAN for reading and attention.

Phonological processing deficits may or may not be overlapping in children with SLDR and children with ADHD. Some have found no support for the assumption that a phonological system is relatively more intact for one group of poor readers when compared with another. Our results would disconfirm the perspective that phonological processing is a common problem between children with dysfluent readers and children rated as more inattentive or hyperactive. Our results coincide with those of Douglas and Benezra (1990), as well as Pennington, Groisser, and Welsh (1993), who found doubly dissociative relations of cognitive processing between ADHD and reading disorders, and would disagree with those who have found that children with and without SLDR and ADHD were found to share a common problem in phonological processing, when other factors were partialled out of the analysis (McGee et al., 1989; Swanson et al., 1999).

Errors and Self-Corrections

Errors and self-corrections on the RAN tasks demonstrated a doubly dissociative relation to reading outcomes and ADHD-related behaviors. Students who made no errors or self-corrections on the RAN-Letters task were more likely, on average, to have better single-word reading scores and oral-reading fluency. Students who made no errors on the RAN-Colors task were more likely, on average, to have better teacher ratings of hyperactive and impulsive control, and those who made no self-corrections were more likely to have better teacher ratings of attention as well as hyperactive and impulsive control. The examination of errors and self-corrections on RAN tasks have never been studied before in the context of a double dissociation in typically developing students. This finding echoes other RAN studies that have examined errors. For example, a group of students with a specific learning disorder in reading (SLDR) made significantly more errors on the RAN-Letters task than either the ADHD or control group. But no differences in errors were found between the ADHD and control group (Semrud-Clikeman et al., 2000). Denckla and Cutting (1999) have suggested that certain error types within word-list learning tasks link “dyslexic” and “dysexecutive” errors because such errors reflect (a) impaired phonological working memory, as in self-repetitions, and (b) impaired specific word retrieval, as when over-categorical recall leads to some random color being recalled instead of the shown color.

In other contexts such as self-regulated learning and metacognition in learning, self-correction is generally regarded as a positive example of executive functioning. Self-correction on RAN-Letters, however, was correlated with poorer reading fluency (i.e., fewer words read correctly in a minute) and lower scores on single word reading. It is possible that self-correction on a comprehension task differs from a simpler, more basic, context-independent task such as letter-recognition, for example, on RAN-Letters.

Working Memory

Auditory working-memory (Digit Span backward) was significantly associated with teacher-rated inattention symptoms. Because Digit Span backward assesses the ability to retain several elements that have no logical relation to each other, plus the additional complication of planning, and the ability to transform the input before responding (Sattler, 2008), low scores on this task likely indicate correspond well with decreased inattention in the classroom. Visual-spatial working-memory (Finger Windows forward) was significantly associated with parent-rated hyperactivity or impulsivity. Working-memory measures were not associated with reading outcomes. The findings for working memory partly corroborate the findings from RAN-Colors, but they essentially do not provide any predictive ability or additional information in excess of those from the RAN measures in our sample.

Visual-spatial working-memory correlated significantly with RAN-Letters, but auditory working-memory did not correlate well with either RAN task. Also, auditory working-memory showed stronger correlations with teacher-rated inattention and hyperactivity than with visual-spatial working-memory. Thus, auditory working-memory (Digit Span) revealed a different correlational pattern than visual-spatial working-memory.

Similar to the findings of Phelps (1996), we did not find that memory measures had good discriminant validity in the assessment of children with reading or attention difficulties. However, we were able find good predictive associations about inattentive and hyperactive symptoms from RAN-Color errors and self-corrections. Our results indicated that what teachers could pick up on about their students about their behavior in the classroom could also be tapped from color RAN, but not necessarily from working-memory measures.

Limitations

The results of the current study may be interpreted with the following possible limitations.

Sample recruitment. Participants were recruited from schools located in suburban Montreal through school participation in the study. Although a representative sample was achieved based on the demographics of the school population, families that agreed to participate may have been biased toward participation because of some perceived external benefit. Parents who agreed to participate in the study might have children with little to no academic or behavior difficulties in contrast to other families that might have chosen not to participate based on concern about potential stigma surrounding their children. Conversely, some families who agreed to participate in the study might have children with suspected reading or attention difficulties, and thus were more likely to participate in the study in order to access resources. Parents were given the option of requesting their child's testing results, and five parents made that request. It is possible that sample recruitment was not representative of the population at large, although individual variable-analyses indicated that RAN-task total time, reading outcomes, and teacher-behavior ratings, were normally distributed. The control variables (receptive vocabulary, phonological processing, working memory) were also in the average range in comparison to same age peers in the population at large. Sample size was also a limitation in the current study, as a larger sample size could have resulted in increased power and a lower likelihood of Type I and Type II errors based on the number of variables considered in the study. Larger sample sizes could have allowed for cross-comparisons based on characteristics, such as age and verbal comprehension ability, which could have interesting developmental implications for the model. Interpretive power could also have a benefit of having a larger and more varied sample. We were also not sure if the reduced student (n = 96) and parent samples (n = 66) were systematic or random. One could attempt to check that in future studies.

Additional variables. Variables such as cognitive processing speed, additional measures of attention, such as sustained attention and executive functioning could be useful to further explore the relations between RAN performance, reading outcomes, and behavioral symptoms of ADHD. Although an overall estimate of receptive vocabulary was available, the addition of verbal comprehension measures, as an estimate of IQ, administered to the whole sample could allow for an extended interpretation. Perhaps the addition of other reading outcomes such as reading comprehension or word attack could further provide insight into the double dissociation hypothesis. The inclusion of the other RAN tasks (i.e., digits and objects) or types of naming (e.g., discrete-trial RAN, rapid alternating stimulus (RAS) tasks) may additionally provide some further insight.

Updated measures. Some of the measures used in this study currently have updated forms as well as normative updates (e.g., WRAML2, WISC-IV, CTOPP2). One of the considerations of the study was to use research measures that would not interfere with any other ongoing psychoeducational assessment undertaken at the school-level for programming or special education identification purposes, but the interpretation of results should be considered with this in mind. Future studies may wish to use these updated versions.

Cross-cultural considerations. Because this study was conducted in English with an English-speaking sample, extrapolations to studies of children in other languages, for example, with heavier emphasis on phonologically transparent orthography (e.g., German) or pictographic orthography (e.g., Chinese) may be limited.

Implications

Practice. Educators in the primary grades have a critical role in helping their students become literate, encouraging children to become lifelong readers, and identifying those who are struggling with reading skills. The use of clinical tools such as RAN tasks provides valuable insight into basic-skills deficits that inhibit the acquisition of reading at an age appropriate level and indicate areas for intervention. For example, our findings that errors and self-corrections on the RAN tasks demonstrated a doubly dissociative relation to reading outcomes and ADHD-related behaviors, suggesting that self-correcting, reflective, or metacognitive-monitoring skills may be tapped through the use of RAN tasks. These skills can be learned, and may be worth explicitly teaching to those children who experience reading or attention difficulties. Strategies to reduce or monitor error rate and self-corrections could provide possible areas for intervention. Conversely, noting the presence or type of errors or self-corrections when administering RAN tasks could provide insight regarding a child's reflective or metacognitive monitoring skills. Strengthened pre- and postservice training for all professionals involved with students who exhibit reading difficulties or symptoms related to behavioral inattention or hyperactivity or impulsivity is necessary to decrease fragmentation of knowledge regarding assessment, identification, and accommodation (Philpott & Cahill, 2008).

Evaluation and identification of inattention and reading difficulties at an early age allow educators and practitioners to intervene early, potentially improving the long-term academic achievement outcomes of children who are at-risk. Brief assessments such as RAN are useful in predicting reading performance, even among children who do not exhibit reading difficulties

(Kirby, Georgiou, Martinussen, & Parrila, 2010; Neuhaus & Swank, 2002; Pham et al., 2011). Slower RAN speed, particularly in RAN-Colors, suggests difficulties with control of attention, likely related to abnormal fluctuations or breakdown of neural connections (Misra, Katzir, Eolf, & Poldrack, 2004). Although these fluctuations may provide a basis for understanding levels of inattention, they may also facilitate more direct assessment of contributors to specific reading skills, particularly fluency, among typically developing children. These findings contribute to the development of a model of how the domains of reading and attention are interrelated. Researchers and practitioners may be able to identify and intervene early with children who are considered at-risk for developing reading or attention problems, with the aid of RAN tasks.

We found that the relations between teacher, parent, and brief examiner ratings of children's ADHD-symptoms to be only moderately correlated, similar to a number of studies that have found low or no association between teacher and parent ratings of ADHD (Antrop, Roeyers, Oosterlaan, & Oost, 2002; Mitsis et al., 2000; Wolraich et al., 2004). Our findings lend support to the importance of implementing rating scales and interviews from multiple informants as well as the careful selection of a multi-modal assessment battery in the assessment of children's attention and reading difficulties.

In accord with others who have investigated typically developing children with an eye on classroom behavior and reading challenges (e.g., Pham et al., 2011; Rabiner et al., 2004; Stringer et al., 2004), this study provided additional support for the psychologist and researcher to assess attention and reading problems on a continuum, rather than determining whether they are simply present or absent in a category. Even if a student does not meet diagnostic criteria for a disorder such as SLDR or ADHD, the child may still have some degree of reading or attention reading difficulty occurring at a subthreshold level that may still warrant some type of early intervention.

Theory. Multiple possible theoretical explanations for the relation between naming speed and reading have been proposed, based on different conceptual analyses of what is involved in naming speed and reading: phonological processing, orthographic processing, general processing speed, and executive processes or domain general automaticity deficits (Kirby et al., 2010; Leung & Stringer, 2014--Manuscript 1). The available theoretical explanations suggest a number of key processes shared by RAN and reading tasks and may each contribute some partial explanation for RAN performance. The phonological processing interpretation implies that naming-speed tasks are at least somewhat phonological in nature, leading to the question of whether naming speed contributes anything beyond phonological processing to reading. From our findings, total letter rapid-naming time contributed to reading beyond phonological processing. Total color rapid-naming time also predicted examiner ratings of behaviors during cognitive attention tasks, but phonological processing did not. As a result, we would argue that the phonological processing interpretation is not sufficient to explain RAN performance.

The orthographic interpretation emphasizes that RAN tasks and reading require instantaneous access to lexical representations and suggests that this may be the basis of the relation, which in turn leads to the question of whether RAN type may be differentially related to reading or if RAN types all have the same relation to reading. From our findings, all RAN types do not have the same relation to reading. RAN-Letters was clearly related to performance on reading measures, and there was evidence supporting RAN-Colors relations to behavioral measures of attention, hyperactivity, and impulsivity. Thus, instantaneous access to lexical representations could be a basis of the relation of RAN-Letters to reading, but does not explain

RAN-Colors relations to behavior. As a result, we would argue that the orthographic interpretation is not sufficient to explain RAN performance.

The processing-speed interpretation stresses the importance of speed or efficiency in responding, that is critical for some aspects of reading (e.g., reading speed or fluency), which again leads to the question of whether quick processing speed on all types of RAN predicts reading or if it does not. From our findings, quick speed on RAN-Letters or RAN-Colors did not clearly predict performance on reading measures. The evidence supporting a double dissociative relation of RAN to reading and behavioral symptoms of ADHD found in this study contradict the theoretical general processing-speed interpretation, although aspects of processing speed may be worth further investigation within the RAN double dissociation.

We explored the interpretation of RAN that points to the importance of executive processes to orchestrate successful RAN performance, by considering variables such as working memory, attentional control, inhibitory responses in RAN, and reading performance. Other researchers have concluded that RAN taps both visual-verbal (language domain) and processing speed (executive domain) contributions to reading (Denckla & Cutting, 1999). Wolf et al. (2000) argued that rapid naming tasks are composed of attentional, visual, lexical, temporal, and recognition subprocesses that all contribute to naming speed performance. Our findings support the executive processes interpretation of RAN performance, at least in the consideration of inhibitory responses in RAN in relation to behavioral symptoms disrupted in children with a range of attention or hyperactivity or impulsivity concerns in the typical classroom. Our interpretation points to the importance of executive processes to orchestrate all of these variables in synchrony for performance to be successful, which should warrant further empirical investigation into the role of processes such as attentional control and inhibitory responses in RAN and reading performance.

Future Directions

The results of this study emphasize the practicality of brief assessments such as RAN to predict reading performance among typical children and those who exhibit significant reading difficulties.

RAN speed is uniquely associated with a range of reading tasks beyond that explained by phonological processing, and early identification of children at risk for reading failure would be improved by the inclusion of variable RAN measures. Poor response to instruction of students who have slow naming speed should be considered when designing interventions. Further research is required to specify the theoretical nature of naming speed and to determine how to help students with slow naming speed (Kirby et al., 2010).

Future research should also continue to examine samples of typically developing as well as clinical samples of children with ADHD and diagnosed SLD in reading. Because previous ADHD studies often did not separate differences between inattentive and hyperactive-impulsive symptoms (e.g., Carte et al., 1996; Semrud-Clikeman et al., 2000), future research should clearly outline the differences between symptoms and their relations to RAN performance. Longitudinal studies of RAN performance in the prediction of reading outcomes can also be helpful to look at how RAN can be used to predict reading outcomes in each grade level, and could have important developmental implications.

Further research could also provide additional information to the double dissociation hypothesis by considering the developmental framework of reading. This would nuance what is currently a preliminary model of the relations between RAN, reading, and ADHD symptoms.

Reading difficulties may be most suitably studied (e.g., in the classroom) with the assumption that these issues are situated on a normally distributed continuum rather than as discrete, categorical, sets of problems. Evidence in the literature regarding reading difficulties is converging on support for the consideration of reading as an ability that is more or less normally distributed, with reading difficulties at the lower tail (see Snow, Burns, & Griffin, 1998; Stanovich & Siegel, 1994). This is in opposition to a more traditional categorical approach to diagnosis of a reading disorder or reading disability (or a subtype of reading disability known as "dyslexia") based on an intelligence quotient (IQ)-achievement discrepancy model.

Alphanumeric RAN is a sensitive predictor of reading ability for children with varying levels of reading problems (Denckla & Rudel, 1976b), and typical children (Pham et al., 2011). Given the evidence that supports the assessment of attention and reading difficulties on a continuum or broader scale, RAN studies in these populations should be investigated as continuous and not categorical dimensions. This implies that future empirical studies should make use of regression analyses to better understand patterns of behavior. These should include full models as well as step-wise approaches.

Appendix A

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PARENT INFORMATION LETTER AND CONSENT FORM

Institution: Faculty of Education, McGill University

Title of Project: Inattentive behaviors and cognition as predictors of later academic outcomes

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Introduction: Classrooms across the province include children with a wide range of abilities. Children may have good attention skills or may have mild or moderate difficulties with paying attention and concentrating in class. We are interested in children's ability to pay attention in class and the development of reading, math and memory abilities. We are going to work with your child's classroom teacher to learn more about how to help children pay attention in the classroom. Your child's teacher has agreed to be part of this 2-year study.

There are three phases to this study:

Phase 1: We will be asking your child's teacher to complete a short questionnaire that will provide us with information about your child's ability to pay attention in class. We will then ask your child to perform some very short reading and math activities. These will take no more than 10 minutes all together. You will not be asked to do anything for this Phase.

Phase 2: In this second stage, we will be looking specifically at children whom teachers had rated in Phase 1 as either paying very good attention in class or who have difficulties with concentrating in class. We will let you know if your child is selected for phase 2 by sending a letter to you.

We will need you and your child's teacher to answer some questions about how your child gets on in school. These short questionnaires will take approximately 15 minutes to complete. Your child will be asked to do some simple activities that involve looking through a map to locate specific signs, listening to a long series of tones, and withholding a response when they see a particular number, memory games and some reading and math activities. These tasks are specifically developed for young children who should find them fun to complete. These will be completed in school in a quiet room and will take approximately 40 minutes.

Phase 3: In this third stage, we will see your child again for a total of two more times, once at 12 months and again at 24 months. On both these occasions your child will complete the same activities as described above in Phase 2 which will take approximately 40 minutes. You and your child's teacher will complete the same attention and behaviour questionnaires as in Phase 2. This will take approximately 15 minutes.

The information collected will let us look at the development of attention abilities in elementary aged school children and provide more knowledge about how attention develops in relation other important skills such as reading and math.

Advantages of the proposed studies: We will assess your child's attention, memory reading and math abilities. We will provide the results of these investigations to you and, upon your request, to your child's teachers.

In addition, your child might find participating in the research to be enjoyable and interesting. You may learn more about your child's functioning at home and at school.

The results of this study will also help us understand more about helping children pay attention in class. In understanding the development of attention skills and the link with other skills such as reading and math abilities, it is our goal to build and improve existing educational interventions and support services that can be available to you and your child should you need them.

Disadvantages of the proposed studies: Your child may miss some class time for the Stage 2 research assessments, approximately 40 minutes. However, we will talk with your child's teacher to pick a time that is good for the student. Your child may also find the testing session to be tiring but we will give your child small breaks when needed. Students will be encouraged to do their best and positive feedback will be given for effort.

There are no other known discomforts or disadvantages associated with participating in the study.

Confidentiality: We respect your privacy. All the information will be kept confidential, except as required or permitted by law. Your child will be assigned a study number and the information will be filed using this unique identifier. Besides our research staff, only members of regulatory agencies or members of the Research Ethics Board may have access to the data, unless you give permission to release information through someone you choose. Following completion of the research study the forms and documents will be destroyed after 3 years.

Participation: Participation is voluntary. You may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. If you have any questions or concerns about rights as a research participant in this study, please contact the Research Ethics Officer at McGill University at 514-398-6831

Incidental Findings: The cognitive and behavioral findings will be communicated to you and, upon your request, to educators as indicated above.

Compensation: Your child will also receive a small gift as a compensation for participation.

Contact Numbers: If you have any questions about the research, please contact Dr Kim Cornish at the Faculty of Education at (514) 398-3434 or kim.cornish@mcgill.ca

Declaration of the participant:

In signing this consent form, I recognize that all aspects of the study have been explained to me, and that I have been informed about the study. I also agree that I have had the opportunity to ask questions about the study, and that all my questions have been answered satisfactorily.

I, ___________________, have read the above description with one of the investigators, ___________________. I fully understand the procedures, advantages and disadvantages of the study, which have been explained to me. I freely and voluntarily consent for my child to participate in this study.

____

Name of participant Date

____

Name of parent (legal tutor) Signature of parent (legal tutor) Date

____

Name of person obtaining consent Signature of person obtaining consent Date

McGill

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CHILD ASSENT FORM

Attention, Reading and Math Study, McGill University and the University of Toronto

Why are we doing this study?
We are working with your classroom teacher to learn more about how children concentrate in class and how this relates to their reading and math in school.

We are doing these tests to learn more about how children do simple math sums, read and concentrate and remember instructions in class. Some of the games we are going to play may be very easy and others may be more difficult. We want to learn which ones you find difficult and which you find easy. Your participation will help us to learn more about how you pay attention and learn in class.

What will happen during this study?
You understand that you are being asked to help with a study. You will be asked to do some reading and math activities. You will also get to do some memory and concentration games. Some of the activities may be like the work you do in class and others will be like games you do at home.

You can ask questions at any time and you can stop doing the study at any time if you want for any reason.

Are there good things and bad things about this study?
You might find helping out in this study fun. You will also get to learn more about research. You will have to miss some of your classroom activities to work with the researcher. You might get a bit tired but you can stop or take a break as often as you wish.

Can I decide if I want to do these activities?
Your parents have given permission for you to participate in this testing. You do not have to participate in this process if you don't want to. Nobody will be angry or upset if you do not want to be in the study. If you do want to participate you can decide not to answer any questions that you don't want to. You can stop participating at any time and nobody will be upset with you.

Who will know what I did in this study?
Sometimes we will write down the answers you give me and sometimes you will be writing down your own answers. The work that we do together will only be seen by the people that your

parents give me permission to speak with, like your teacher for example. Otherwise no one will know your results.

Do you have any questions? Would you like to participate?

Assent
I read this form to ___________________________________ and acknowledge that he/she gave verbal assent to participate.

Signature ____________________ Date ___________________

Appendix B

Full sample of intercorrelations among teacher, parent, and examiner ratings of inattention, hyperactivity, and impulsivity

Variable/measure	2	3	4	5	6
7. SWAN-T inattention	**.86*****	**.51*****	**.40*****	**-.30***	**-.37****
	n = 119	n = 77	n = 77	n = 63	n = 63
8. SWAN-T hyperactivity and impulsivity		**.33****	**.39*****	**-.34****	**-.36****
		n = 77	n = 77	n = 63	n = 63
9. SWAN-P inattention			**.65*****	-.05	-.12
			n = 78	n = 41	n = 41
10. SWAN-P hyperactivity and impulsivity				-.05	-.13
				n = 41	n = 41
11. Examiner-rated behaviors during vigilance task					**.71*****
					n = 63
12. Examiner-rated behaviors during search task					

Note. SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (T = Teacher or P = Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

Appendix C

Full sample descriptive statistics

Variable/measure	*n*	Mean	*SD*	Range
Age	122	7.96	1.01	6.07 – 11.04
Grade	122	2.21	.92	1 – 4
Parent's highest education	72	5.32 (College graduate)	1.845	2 – 8 (Completed Grade 11 to Post Graduate Degree)
Receptive vocabulary[a]	68	94.37 (Average)	13.13	73 – 137 (Borderline – Very Superior)
Digit Span total[b]	65	10.58 (Average)	2.92	6 – 17 (Low Average – Very Superior)
Finger Windows forward[b]	65	10.09 (Average)	2.63	3 – 17 (Very Low – Very Superior)
CTOPP				
Elision raw	96	11.72	4.80	2 – 19
Elision scaled score[b]	96	10.48 (Average)	2.58	5 – 16 (Borderline – Very Superior)
RAN-Letters total time	96	43.08	12.16	28 – 100
Errors	96	.24	.61	0 – 3
Self-corrections	96	.18	.435	0 – 2
Scaled score[b]	96	10.87 (Average)	2.13	7 – 15 (Low Average – Superior)
RAN-Colors total time	96	69.86	17.66	46 – 156
Errors	96	.14	.37	0 – 2
Self-corrections	96	.16	.39	0 – 2
Scaled score[b]	96	9.65 (Average)	2.48	3 – 16 (Very Low – Very Superior)
Reading Measures				

DIBELS ORF median words correct	121	91.02	41.35	8 – 194
WJ-III Letter-Word ID raw	65	40.46	12.75	10 – 64
WJ-III Letter-Word ID[a]	65	107.85 (Average)	9.15	83 – 128 (Low Average – Superior)
SWAN-T				
Inattention[c]	119	32.78	13.405	4 – 54
Hyperactivity and Impulsivity[c]	119	35.02	12.25	1 – 54
Total score	119	67.80	24.72	7 – 108
SWAN-P				
Inattention[c]	78	33.72	9.50	9 – 53
Hyperactivity and Impulsivity[c]	78	33.115	8.84	15 – 54
Total score	78	66.84	16.68	27 – 107
Examiner ratings of behaviors				
Visearch[d]	63	2.05	3.08	0 – 18
Vigilance[d]	63	1.90	2.98	0 – 19

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN-T/P = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher/Parent form).

[a]Scores from these measures are based on a standard score, mean = 100, SD = ± 15.

[b]Scores from these measures are based on a scaled score, mean = 10, SD = ± 3.

[c]Scores from these measures are based on a raw score: 0 (Far below average) to 6 (Far above average).

[d]Scores from these measures are based on a raw score: 0 (Not at all) to 3 (Very much).

Appendix D

Full sample intercorrelations among variables (excluding working memory)

			2	3	4	5	6	7	8	9	10	11	12	13
1.	Sex		-.02	-.16	-.11	-.14	.08	.01	**.25****	**.25****	.21	**.23***	-.13	-.15
		n =	122	96	96	96	121	65	119	119	78	78	63	63
2.	Age			**.34****	**-.31****	**-.29****	**.64*****	.05	**.18***	**.20***	-.20	-.01	-.07	-.08
		n =		96	96	96	121	65	119	119	78	78	63	63
3.	CTOPP Elision[1,2]				**-.37*****	**-.24***	**.54*****	**.64*****	.19	.09	.12	-.02	-.17	-.09
		n =			96	96	96	54	93	93	66	66	54	54
4.	CTOPP RAN-Letters time[3]					**.45*****	**-.66*****	**-.65*****	**-.23***	-.10	-.08	.11	.11	.13
		n =				96	96	54	93	93	66	66	54	54
5.	CTOPP RAN-Colors time[3]						**-.47*****	**-.43****	**-.22***	-.07	-.22	.03	**.37****	**.38****
		n =					96	54	93	93	66	66	54	54
6.	DIBELS ORF correct median							.24	**.52*****	**.42*****	.12	.195	**-.31***	**-.26***
		n =						65	118	118	78	78	63	63
7.	WJ-III Letter Word ID[1]								.10	.02	.07	-.05	.03	-.10
		n =							65	65	43	43	63	63
8.	SWAN-T Inattention									**.86*****	**.51*****	**.40*****	**-.30***	**-.37****
		n =								119	77	77	63	63
9.	SWAN-T Hyperactivity and Impulsivity										**.33****	**.39*****	**-.34****	**-.36****
		n =									77	77	63	63
10.	SWAN-P Inattention											**.65*****	-.05	-.12
		n =										78	41	41
11.	SWAN-P Hyperactivity and Impulsivity												-.05	-.13
		n =											41	41
12.	Examiner-rated behaviors during Vigilance task													**.71*****

		2	3	4	5	6	7	8	9	10	11	12	13
	n =												63
13.	Examiner-rated behaviors during Visearch task												
	n =												

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix E

Full sample correlation matrix of variables (working memory included)

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Sex	-.02	-.16	-.11	-.14	.08	.01	**.26***	.01	.12	-.12	**.25****	**.25****	.21	**.23***	-.13	-.15
n =	122	96	96	96	121	65	65	65	65	64	119	119	78	78	63	63
2. Age		**.34****	**-.31****	**-.29****	**.64*****	.05	**.43*****	**.27***	**.47*****	**.32****	**.18***	**.20***	-.20	-.01	-.07	-.08
n =		96	96	96	121	65	65	65	65	64	119	119	78	78	63	63
3. CTOPP Elision[1,2]			**-.37*****	**-.24***	**.54*****	**.64*****	.19	.25	.15	**.32***	.19	.09	.12	-.02	-.17	-.09
n =			96	96	96	54	54	54	54	53	93	93	66	66	54	54
4. CTOPP RAN-Letters time[3]				**.45*****	**-.66*****	**-.65*****	-.25	-.26	**-.48*****	**-.41****	**-.23***	-.10	-.08	.11	.11	.13
n =				96	96	54	54	54	54	53	93	93	66	66	54	54
5. CTOPP RAN-Colors time[3]					**-.47*****	**-.43****	-.26	-.07	-.17	-.13	**-.22***	-.07	-.22	.03	**.37****	**.38****
n =					96	54	54	54	54	53	93	93	66	66	54	54
6. DIBELS ORF Correct Median						.24	**.48*****	**.39****	**.49*****	**.50*****	**.52*****	**.42*****	.12	.20	**-.31***	**-.26***
n =						65	65	65	65	64	118	118	78	78	63	63
7. WJ-III Letter Word ID[1]							.09	.04	.07	.01	.10	.02	.07	-.05	.03	-.10
n =							65	65	65	64	65	65	43	43	63	63
8. WISC-III Digit Span forward[1,4]								**.56*****	**.30***	**.35****	**.44*****	**.38****	**.31***	.19	.05	-.04
n =								65	65	64	65	65	43	43	63	63
9. WISC-III Digit Span backward[1,4]									**.27***	**.46*****	**.48*****	**.37****	.25	.18	-.04	-.13
n =									65	64	65	65	43	43	63	63
10. WRAML Finger Windows forward[1,5]										**.57*****	**.28***	**.26***	-.22	-.24	-.13	-.09
n =										64	65	65	43	43	63	63
11. WRAML Finger Windows backward[1,5]											**.29***	.16	.12	.01	-.06	.025
n =											64	64	42	42	62	62

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12. SWAN-T Inattention												**.86*****	**.51*****	**.40*****	**-.30***	**-.37****
n =												119	77	77	63	63
13. SWAN-T Hyperactivity													**.33****	**.39*****	**-.34****	**-.36****
n =													77	77	63	63
14. SWAN-P Inattention														**.65*****	-.05	-.12
n =														78	41	41
15. SWAN-P Hyperactivity															-.05	-.13
n =															41	41
16. Examiner-rated behaviors during Vigilance task																**.71*****
n =																63
17. Examiner-rated behaviors during Visearch task																

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Weschler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

[4] Measure of auditory working-memory

[5] Measure of visual-spatial working-memory

Appendix F

Summary of regression analyses for variables predicting reading fluency (n = 96) and single-word reading (n = 54) with working-memory variables excluded

	Reading Models									
	DIBELS ORF median correct (n = 96)					WJ-III Letter- Word ID (n = 54)				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	12.77	4.94	**.15***	2.59	.01	1.36	1.33	.08	1.02	.31
Age	15.65	2.91	**.35*****	5.37	.00	4.42	.78	**.43*****	5.68	.00
CTOPP Elision[1,2]	2.37	.57	**.28*****	4.18	.00	.78	.16	**.39*****	4.89	.00
RAN-Letters[3]	-62.40	11.40	**-.38*****	-5.47	.00	-9.85	3.08	**-.28****	-3.20	.00
RAN-Colors[3]	-19.87	12.12	-.11	-1.64	.11	-3.79	3.33	.09	-1.14	.26
R^2			.69					.76		
Adj. R^2			.68					.74		
F			**40.45*****		.00			**30.89*****		.00

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix G

Summary of regression analyses for variables predicting reading fluency (n = 96) and single-word reading (n = 54) with working-memory variables included

	Reading Models									
	DIBELS ORF median correct (n = 96)					WJ-III Letter- Word ID (n = 54)				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	15.34	7.13	**.19***	2.15	.04	1.15	1.45	.06	.79	.43
Age	8.83	4.32	**.19***	2.05	.05	4.03	.87	**.40*****	4.61	.00
CTOPP Elision[1,2]	2.33	.80	**.25****	2.89	.01	.68	.16	**.35*****	4.17	.00
Digit Span forward[1,4]	.81	2.26	.04	.36	.72	.16	.46	.03	.35	.73
Digit Span backward[1,4]	3.10	3.07	.09	1.01	.32	.71	.62	.10	1.14	.26
Finger Windows forward[1,5]	-.33	1.32	-.03	-.25	.81	-.05	.27	-.02	-.18	.86
Finger Windows backward[1,5]	.96	.91	.10	1.05	.30	.05	.19	.02	.25	.80
RAN-Letters[3]	-73.24	16.60	**-.45*****	-4.41	.00	-9.46	3.36	**-.27****	-2.81	.01
RAN-Colors[3]	-24.05	16.89	-.13	-1.43	.16	-5.59	3.42	-.14	-1.63	.11
R^2			.76					.79		
Adj. R^2			.72					.75		
F			**15.49*****		.00			**17.96*****		.00

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.
[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Appendix H

Summary of regression analyses for variables predicting teacher-rated ADHD-symptoms with working-memory variables excluded (n = 93)

	Teacher-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	10.20	2.58	**.39*****	3.96	.00	8.50	2.39	**.37****	3.55	.00
Age	.22	1.54	.02	.14	.89	1.80	1.43	.14	1.26	.21
CTOPP Elision[1,2]	.56	.30	.21	1.89	.06	.32	.28	.13	1.15	.26
RAN-Letters[3]	-3.26	5.95	-.06	-.55	.59	.94	5.53	.02	.17	.87
RAN-Colors[3]	-4.82	6.23	-.08	-.77	.44	2.11	5.79	.04	.36	.72
R^2			.22					.15		
Adj. R^2			.17					.10		
F			**4.85****		.00			**3.12***		.01

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix I

Summary of regression analyses for variables predicting teacher-rated ADHD-symptoms with working-memory variables included (n = 53)

	Teacher-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	12.32	3.93	**.40****	3.14	.00	10.78	3.72	**.41****	2.89	.01
Age	-3.22	2.38	-.19	-1.35	.18	-.53	2.25	-.04	-.23	.82
CTOPP Elision[1,2]	.71	.44	.21	1.60	.12	.62	.42	.22	1.49	.14
Digit Span Forward[1,4]	.94	1.25	.11	.75	.46	.67	1.18	.09	.57	.58
Digit Span Backward[1,4]	3.73	1.69	**.30***	2.21	.03	2.26	1.60	.21	1.41	.17
Finger Windows Forward[1,5]	.61	.73	.13	.84	.40	.27	.69	.07	.39	.70
Finger Windows Backward[1,5]	-.01	.50	.00	-.02	.99	-.21	.48	-.07	-.44	.66
RAN-Letters[3]	.16	9.15	.00	.02	.99	-2.48	8.67	-.05	-.29	.78
RAN-Colors[3]	-9.77	9.30	-.14	-1.05	.30	1.19	8.81	.02	.14	.89
R^2			.47					.35		
Adj. R^2			.36					.21		
F			**4.25****		.00			**2.55***		.02

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.
[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Appendix J

Summary of regression analyses for variables predicting parent-rated ADHD-symptoms with working-memory variables excluded (n = 66)

	Parent-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	3.53	2.30	.19	1.54	.13	4.69	2.20	**.27** *	2.13	.04
Age	-2.25	1.44	-.21	-1.56	.12	.79	1.38	.08	.58	.57
CTOPP Elision[1,2]	.35	.27	.19	1.28	.21	.15	.26	.09	.58	.57
RAN-Letters[3]	1.63	5.31	.05	.31	.76	6.07	5.08	.18	1.20	.24
RAN-Colors[3]	-9.98	5.84	-.25	-1.71	.09	-.14	5.59	-.00	-.03	.98
R^2			.12					.09		
Adj. R^2			.05					.01		
F			1.68		.15			1.19		.33

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix K

Summary of regression analyses for variables predicting parent-rated ADHD-symptoms with working-memory variables included (n = 36)

	Parent-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	2.13	3.89	.10	.55	.59	6.77	3.61	.34	1.88	.07
Age	-1.84	2.62	-.15	-.70	.49	3.68	2.43	.33	1.52	.14
CTOPP Elision[1,2]	-.05	.52	-.02	-.10	.92	-.22	.48	-.10	-.46	.65
Digit Span Forward[1,4]	1.53	1.41	.26	1.09	.29	.06	1.30	.01	.05	.97
Digit Span Backward[1,4]	.19	1.93	.02	.10	.92	-.84	1.78	-.11	-.47	.64
Finger Windows Forward[1,5]	-1.16	.89	-.32	-1.30	.20	-2.26	.82	**-.70***	-2.75	.01
Finger Windows Backward[1,5]	.77	.57	.31	1.35	.19	.79	.53	.34	1.50	.15
RAN-Letters[3]	-.62	9.78	-.02	-.06	.95	-8.82	9.06	-.24	-.97	.34
RAN-Colors[3]	-7.72	9.85	-.17	-.78	.44	8.12	9.13	.19	.89	.38
R^2			.30					.30		
Adj. R^2			.06					.06		
F			1.24		.31			1.26		.30

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.
[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Appendix L

Summary of regression analyses for variables predicting examiner-rated behaviors with working-memory variables excluded (n = 54)

	Examiner-rated behaviors during cognitive task models									
	Vigilance					Visearch				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	-3.94	2.96	-.06	-.40	.69	-.14	.23	-.09	-.63	.54
Age	-.09	.21	.10	.63	.53	-.04	.13	-.05	-.33	.74
CTOPP Elision[1,2]	.08	.13	-.14	-.92	.36	-.00	.03	-.02	-.16	.87
RAN-Letters[3]	-.02	.03	-.09	-.54	.60	-.21	.52	-.07	-.41	.69
RAN-Colors[3]	-.26	.49	**.38***	2.46	.02	1.37	.57	**.37***	2.42	.02
R^2			.16					.15		
Adj. R^2			.07					.07		
F			1.83		.13			1.77		.14

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix M

Summary of regression analyses for variables predicting examiner-rated behaviors with working-memory variables included (n = 53)

	Examiner-rated behaviors during cognitive task models									
	Vigilance					Visearch				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	-.17	.24	-.11	-.69	.49	-.17	.25	-.11	-.68	.50
Age	.03	.15	.04	.22	.83	-.09	.15	-.09	-.56	.58
CTOPP Elision[1,2]	-.03	.03	-.19	-1.19	.24	-.01	.03	-.08	-.50	.62
Digit Span Forward[1,4]	.11	.08	.26	1.45	.15	.08	.08	.18	1.03	.31
Digit Span Backward[1,4]	-.04	.10	-.06	-.36	.72	-.05	.11	-.08	-.47	.64
Finger Windows Forward[1,5]	-.03	.04	-.11	-.60	.55	-.03	.05	-.11	-.60	.55
Finger Windows Backward[1,5]	.02	.03	.10	.59	.56	.05	.03	.27	1.60	.12
RAN-Letters[3]	-.31	.56	-.10	-.55	.59	-.09	.59	-.03	-.15	.88
RAN-Colors[3]	1.38	.57	**.39***	2.42	.02	1.44	.60	**.38***	2.40	.02
R^2			.21					.23		
Adj. R^2			.05					.07		
F			1.27		.28			1.43		.20

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Linking Text: Manuscript 2 to Manuscript 3

Manuscript 3 reports a one-year longitudinal study using baseline RAN data to predict oral-reading fluency, reading-achievement scores, and teacher-rated behavior after one-year. It builds on the correlation results from Manuscript 2 by adding a longitudinal dimension. This study contributes to a deeper and more comprehensive understanding of the predictive relations among RAN performance, long-term academic outcomes of reading fluency, and teacher ratings of ADHD-symptoms.

We learned in Manuscript 2 that RAN tasks are differentially related to behavioral ADHD-symptoms (namely, inattention, hyperactivity, or impulsivity), with the RAN-Colors task correlating to experimenter-rated behaviors, RAN-Colors errors and self-corrections correlating to teacher-rated inattention, hyperactivity, and impulsivity, and with RAN-Letters task time, errors, and self-corrections associated with measures of oral-reading fluency and single-word reading outcomes, when simultaneously assessed. Slower rapid naming of letters was associated with poorer reading fluency and single-word reading scores. Slower rapid naming of colors was associated with examiner ratings, but not teacher-rated or parent-rated symptoms of inattention, hyperactivity, and impulsivity, but errors and self-corrections were associated with teacher ratings.

Manuscript 3 is situated within a developmental framework that draws upon constructs from educational and cognitive psychology, and seeks to answer questions regarding the use of RAN, reading-assessment measures, and behavioral indicators of inattention and hyperactivity or impulsivity one-year after initial administration. Because it follows directly from the extensive literature review regarding the RAN double dissociation hypothesis as well as related measures of interest, Manuscript 3 does not contain an extensive literature review. Rather, the literature addressed in this second manuscript focused more on specific research about longitudinal studies of RAN and its relations to reading development in the early grades and symptoms of ADHD (inattention, hyperactivity, and impulsivity). Nevertheless, there will be some redundancy. As with Manuscript 2, a reduction will be undertaken after the dissertation has been defended in order to prepare the document for journal submission.

Manuscript 3 provides evidence for whether the predictive value of the RAN tasks persists a year later. It is important in educational practice to have a sense of the "shelf life" of predictive measures as well as ecological validity. How well do basic reading indicators (i.e., RAN-Colors, RAN-Letters, and phonological processing as measured by Elision) correlate with reading measures (i.e., DIBELS, Letter Word Identification, Reading Fluency), cognitive measures of attention (i.e., working memory) and ratings of ADHD-symptoms after a period of one-year?

Manuscript 3

Looking through the Crystal Ball One-Year Later: Letter-RAN Predictions of Reading Fluency and Color-RAN Predictions of Attention Symptoms

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Abstract

The current study examined the interrelations among rapid automatized naming (RAN), reading skills, and the behavioral symptoms of inattention, hyperactivity, and impulsivity among typically developing children in order to investigate the possibly doubly dissociative relation of RAN in reading and attention skills in a longitudinal design. Ninety-six students, 6 to 9 years old, completed continuous RAN measures consisting of two stimuli (letter and color) at baseline, and reading tasks (two measures of reading fluency and single-word reading) one-year later. Teacher-rated ADHD-symptoms and parent-rated ADHD-symptoms were also collected one-year later. Individual regression analyses revealed that RAN tasks measured at baseline were differentially predictive of behavioral ADHD-symptoms and reading outcomes. Slower rapid naming of letters predicted poorer reading fluency and single-word reading scores. Slower rapid naming of colors predicted lower scores on oral-reading fluency, silent-reading fluency, and teacher-rated symptoms of inattention. Age and sex were also significant predictors of the outcome variables. Baseline working-memory measures were not predictive of reading and ADHD-symptom variables. Furthermore, making self-corrections on RAN-Colors was associated with teacher ratings of inattention, hyperactivity, and impulsivity, whereas making errors on RAN-Letters was associated with passage oral-reading fluency only. The study confirmed a double dissociation of the RAN tasks in reading outcomes and attention skills in typically developing children after one-year.

Keywords: Reading; rapid automatized naming; fluency, attention, attention deficit/hyperactivity disorder

Looking through the Crystal Ball One-Year Later: Letter-RAN Predictions of Reading Fluency and Color-RAN Predictions of Attention Symptoms

Rapid automatized naming (RAN) predicts a variety of reading abilities including word identification (e.g., Bowers, Steffy, & Tate, 1988; Bowey, Storey, & Ferguson, 2004; Compton, 2003; Mann, 1984; Meyer, Wood, Hart, & Felton, 1998; Miller et al., 2006; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Torgesen, Wagner, Simmons, & Laughon, 1990) and reading fluency (e.g., Georgiou, Parrila & Kirby, 2006; Katzir et al., 2006; Savage & Frederickson, 2005; Schatschneider et al., 2002). Some studies have found relations between RAN performance and reading comprehension (e.g., Katzir et al., 2006; Murphy, Pollatsek, & Well, 1988) and spelling (Plaza & Cohen, 2004), but others have not (e.g., Allor, 2002; Meyer et al., 1998). Converging evidence indicates that alphanumeric RAN performance is a reliable indicator of certain reading skills such as single-word reading and reading-fluency performance.

Performance on RAN tasks has been shown to be a useful clinical tool for probing reading performance both concurrently (Plaza & Cohen, 2003; Wolf & Bowers, 1999) and longitudinally (Kirby, Parrila, & Pfeiffer, 2003; Schatschneider et al., 2004). For example, Plaza and Cohen (2003) examined 267 French-speaking first-grade children on tasks assessing phonological processing, syntactic awareness, and naming speed. Letter-naming speed was one of three separate predictors of reading and spelling performance (including phonological processing and syntactic awareness--the understanding of grammar and the way words are put together to form phrases, clauses, or sentences in written language).

RAN has also been shown to be powerful indicator of reading performance longitudinally (e.g., Catts, 1993; Kirby et al., 2003; Landerl & Wimmer, 2008; Schatschneider et al., 2004;

Wolf, Bally, & Morris, 1986). Studies of early reading development have identified rapid naming in kindergarten as a major predictor--along with phonological awareness--of fourth- and seventh-grade reading skill (Badian, Duffy, Als, & McAnulty, 1991; Wolf et al., 1986; Wolf & Obregón, 1992). Kindergarten measures of RAN speed were significant predictors of word-reading ability for children in first and second grade (Catts, 1993). Longitudinal studies have also revealed an interaction between age and RAN type. For children entering first and second grades, nonalphanumeric RAN (N-RAN) stimuli lost their predictive capacity for word-reading abilities, but alphanumeric (A-RAN) stimuli continued to predict word-reading abilities (Wolf et al., 1986). In a group of 115 German students, the strongest specific predictor of reading fluency in grade 8 was RAN-Objects assessed in grade 1, over other prediction measures such as letter knowledge, phonological short-term memory, phonological awareness, and nonverbal IQ (Landerl & Wimmer, 2008). Kirby et al. (2003) determined that individual differences in RAN-Colors and Objects speed measured on 79 children in senior kindergarten were still moderately associated with reading success five years later, despite controlling for initial general mental ability and letter knowledge. Measures of letter name and letter sound knowledge, RAN-Letters and Objects, and phonological awareness assessed in kindergarten were good predictors of multiple reading outcomes in 945 American children in grades 1 and 2 (Schatschneider et al., 2004). RAN's relations to sight-word reading was reviewed in a longitudinal investigation that found that nonalphanumeric RAN performance in prereaders predicted later reading speed and subsequent alphanumeric RAN performance (Lervåg & Hulme, 2009). The relations between RAN tasks and reading ability appear to change as higher-order reading skills become more important. A significant relation between performance on the RAN tasks and reading comprehension was found in several longitudinal studies with this relation weakening as participants age (Badian, 1998; Catts, 1993; Wolf et al., 1986).

There is also some evidence that the type of stimuli used for the RAN task may be particular to specific types of developmental issues such as reading difficulties and behavioral symptoms of classroom inattention, hyperactivity, and impulsivity. The use of RAN tasks may be beneficial for differentiating between problems of reading and attention or hyperactivity, especially because these problems often co-occur in clinical populations (e.g., August & Garfinkel, 1990; Dykman & Ackerman, 1991). Estimates of the prevalence of children with attention-deficit/hyperactivity disorder (ADHD) with a comorbid specific learning disorder in reading (SLDR) has been found to range from 15% to 44% (Mayes & Calhoun, 2006), or about one-third (DuPaul & Stoner, 2003), or 26-50% (Holborow & Berry, 1986; Lambert & Sandoval, 1980).

In Leung, Rogers, and Stringer (2014) [Manuscript 2], we found evidence to support two contrasting patterns of group differences between attention-related difficulties and reading difficulties based on RAN performance type stimuli: (a) Typical and students with ADHD perform similarly in alphanumeric RAN performance but differ on nonalphanumeric N-RAN tasks, and (b) typical and students with reading disorders are similar in N-RAN performance but differ on alphanumeric A-RAN tasks. Stringer, Toplak, & Stanovich (2004) referred to this as the *RAN double dissociation*.

In our cross-sectional, exploratory study of 96 students 6 to 9 years old, RAN-Letters total time was the only significant predictor of reading fluency and single-word reading, after controlling for children's sex, age, phonological processing skill, and working memory. However, RAN-Colors total time predicted examiner ratings of behaviors during cognitive attention tasks after controlling for child's sex, age, phonological processing skill, and working memory. Furthermore, errors on RAN-Colors were associated teacher ratings of hyperactivity or impulsivity from the *Strengths and Weaknesses of ADHD-Symptoms and Normal Behavior Scale* (SWAN; Swanson et al., 2006), and self-corrections on RAN-Colors were associated with passage oral reading fluency, teacher ratings of inattention, hyperactivity, or impulsivity. Errors and self-corrections made on RAN-Letters were associated with reading outcomes but not attention measures. Results supported a double dissociation of the RAN tasks in reading outcomes and attention skills in typically developing children. These relations were also generally sustained even when extreme cases were removed.

Very few studies to date have explored the problem of year-long predictive validity of RAN measures in the context of reading and ADHD-symptoms. Although previous research has identified contemporary associations between cognitive deficits and symptom phenotypes in ADHD, no studies have as yet attempted to identify direction of effect (Arnett et al., 2012). Arnett et al. examined competing hypotheses about longitudinal associations between rapid naming speed and symptoms of inattention in children. They tested 1506 school-age twins from Australia and the U.S. for inattention, hyperactivity, impulsivity, and rapid naming speed at three and four time points, respectively. Symptom severity of inattention from kindergarten to grade 4 was consistently predicted by previous rapid naming, over and above auto-regressive and correlational associations in the model. They also found that inattention symptoms have a small but significant predictive effect on subsequent rapid naming. Their findings supported a reciprocal relationship between naming speed and ADHD inattentive symptoms. The use of RAN tasks within the context of ADHD to explore differentiation between learning difficulties related to attention or basic processes in reading appears to be in its infancy and could prove to be a promising area rich in research opportunities.

Purpose

The goal of this study was to further explore a RAN double dissociation hypothesis wherein two main relations are proposed to exist: performance on continuous nonalphanumeric RAN-Colors is related to attentional processes and performance on continuous alphanumeric RAN-Letters is related to reading skills. We wished to examine RAN-Letters and RAN-Colors data as predictors of oral-reading fluency, single-word reading, and ADHD-symptoms in a one-year longitudinal, exploratory study. This study explored potential relations among RAN performance, ADHD-symptom ratings, and academic reading fluency outcomes in a sample of typical school children.

Specifically, we asked how well do basic reading indicators (RAN-Letters, RAN-Colors, and phonological awareness as measured by Elision) at baseline correlate with reading outcomes (DIBELS Oral Reading Fluency (ORF), Letter-Word Identification (ID), Reading Fluency), and attention outcomes (working memory, teacher ratings of inattention or hyperactivity or impulsivity) when tested after a period of one-year?

We anticipated that poor performance (longer total time, greater frequency of errors and self-corrections) on continuous nonalphanumeric RAN-Colors at baseline would be predictive of attention and particularly ADHD-symptoms (inattention or hyperactivity or impulsivity) after one-year, and poor performance on continuous alphanumeric RAN-Letters (longer total time, greater frequency of errors) at baseline would be related to poor reading skills and particularly single-word reading and oral-reading fluency rate and accuracy after one year. Other variables that may account for some variance among the relations between RAN, attention, and reading skills, may include phonological awareness, vocabulary as a measure of general ability, age, sex, and working memory.

Methodology

For a detailed description of the methods, please refer to Leung et al. (2014a) [Manuscript 2].

Participants

The total sample consisted of 96 students as described in Leung et al. (2014a) [Manuscript 2]. There was zero attrition. This manuscript uses the term "typically developing" throughout to describe the participating sample in reference or comparison to a non-referred or non-clinical sample of students. However, some of these participants may or may not be "typically developing" in the truest sense. Rather, these children are likely representative of what might be considered a typical school sample of children in the regular classroom setting, particularly in the early grades prior to possible later identification and intensive support for those children who may benefit.

Measures

We used measures from the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999) that were administered to all participants at baseline: RAN-Letters, RAN-Colors, and Elision (as a measure of phonological processing). Elision measures the ability to remove phonological segments from spoken words to form other words. Participants were tested in the spring of 2010 (May to June).

Approximately one-year later (April to May of 2011), all participants were seen again and administered a new set of measures. Participants were administered their grade appropriate Oral Reading Fluency subtest from the *Dynamic Indicators of Basic Early Reading Skills* (DIBELS; Good & Kaminski, 2002), as well as two subtests from the *Woodcock-Johnson-III*

Tests of Achievement with Normative Update (WJ-III; Woodcock, McGrew, & Mather, 2001): Letter-Word Identification and Reading Fluency. The latter two measures were intended to assess norm-referenced reading achievement. The Letter-Word Identification subtest assesses single-word reading skills. This subtest has been used by other researchers as a measure of early reading ability (Wood & Felton, 1994; Rabiner & Coie, 2000). The number of items answered correctly on this subtest was converted to a standard score and served as one measure of early reading achievement. The other measure, Reading Fluency, was administered in a group format with approximately 10 children per group. Students were seated in individual desks and instructions were given by the examiner to the whole group. They were asked to read printed statements rapidly and respond with true or false (yes or no), under a three-minute timed condition with a pencil with no eraser. Students could ask for clarification and were observed carefully to ensure that they filled in practice items correctly, for example, "Some apples are green." Reading Fluency is a speeded semantic-decision task that requires reading ability. However, this test also requires a store of general information to be able to confirm the accuracy of a statement that is read. Consequently, this test measures automaticity of access to words and their meanings in the mental lexicon as well as simple sentence comprehension (Wendling, Schrank, & Schmitt, 2007), a task that could potentially be predicted by both alphanumeric or nonalphanumeric performance because it appears to combine features of automatic orthographic knowledge and retrieval, semantic processes, and the required use of executive functions (e.g., visual scanning, coordination of responses, inhibition, shifting set).

The WJ-III Tests of Achievement (WJ-III) is a standardized task battery that can be used throughout the academic trajectory and taps both reading and mathematics abilities. Test-retest reliability of the Broad Reading scale consisting of combined scores of each of the reading measures from the WJ-III (Letter-Word Identification, Reading Fluency, and Passage Comprehension which was not administered in this study) is excellent (0.93) and the technical manual also provides strong evidence for construct validity of this scale. Correlations between the WJ-III Broad Reading scale and similar scales of other published, norm-referenced achievement tests range from 0.67 to 0.76 (McGrew & Woodcock, 2001; Therrien, Wickstrom, & Jones, 2006). The median test reliability coefficient was .90, and the standard error of measurement was 4.79 for the Reading Fluency subtest (McGrew, & Woodcock, 2001).

Letter-Word Identification took approximately three to five minutes to complete, and Reading Fluency took approximately five minutes to complete.

Reading achievement measures such as Reading Fluency, Letter-Word Identification, and the DIBELS are advantageous in a longitudinal school-based study, because the assessment is simple and brief (typically three to five minutes), designed for comparison to same age peers or repeated measurement (in the case of the DIBELS), generally sensitive to short-term as well as longer-term gain in academic skills, and linked to curriculum (especially DIBELS).

Screening for ADHD-Symptoms. The teacher form of the SWAN-T (Swanson et al., 2006) was readministered to each participant's current teacher to screen participants for classroom ADHD-symptoms and the selection of a subsample of students to receive follow-up, in-depth measures. After screening the 96 children, the SWAN-T data were again examined in order to stratify the sample. Students scoring in the high, middle, and low ranges of the SWAN-T were selected for additional testing. Students were selected based on a visual inspection of data to identify natural breaks in the data range of the total SWAN-T score that allowed three groups to be designated. That is, after the teachers had submitted their completed questionnaires, the psychologist post-doctoral fellow leading the project chose participants with approximations of high, medium, and low average total scores on the SWAN-T. For example, students with 14 to 18 scores of 0 (i.e., "far below average") or 6 (i.e., "far above average") out of 18 items would likely be picked to represent "low" or "high" attenders. These cut-offs were arbitrarily created by visually scanning the received questionnaires and determining that "low" or "high" attenders tended to have clusters of scores at either the low end (around 0) or high (around 6) end of the rating scale.

A subset of participants (n = 41, 54% male) participated in a second phase of more in-depth assessment. The correlation between baseline phase two students and year two phase two students was quite high, $r(96) = .71$, $p < .001$. The same auditory (Digit Span) and visual-spatial (Finger Windows) working-memory measures (as described in Leung, Stringer, & Rogers, 2014--Manuscript 2) were given to the phase two subset of students.

Missing data. Corrective action was taken on two teacher SWAN forms and ten parent forms to address missing item-responses. The issue was resolved by replacing missing values with the rounded average of the individual's score on the remaining eight items within the subscale. Eleven of the twelve forms were missing one response; the remaining one had two missing items. The pattern of missing data appeared to be random, although more missing items were noted from the Inattention subscale (10) than from the Hyperactivity and Impulsivity subscale (2).

Data-Analysis Procedures

Distributions of all variables were examined, and log transformations were used for the variables showing excessive skewness (i.e., RAN-Letters total time, and RAN-Color total time). Preliminary analyses were performed to confirm scale reliability in the sample and to ensure that characteristics of the measures did not violate statistical test assumptions. Descriptive statistics were performed on all main variables of interest. Correlations were calculated to investigate the relation between RAN, reading, and attention measures. Methodological considerations justified keeping inattentive and hyperactive and impulsive subscales on the teacher and parent ratings separate in all analyses, although they were highly correlated with each other. Paired-sample *t* tests were conducted to compare baseline and year-one repeated measures of SWAN ratings, reading measures, and working memory. Hierarchical regression analyses were conducted to examine the relations between RAN performance, reading skills, and ratings of attention, while controlling for variables such as working memory and phonological processing. Separate multiple regression analyses were applied to determine the predictive relation of RAN measures on reading and attention ratings. Independent *t* tests and Cohen's *d* effect size statistics were calculated to investigate the significance of differences between total errors and self-corrections on the RAN-Letters and RAN-Colors tasks on reading and attention rating outcomes.

Results

Test-Retest Reliability between Baseline and One-Year

An intercorrelation matrix of the attention ratings provided by teachers and parents at year one were presented in relation to ratings provided by the previous teacher and parent at baseline (Table 8). (Tables are currently numbered continuously through the full thesis; they will be renumbered when publications versions of each paper are prepared.)

Table 8

Intercorrelation matrix of ADHD-symptom ratings between baseline and one-year

		2	3	4	5	6	7	8
1. SWAN-T Inattention -- 1 Year	*r* =	**.82*****	**.56*****	**.44*****	**.80*****	**.70*****	**.42*****	**.30***
	p =	.00	.00	.00	.00	.00	.00	.02
	n =	96	66	66	93	93	66	66
2. SWAN-T Hyperactivity and Impulsivity -- 1 Year	*r* =		**.40****	**.45*****	**.65*****	**.68*****	**.25***	**.26***
	p =		.00	.00	.00	.00	.05	.03
	n =		66	66	93	93	66	66
3. SWAN-P Inattention -- 1 Year	*r* =			**.68*****	**.35****	**.26***	**.72*****	**.47*****
	p =			.00	.00	.03	.00	.00
	n =			66	65	65	51	51
4. SWAN-P Hyperactivity and Impulsivity -- 1 Year	*r* =				**.42*****	**.40****	**.52****	**.62****
	p =				.00	.00	.00	.00
	n =				65	65	51	51
5. SWAN-T Inattention -- Baseline	*r* =					**.88****	**.50*****	**.37****
	p =					.00	.00	.00
	n =					93	65	65

6. SWAN-T Hyperactivity and Impulsivity -- Baseline	r =						**.29**[*]	**.35**[**]
	p =						.02	.00
	n =						65	65
7. SWAN-P Inattention -- Baseline	r =							**.63**[**]
	p =							.00
	n =							66
8. SWAN-P Hyperactivity and Impulsivity -- Baseline	r =							
	p =							
	n =							

Note. SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (T = Teacher or P = Parent form).

[*] $p < .05$; [**] $p < .01$; [***] $p < .001$.

p and r values have been rounded to the nearest hundredth decimal place.

In general, all teacher ratings significantly correlated with previous teacher ratings and parent ratings in the current and previous year, indicating strong test-retest reliability from baseline to one year later. All parent ratings significantly correlated with previous and current teacher ratings, as well as their own ratings in previous year. The strongest correlations existed between subscales on the teacher ratings for both baseline, $r(93) = .88$, $p < .001$, and one-year later, $r(96) = .82$, $p < .001$. There was also strong agreement on inattentive symptoms from baseline to year one later for teachers, $r(93) = .80$, $p < .001$, and slightly less so for hyperactive and impulsive symptoms, $r(93) = .68$, $p < .001$. Parent ratings also correlated from baseline to one-year for both inattention, $r(51) = .72$, $p < .001$, and hyperactivity and impulsivity, $r(51) = .62$, $p < .001$. Weaker correlations were found between teacher ratings of students on hyperactivity and impulsivity symptoms at year one and parent ratings of inattention, $r(66) = .25$, $p < .05$, and hyperactivity and impulsivity at baseline, $r(66) = .26$, $p < .05$.

A series of paired-samples *t* tests were conducted to compare baseline and one year SWAN ratings for teachers and parents. On teacher ratings of inattention, there was no significant difference between scores at baseline ($M = 30.43$, $SD = 13.05$) and one year ($M = 30.90$, $SD = 12.18$); $t(92) = -.57$, $p = .57$. On teacher ratings of hyperactivity or impulsivity, there was no significant difference between scores at baseline ($M = 32.90$, $SD = 11.64$) and one year ($M = 32.96$, $SD = 11.89$); $t(92) = -.06$, $p = .96$. On parent ratings of inattention, there was no significant difference between scores at baseline ($M = 35.30$, $SD = 8.93$) and one year ($M = 34.86$, $SD = 8.92$); $t(50) = .47$, $p = .64$. On parent ratings of hyperactivity or impulsivity, there was no significant difference between scores at baseline ($M = 33.33$, $SD = 8.35$) and one year ($M = 32.55$, $SD = 8.97$); $t(50) = .74$, $p = .46$. Teacher and parent ratings did not significantly change from baseline to one year later, indicating that ADHD-symptoms remained fairly stable during this time period.

Descriptive Statistics

Descriptive statistics of the one-year experimental measures of inattention, RAN, and reading measures are presented in Table 9.

Table 9

One-year descriptive statistics

Variable/measure	*n*	*Mean*	*SD*	*Range*
Age at one-year	96	8.69	.91	7.07 to 10.06
Grade	96	2.96	.81	2 to 4
Digit Span Total[b]	43	9.79 (Average)	2.91	5 to 15 (Borderline to Superior)
Finger Windows Forward[b]	43	9.98 (Average)	2.50	3 to 15 (Moderately Impaired to Superior)
Reading Measures				
DIBELS Oral Reading Fluency median words correct	96	102.26	32.47	19 to 208
WJ-III Letter-Word ID raw score	96	47.35	6.83	28 to 63
WJ-III Letter-Word ID[a]	96	103.85 (Average)	9.14	78 to 123 (Borderline to Superior)
WJ-III Reading Fluency raw score	96	37.76	11.32	10 to 76
WJ-III Reading Fluency[a]	96	100.68 (Average)	10.05	73 to 131 (Borderline to Very Superior)
SWAN-T				
Inattention[c]	96	30.99	12.13	5 to 54
Hyperactivity and Impulsivity[c]	96	33.00	11.87	5 to 54
Total score	96	63.99	22.88	12 to 108
SWAN-P				
Inattention[c]	66	33.71	8.52	17 to 52

Hyperactivity and Impulsivity[c]	66	32.08	8.45	11 to 52
Total score	66	65.79	15.56	39 to 101

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN-T/P = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher/Parent form).

[a]Scores from these measures are based on a standard score, mean = 100, SD = ± 15.

[b]Scores from these measures are based on a scaled score, mean = 10, SD = ± 3.

[c]Scores from these measures are based on a raw score: 0 (Far below average) to 6 (Far above average).

[d]Scores from these measures are based on a raw score: 0 (Not at all) to 3 (Very much).

In general, children in this sample performed in the average range on all measures as expected. The results reported in Table 9 suggest that the tasks had adequate psychometric characteristics for the age ranges included in this study. Values were in the acceptable range, and performance was free from floor and ceiling effects on all tasks.

Relations among Primary Variables of Interest

An intercorrelation matrix of the primary variables of interest was also constructed (Table 10). A summary of the major intercorrelations is presented later in Table 15.

Table 10

Full intercorrelation matrix of variables at one-year

		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Sex	*r* =	.04	-.16	-.11	-.14	.17	.04	.20	.11	.12	.17	.01	**.32****	**.34****	.06	.21
	p =	.68	.11	.29	.18	.10	.67	.05	.47	.44	.28	.97	.00	.00	.63	.10
	n =	96	96	96	96	96	96	96	43	43	43	43	96	96	66	66
2. Age[3]	*r* =		**.33****	**-.31****	**-.28****	**.40*****	**.53*****	**.58*****	**.49****	.29	.18	**.40****	.07	.06	-.02	-.03
	p =		.00	.00	.01	.00	.00	.00	.00	.06	.24	.01	.47	.54	.89	.80
	n =		96	96	96	96	96	96	43	43	43	43	96	96	66	66
3. CTOPP Elision[1,2,4]	*r* =			**-.37*****	**-.24***	**.49*****	**.60*****	**.43*****	.26	.30	.17	**.46****	.16	.03	.17	.04
	p =			.00	.02	.00	.00	.00	.09	.05	.28	.00	.11	.81	.16	.75
	n =			96	96	96	96	96	43	43	43	43	96	96	66	66
4. CTOPP RAN-Letters time[2,5]	*r* =				**.45*****	**-.61*****	**-.52*****	**-.48*****	**-.32***	-.20	-.10	**-.32***	-.17	-.10	-.05	-.12
	p =				.00	.00	.00	.00	.03	.20	.54	.04	.10	.33	.70	.32
	n =				96	96	96	96	43	43	43	43	96	96	66	66
5. CTOPP RAN-Colors time[2,5]	*r* =					**-.47*****	**-.38*****	**-.43*****	**-.34***	**-.35***	-.16	**-.32***	**-.30****	-.16	-.22	-.19
	p =					.00	.00	.00	.03	.02	.30	.04	.00	.12	.07	.13
	n =					96	96	96	43	43	43	43	96	96	66	66

6. DIBELS ORF median correct[3]	r =						**.76*****	**.81*****	**.34***	**.43****	**.36***	**.47****	**.45*****	**.27****	.17	.24
	p =						.00	.00	.03	.00	.02	.00	.00	.01	.18	.05
	n =						96	96	43	43	43	43	96	96	66	66
7. WJ-III Letter Word ID[1,3]	r =							**.68*****	**.37***	**.39****	.29	**.40****	**.34****	**.23***	.17	.15
	p =							.00	.01	.01	.06	.01	.00	.03	.18	.22
	n =							96	43	43	43	43	96	96	66	66
8. WJ-III Reading Fluency[1,3]	r =								**.46****	**.51*****	**.49****	**.58*****	**.44*****	**.27****	.17	**.28***
	p =								.00	.00	.00	.00	.00	.01	.18	.03
	n =								43	43	43	43	96	96	66	66
9. WISC-III Digit Span forward[1,3,6]	r =									**.41****	.11	.16	.23	.09	.17	.00
	p =									.01	.48	.32	.13	.55	.40	.10
	n =									43	43	43	43	43	27	27
10. WISC-III Digit Span backward[1,3,6]	r =										.26	**.34***	**.31***	**.32***	.17	.23
	p =										.10	.03	.04	.04	.40	.25
	n =										43	43	43	43	27	27
11. WRAML Finger Windows forward[1,3,7]	r =											**.43****	**.42****	**.37***	.10	.15
	p =											.00	.01	.02	.64	.45
	n =											43	43	43	27	27

12. WRAML Finger Windows backward[1,3,7]	*r* =													.24	.19	-.01	.17
	p =													.13	.23	.97	.39
	n =													43	43	27	27
13. SWAN-T Inattention[3]	*r* =														**.82*****	**.56*****	**.44*****
	p =														.00	.00	.00
	n =														96	66	66
14. SWAN-T Hyperactivity and Impulsivity[3]	*r* =															**.40****	**.45*****
	p =															.00	.00
	n =															66	66
15. SWAN-P Inattention[3]	*r* =																**.68*****
	p =																.00
	n =																66
16. SWAN-P Hyperactivity and Impulsivity[3]																	

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Weschler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$ (two-tailed).

p and *r* values are rounded to the nearest hundredth decimal place.

[1] Raw score

[2] Baseline Measure

[3] 12-month

[4] Measure of phonological processing

[5] Total time

[6] Measure of auditory working-memory

[7] Measure of visual-spatial working-memory

Sex differences. Being female significantly and moderately correlated positively with 12-month teacher ratings of attention (higher ratings mean positive behaviors), $r(96) = .32$, $p < .01$ (meaning that boys were rated as less attentive than girls), and hyperactive and impulsive control, $r(96) = .34$, $p < .01$. No other sex differences were found.

Age. The age of participants was significantly correlated with scores on most performance measures (that is, phonological processing, some working-memory measures, and all reading measures). There was no correlation between age and SWAN ratings by either the teacher or parent.

Phonological processing (Elision). Elision, a subtest of the CTOPP, correlated positively with all 12-month reading measures: passage oral reading fluency, $r(96) = .49$, $p < .001$, single-word reading, $r(96) = .60$, $p < .001$, Reading Fluency, $r(96) = .43$, $p < .001$, and also 12-month Finger Windows backward, $r(96) = .46$, $p < .001$. Higher scores on phonological processing were associated with higher scores in oral reading fluency, single-word reading, norm-referenced silent reading fluency, and backward visual-spatial working-memory.

RAN.

Letters. RAN-Letters total time was negatively correlated with one-year passage oral reading fluency, $r(96) = -.61$, $p < .001$, single-word reading, $r(96) = -.52$, $p < .001$, Reading Fluency, $r(96) = -.48$, $p < .001$, forward Digit Span, $r(43) = -.32$, $p < .05$, backward Finger Windows, $r(43) = -.32$, $p < .05$, meaning that students who were slower on the RAN-Letters task had lower scores in oral-reading fluency, norm-referenced single-word reading and reading fluency tasks, and some working-memory tasks, measured one-year after the initial assessment.

Colors. RAN-Colors total time was negatively correlated with passage oral-reading fluency, $r(96) = -.47$, $p < .001$, single-word reading, $r(96) = -.38$, $p < .001$, Reading Fluency, *r*(96) = -.43, $p < .001$, working-memory tasks (Digit Span forward, *r*(43) = -.34, $p < .05$, Digit Span backward, *r*(43) = -.35, $p < .05$, Finger Windows backward, *r*(43) = -.32, $p < .05$) and teacher-rated attention, *r*(96) = -.30, $p < .01$, meaning that longer times taken on the RAN-Colors task was associated with lower 12-month scores on reading measures, working memory, and teacher-rated attention scores.

Reading measures.

Passage oral-reading fluency (DIBELS Correct Median). Passage oral-reading fluency was positively correlated with all reading, working memory, and teacher ratings.

Single-word reading (Letter-Word Identification). Single-word reading was associated with age, phonological processing, RAN total time, auditory working-memory tasks, forward visual-spatial working-memory, and teacher-rated symptoms of ADHD.

Reading growth from baseline to one-year. Two paired-samples *t* tests were conducted to compare baseline and one-year reading measures. Median correct scores on grade-level oral reading fluency passages improved significantly from baseline (*M* = 82.97, *SD* = 40.56) to one year (*M* = 102.26, *SD* = 32.47); *t*(95) = -8.88, *p* = .00. Performance on Letter-Word Identification improved from baseline (*M* = 44.28, *SD* = 8.98) to one year (*M* = 47.44, *SD* = 7.17); *t*(53) = -5.44, *p* = .00.

Behavioral ADHD-symptom ratings.

Teacher-rated student ADHD-symptoms (SWAN-T). Inattentive behavior was significantly correlated with sex, *r*(96) = .32, $p < .01$, baseline RAN-Colors total time, *r*(96) = -.30, $p < .01$, 12-month reading outcomes, backward Digit Span, and forward Finger Windows. Hyperactive or impulsive behavior was significantly correlated with sex, *r*(96) = .34, $p < .01$, 12-month reading outcomes, backward Digit Span, and forward Finger Windows.

Parent-rated student ADHD-symptoms (SWAN-P). Parent-rated inattention was not significantly correlated with most performance measures. Parent-rated hyperactive behavior was significantly correlated with Reading Fluency, $r(66) = .28$, $p < .05$.

Working-memory measures on a subset of participants with high, low, and moderate levels of inattention.

Auditory working-memory (Digit Span). Digit Span forward was positively correlated with age, RAN-Letter time, RAN-Color time, reading outcomes, and Digit Span backward. Digit Span backward was correlated with RAN-Colors time, all reading outcomes, as well as most behavioral-ratings of ADHD, that is, teacher-rated inattention, hyperactivity, and impulsivity, and parent-rated inattention.

Visual-spatial working-memory (Finger Windows). Finger Windows forward was correlated with DIBELS and Reading Fluency, but not single-word reading, nor any other measures. Finger Windows backward was correlated with age, phonological processing, RAN-Letters and RAN-Colors times, all reading measures, Digit Span forward, as well as with teacher-rated inattention, hyperactive, and impulsive behavior.

The backward versions of working-memory tasks had stronger correlations with ADHD-ratings than did forward versions. Auditory working-memory (Digit Span) revealed a different correlational pattern than visual-spatial working-memory in general, and many were correlated with the 12-month reading and ADHD-ratings.

Test-retest reliability between baseline and one-year. An intercorrelation matrix of the working-memory measures at one-year were presented in relation to ratings provided by the previous teacher and parent at baseline (Table 11). Correlations from baseline to one-year on the working-memory measures ranged from $r = .30$ on Finger Windows forward to $r = .66$ on Digit Span forward ($p < .05$ to $p < .001$).

A series of paired-samples t tests were conducted to compare baseline and one-year working-memory variables. Performance on Digit Span forward did not significantly differ from baseline ($M = 7.83$, $SD = 1.80$) to one year ($M = 7.98$, $SD = 2.04$); $t(40) = -.61$, $p = .55$. Performance on Digit Span backward also did not significantly differ from baseline ($M = 3.78$, $SD = 1.24$) to one year ($M = 4.15$, $SD = 1.42$); $t(40) = -1.75$, $p = .09$. Performance scores on Finger Windows forward dropped from baseline ($M = 11.15$, $SD = 3.26$) to one year ($M = 9.85$, $SD = 3.90$); $t(40) = 2.18$, $p = .04$. Performance on Finger Windows backward improved from baseline ($M = 7.55$, $SD = 4.13$) to one year ($M = 9.93$, $SD = 3.93$); $t(39) = -4.13$, $p = .00$. Growth on measures of working memory appeared to be variable in this sample of children.

Table 11

Intercorrelation matrix of working-memory variables between baseline and one-year

		2	3	4	5	6	7	8
1. Digit Span Forward -- One-Year	*r* =	**.46*****	.20	**.28***	**.66*****	**.37****	**.42****	**.29***
	p =	.00	.11	.02	.00	.01	.00	.04
	n =	68	68	68	52	52	52	51
2. Digit Span Backward -- One-Year	*r* =	--	.23	**.41****	**.63*****	**.63*****	**.31***	**.59*****
	p =		.06	.00	.00	.00	.03	.00
	n =		68	68	52	52	52	51
3. Finger Windows Forward -- One-Year	*r* =		--	**.46*****	**.33***	**.28***	**.30***	**.38****
	p =			.00	.02	.05	.03	.01
	n =			68	52	52	52	51
4. Finger Windows Backward -- One-Year	*r* =			--	.22	**.29***	**.52*****	**.64*****
	p =				.13	.04	.00	.00
	n =				52	52	52	51
5. Digit Span Forward -- Baseline	*r* =				--	**.56*****	**.30***	**.35****
	p =					.00	.01	.01
	n =					65	65	64
6. Digit Span Backward -- Baseline	*r* =					--	**.27***	**.46*****
	p =						.03	.00
	n =						65	64
7. Finger Windows Forward -- Baseline	*r* =						--	**.57*****
	p =							.00
	n =							64
8. Finger Windows Backward -- Baseline								--

Relations among RAN, reading skills, and ADHD-symptom ratings. Results of the individual regression analyses (β) predicting reading fluency and attention ratings from RAN performance are presented in Table 12 (12a without working memory, 12b with baseline working-memory variables, and 12c with one-year working-memory variables). See Appendices R through Z for the complete regression models with detailed statistical values. Because there was no a priori evidence to indicate the relative importance of the variables, a simultaneous rather than stepwise entry of the variables was appropriate for the regression analyses.

Phonological processing and RAN-Letters total time significantly contributed to the variance on all reading tasks (passage oral-reading fluency, norm-referenced single-word reading, and silent-reading fluency), although the effect was stronger for oral-reading fluency and single-word reading. RAN-Colors total time at baseline was a significant predictor of 12-month oral-reading fluency, silent-reading fluency, and teacher ratings of inattention. Participants who took more time on RAN tasks were more likely to have lower reading scores. Age was also a significant predictor of performance on both norm-referenced single-word reading and reading fluency tasks (older children received higher scores). Sex was also a significant predictor of silent-reading fluency and teacher-rated ADHD-symptoms.

Table 12a

One-year individual linear regression models (working-memory measures excluded)--Beta coefficients

		Dependent Variables						
		Reading			Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms	
		DIBELS ORF median correct (n = 96)	WJ-III Letter-Word ID (n = 96)	WJ-III Reading Fluency (n = 96)	SWAN Inattention (n = 96)	SWAN Hyperactivity and Impulsivity (n = 96)	SWAN Inattention (n = 66)	SWAN Hyperactivity and Impulsivity (n = 66)
Predictor Variables	Sex	.15	.06	**.18***	**.33****	**.33****	.05	.17
	Age[1]	.14	**.29*****	**.40*****	-.06	.00	-.12	-.10
	CTOPP Elision[2,3,4]	**.30****	**.41*****	**.22***	.19	.05	.19	.03
	RAN-Letters[2,5]	**-.36*****	**-.23****	**-.18***	.03	.00	.07	-.07
	RAN-Colors[2,5]	**-.18***	-.10	**-.17***	**-.24***	-.10	-.21	-.14

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Measured at 12 months

[2] Measured at baseline

[3] Raw score

[4] Measure of phonological processing

[5] Total time

Table 12b

One-year individual regression models (baseline working-memory measures included)--Beta coefficients

			Dependent variables						
			Reading			Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms	
			DIBELS ORF median correct (n = 53)	WJ-III Letter-Word ID (n = 53)	WJ-III Reading Fluency (n = 53)	SWAN Inattention (n = 53)	SWAN Hyperactivity and Impulsivity (n = 53)	SWAN Inattention (n = 37)	SWAN Hyperactivity and Impulsivity (n = 37)
Predictor variables	Sex		.15	-.06	.12	**.40****	**.45****	.11	.29
	Age[1]		-.00	.16	.21	-.19	.06	-.24	-.05
	CTOPP Elision[2,3,4]		.16	**.36****	.18	.19	.17	.08	-.06
	Working memory	Digit Span forward[2,3,6]	.02	.11	.10	.15	-.04	.25	.08
		Digit Span backward[2,3,6]	.09	.05	.11	.19	.09	-.09	-.17
		Finger Windows forward[2,3,7]	-.05	-.04	.06	.07	-.03	-.05	-.11
		Finger Windows	.18	.10	.19	.04	.10	.06	.10

backward[2,3,7]							
RAN-Letters[2,5]	**-.40****	**-.28***	-.13	.04	-.00	-.14	-.24
RAN-Colors[2,5]	-.26	-.11	-.20	-.22	-.13	.02	.09

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Measured at 12 months

[2] Measured at baseline

[3] Raw score

[4] Measure of phonological processing

[5] Total time

[6] Measure of auditory working-memory

[7] Measure of visual-spatial working-memory

Table 12c

One-year individual regression models (12-month working-memory measures included)--Beta coefficients

			Dependent variables						
			Reading			Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms	
			DIBELS ORF median correct (n = 43)	WJ-III Letter-Word ID (n = 43)	WJ-III Reading Fluency (n = 43)	SWAN Inattention (n = 43)	SWAN Hyperactivity and Impulsivity (n = 43)	SWAN Inattention (n = 27)	SWAN Hyperactivity and Impulsivity (n = 27)
Predictor variables	Sex		.17	-.07	.15	**.56*****	**.59*****	**.55***	**.64****
	Age[1]		-.00	.16	.13	-.08	.07	-.28	-.43
	CTOPP Elision[2,3,4]		.10	**.33***	.16	.23	.18	.35	.20
	Working memory	Digit Span forward[1,3,6]	-.01	.03	.12	.06	-.18	.39	.24
		Digit Span backward[1,3,6]	.17	.15	.17	.08	.20	.04	.12
		Finger Windows forward[1,3,7]	.16	.17	**.25***	**.27***	.22	.09	-.06
		Finger Windows	.11	-.06	.18	-.03	-.10	-.08	.29

backward[1,3,7]							
RAN-Letters[2,5]	**-.49*****	**-.33***	-.21	-.00	-.05	.08	-.03
RAN-Colors[2,5]	-.13	-.05	-.05	-.10	-.06	.25	.24

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Measured at 12 months

[2] Measured at baseline

[3] Raw score

[4] Measure of phonological processing

[5] Total time

[6] Measure of auditory working-memory

[7] Measure of visual-spatial working-memory

Table 13a

One-year individual t tests on RAN-letters errors, reading measures, and attention ratings

	RAN-Letters					
	Non-error-makers *Mean (SD)*	Error-makers (Range = 1-3) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
12-month reading measures						
DIBELS ORF median correct	105.20 (30.72) *n* = 81	86.40 (37.94) *n* = 15	**2.10***	94	.04	0.60
WJ-III Letter-Word ID	47.91 (6.23) *n* = 81	44.33 (9.12) *n* = 15	1.46	16.50	.16	0.99
WJ-III Reading Fluency	38.60 (11.20) *n* = 81	33.20 (11.26) *n* = 15	1.72	94	.09	0.49
12-month attention measures						
SWAN-T Inattention	30.90 (12.10) *n* = 81	31.47 (12.72) *n* = 15	-.17	94	.87	-0.05
SWAN-T Hyperactivity and Impulsivity	33.20 (11.41) *n* = 81	31.93 (14.50) *n* = 15	.38	94	.71	0.11
SWAN-P Inattention	33.44 (8.12) *n* = 54	34.92 (10.45) *n* = 12	-.54	64	.59	-0.17
SWAN-P Hyperactivity and Impulsivity	31.83 (8.27) *n* = 54	33.17 (9.50) *n* = 12	-.49	64	.63	-0.16

Note. Standard deviations appear in parentheses next to means.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Effect size estimates: Small = <.20; medium = .50; large = >.80.

Table 13b

One-year individual t tests on RAN-letters self-corrections, reading measures, and attention ratings

	RAN-Letters					
	Non-self-correctors *Mean (SD)*	Self-correctors (Range = 1-2) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
12-month reading measures						
DIBELS ORF median correct	104.69 (32.84) *n* = 81	89.13 (27.76) *n* = 15	1.72	94	.09	0.49
WJ-III Letter-Word ID	47.84 (6.57) *n* = 81	44.73 (7.82) *n* = 15	1.63	94	.11	0.46
WJ-III Reading Fluency	38.14 (11.92) *n* = 81	35.73 (7.25) *n* = 15	.75	94	.45	0.21
12-month attention measures						
SWAN-T Inattention	31.10 (12.18) *n* = 81	30.40 (12.28) *n* = 15	.20	94	.84	0.06
SWAN-T Hyperactivity and Impulsivity	33.35 (11.78) *n* = 81	31.13 (12.60) *n* = 15	.66	94	.51	0.19
SWAN-P Inattention	33.96 (8.75) *n* = 54	32.58 (7.67) *n* = 12	.50	64	.62	0.16
SWAN-P Hyperactivity and Impulsivity	32.22 (8.46) *n* = 54	31.42 (8.73) *n* = 12	.30	64	.77	0.10

Note. Standard deviations appear in parentheses next to means.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Effect size estimates: Small = $<.20$; medium = .50; large = $>.80$.

Table 14a

One-year individual t tests on RAN-colors errors, reading measures, and attention ratings

	RAN-Colors					
	Non-error-makers *Mean (SD)*	Error-makers (Range = 1-2) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
12-month reading measures						
DIBELS ORF median correct	101.26 (33.44) *n* = 84	109.25 (24.54) *n* = 12	-.80	94	.43	-0.25
WJ-III Letter-Word ID	47.15 (7.12) *n* = 84	48.75 (4.27) *n* = 12	-.76	94	.45	-0.24
WJ-III Reading Fluency	37.65 (11.81) *n* = 84	38.50 (7.29) *n* = 12	-.24	94	.81	-0.08
12-month attention measures						
SWAN-T Inattention	31.10 (12.41) *n* = 84	30.25 (10.36) *n* = 12	.23	94	.82	0.07
SWAN-T Hyperactivity and Impulsivity	33.25 (11.93) *n* = 84	31.25 (11.78) *n* = 12	.54	94	.59	0.17
SWAN-P Inattention	33.89 (8.57) *n* = 55	32.82 (8.61) *n* = 11	.38	64	.71	0.13
SWAN-P Hyperactivity and Impulsivity	32.31 (8.58) *n* = 55	30.91 (8.01) *n* = 11	.50	64	.62	0.17

Note. Standard deviations appear in parentheses next to means.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Effect size estimates: Small = <.20; medium = .50; large = >.80.

Table 14b

One-year individual t tests on RAN-colors self-corrections, reading measures, and attention ratings

	RAN-Colors					
	Non-self-correctors *Mean (SD)*	Self-correctors (Range = 1-2) *Mean (SD)*	*t*	*df*	*p*	*Cohen's d*
12-month reading measures						
DIBELS ORF median correct	103.70 (32.78) *n* = 82	93.86 (30.28) *n* = 14	1.05	94	.30	0.31
WJ-III Letter-Word ID	47.79 (6.73) *n* = 82	44.79 (7.12) *n* = 14	1.53	94	.13	0.45
WJ-III Reading Fluency	38.29 (11.71) *n* = 82	34.64 (8.39) *n* = 14	1.12	94	.27	0.33
12-month attention measures						
SWAN-T Inattention	32.50 (11.92) *n* = 82	22.14 (9.56) *n* = 14	**3.08****	94	.00	1.21
SWAN-T Hyperactivity and Impulsivity	34.57 (11.48) *n* = 82	23.79 (10.09) *n* = 14	**3.30****	94	.00	0.97
SWAN-P Inattention	34.21 (8.33) *n* = 57	30.56 (9.55) *n* = 9	1.20	64	.24	0.37
SWAN-P Hyperactivity and Impulsivity	32.53 (8.51) *n* = 57	29.22 (7.84) *n* = 9	1.09	64	.28	0.33

Note. Standard deviations appear in parentheses next to means.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Effect size estimates: Small = <.20; medium = .50; large = >.80.

When baseline working-memory variables were entered into the individual regression models, none of the baseline measures of working memory predicted 12-month reading outcomes or attention ratings. RAN-Letters task time and phonological processing at baseline still remained significant predictors of norm-referenced single-word reading. RAN-Letters task time was also a significant predictor of passage oral-reading fluency. RAN-Colors total time at baseline and students' age were not significant predictors of any outcome variable. Sex was a significant predictor of teacher-rated ADHD-symptoms when baseline working-memory variables were entered into the equation. The effect of adding working-memory measures into the regression model was to absorb some of the variance explained by other predictor variables, such as RAN-Colors total time, phonological processing, age, and sex. None of the predictor variables had significant associations with WJ-III Reading Fluency after baseline working-memory measures were entered.

When 12-month working-memory variables were entered into the individual regression models, RAN-Letters task time and phonological processing at baseline remained significant predictors of norm-referenced single-word reading. Auditory working-memory, RAN-Colors total time at baseline, visual-spatial working-memory, and age were not significant predictors of any outcome variables. Sex was a significant predictor of all teacher-rated and parent-rated ADHD-symptoms when working-memory variables were entered into the equations. One-year Finger Windows forward was the one working-memory variable that had significant associations with outcome variables (silent Reading Fluency, and teacher-rated inattention).

RAN-Letters Errors and Self-Corrections Analyses

RAN-letters errors analysis. **S**tudents who made errors on the RAN-Letters task at baseline had statistically lower scores on oral-reading fluency one-year later, but not on single-word reading, nor the silent, speeded, semantic decision-making Reading Fluency task. Groups were not significantly different on teacher ratings of inattention or hyperactivity or impulsivity (i.e., RAN-Letters error-makers were not considered more inattentive and hyperactive or impulsive) by their teachers, parents, or the examiner. Even a year later, some evidence was found to support the RAN double dissociation (RAN-Letters task being associated with reading and not inattention and hyperactivity).

Results of the independent *t*-test analyses and Cohen's *d* effect-size statistics were calculated to investigate the significance and size of differences between error-makers (Table 13a) and self-correctors (Table 13b) on the RAN-Letters task on reading and attention rating outcomes.

RAN-letters self-corrections analysis. Students who made self-corrections on the RAN-Letters task at baseline showed no statistically significant differences on any reading or attention measure ($\alpha = .05$). Thus, findings for RAN-Letters self-corrections a year later did not directly support the RAN double dissociation.

RAN-Colors Errors and Self-Corrections Analyses

Results of the independent *t*-test analyses and Cohen's *d* effect size statistics were calculated to investigate the significance and size of differences between error-makers (Table 14a) and self-correctors (Table 14b) on the RAN-Colors task on reading and attention-rating outcomes at one-year.

RAN-colors errors analysis. Students who made errors on the RAN-Colors task at baseline showed no statistically significant differences on any reading or attention measure ($\alpha = .05$). Thus, findings for RAN-Colors errors did not directly support the RAN double dissociation after one-year.

RAN-colors self-corrections analysis. The group of students who made self-corrections on the RAN-Colors task had statistically lower ratings of inattention as well as hyperactivity or impulsivity (i.e., were considered more inattentive and hyperactive or impulsive) by their teachers one-year after the initial assessment. Self-correctors on RAN-Colors were not significantly different on any reading-outcome measures. Thus, self-correction results were found to be in line with the RAN double dissociation, that is, the RAN-Colors task was associated with inattention and hyperactivity, and not reading outcomes.

There were no significant differences between groups based on the parent ratings of inattention and hyperactivity or impulsivity.

Additional analyses on sex and working memory (errors and self-corrections). A series of one-way between-subjects analyses of variance (ANOVAs) was conducted to compare sex effects on making RAN-errors or self-corrections on reading outcomes and ratings of ADHD-symptoms. When only boys were selected for the analysis, RAN-Letters differences between self-correctors and nonself-correctors were not significant for any outcome measures, nor were they different between error-makers and nonerror-makers. However, RAN-Colors self-correctors and nonself-correctors were significantly different on their SWAN-T Hyperactive and Impulsive ratings one-year later, $F(1, 41) = 5.26$, $p = .03$. This meant that boys who made self-corrections on RAN-Colors at baseline were rated significantly lower (on average) on hyperactive and impulse control by their teacher one-year later. This was the same finding as Leung et al. (2014)--Manuscript 2.

In girls, RAN-Letters errors were associated with all reading outcome measures, such as DIBELS, $F(1, 51) = 11.35$, $p = .00$, Letter-Word Identification, $F(1, 51) = 11.35$, $p = .00$, and Reading Fluency, $F(1, 51) = 10.43$, $p = .00$. RAN-Colors errors were no longer associated with

SWAN-T hyperactive or impulsive ratings, $F(1, 51) = .90$, $p = .35$, after year one. However, baseline self-corrections on RAN-Colors were associated with one-year teacher ratings of inattention, $F(1, 51) = 4.56$, $p = .04$, as well as parent ratings of inattention, $F(1, 35) = 5.02$, $p = .03$. Baseline self-corrections on RAN-Colors were not significantly associated with one-year teacher ratings of hyperactivity or impulsivity, $F(1, 51) = 3.43$, $p = .07$, or parent ratings of hyperactivity or impulsivity, $F(1, 35) = 3.26$, $p = .08$. These findings differed slightly from those in Leung et al. (2014)--Manuscript 2, in which RAN-Colors errors were associated with teacher hyperactivity and impulsivity ratings, and self-corrections were also associated with teacher, but not parent ratings of inattention, hyperactivity and impulsivity. Taken together, results of the analyses for boys and girls supported the existence of a RAN double dissociation one-year later.

None of RAN-Letters errors or self-corrections, nor RAN-Colors errors or self-corrections was associated with measures of visual-spatial working-memory or auditory working-memory variables measured after one-year.

Further analyses were conducted to assess if differences between errors and self-corrections on RAN tasks were robust when (a) the children with the lowest 10% reading scores on passage reading fluency were excluded (which translated to less than 25 DIBELS median words correct), and (b) all children with documented ADHD as well as the top 10% of students with behavioral symptoms of ADHD were excluded (which translated to less than a total score of 98 on the SWAN-T). This tested the sensitivity of the RAN tasks on average or good readers and attenders. If RAN measures can be used to predict reading performance in typically developing children as well as to differentiate between good and poor readers, we would expect that when poor readers are excluded from the analysis, both RAN-Colors and RAN-Letters differences would stay intact. Similarly, if RAN measures can be used to differentiate between children with symptoms of ADHD and children without, as well as to assess ADHD-symptoms on a continuum for typically developing children, we would expect that when children with symptoms of ADHD are excluded from the analysis, RAN-Letters differences would stay intact on reading measures, and RAN-Colors differences would also stay intact on attention measures.

Ten percent of children with severe reading symptoms excluded. A one-way ANOVA was conducted. Children who made errors or self-corrections on RAN-Letters were not significantly different on any reading or attention variables measured after one-year. Similarly, children who made errors on RAN-Colors were not significantly different on any reading or attention variables measured after one-year. However, the RAN-Colors self-corrections group was significantly different on 12-month SWAN-T Inattention, $F(1, 85) = 7.73$, $p = .01$, SWAN-T Hyperactivity and Impulsivity, $F(1, 85) = 9.20$, $p = .00$. This implied that self-corrections on RAN-Colors performance at baseline still remained sensitive to 12-month teacher ratings of attention, hyperactivity, and impulsivity in a classroom sample of typical children when poor readers were excluded from the analysis. However, errors and self-corrections on RAN-Letters, and errors on RAN-Colors, were no longer predictive of reading performance after 12 months. This result implied that in classroom sample of average to good readers, RAN-Colors self-corrections performance remained sensitive to behavioral ADHD-symptoms.

Ten percent of children with ADHD-symptoms excluded. RAN-Letters errors were significantly different on 12-month DIBELS, $F(1, 85) = 4.62$, $p = .04$ and Letter-Word Identification, $F(1, 85) = 3.93$, $p = .05$), but not on any attention measures, as expected. RAN-Letters errors and self-corrections were not significantly different on 12-month Reading Fluency. RAN-Colors self-corrections still showed significant and strong differences on SWAN-T Inattention ratings, $F(1, 85) = 7.25$, $p = .01$, and SWAN-T Hyperactivity and Impulsivity, $F(1,$

85) = 10.66, p = .00, measured one-year later. This implied that, even when higher ratings of dysfunctional behaviors related to ADHD were excluded from the analysis, RAN-Letters errors performance at baseline remained predictive of 12-month reading outcomes, and RAN-Colors self-corrections performance at baseline remained predictive of 12-month teacher ratings of behavioral ADHD-symptoms.

A summary of the significant associations from the multiple linear regression analyses and t tests is presented in Table 15.

Table 15

Summary of significant one-year predictions

	Dependent variables						
	Reading			Teacher-rated ADHD-symptoms		Parent-rated ADHD-symptoms	
Predictor variables	DIBELS ORF	WJ-III Letter Word ID	WJ-III Reading Fluency	Inattention	Hyperactivity and Impulsivity	Inattention	Hyperactivity and Impulsivity
Sex			√	√	√		
Age		√	√				
Elision	√	√	√				
RAN-Letters time	√	√	√				
RAN-Letters errors	√						
RAN-Letters self-corrections							
RAN-Colors time	√		√	√			
RAN-Colors errors							
RAN-Colors self-corrections				√	√		
Digit Span forward--							

Baseline		
Digit Span backward--Baseline		
Finger Windows forward--Baseline		
Finger Windows backward--Baseline		
Digit Span Forward--12-Months		
Digit Span Backward--12-Months		
Finger Windows forward--12 Months	√	√
Finger Windows backward--12 Months		

Conclusions

Answers to the Specific Research Questions

1. How well do basic reading indicators (RAN-Letters, RAN-Colors, and phonological awareness as measured by Elision) at baseline correlate with reading outcomes (DIBELS, Letter-Word Identification, Reading Fluency), and attention outcomes (working memory, teacher ratings of inattention or hyperactivity or impulsivity) when tested after a period of one-year?

Based on the results of the regression analyses, RAN-Letters total time significantly contributed to the variance on all reading tasks (passage oral-reading fluency, single-word reading, and silent-reading fluency), and slower rapid naming of colors was associated with symptoms of inattention at 12-months as rated by the teacher, and lower scores on measures of reading fluency (silent and oral). There was some evidence that performance on continuous nonalphanumeric RAN-Colors is related to attentional processes and performance on continuous alphanumeric RAN-Letters is related to reading skills, even after a period of one-year. In the main regression models (Table 12a), all variables predicted 12-month Reading Fluency (RAN-Letters time, RAN-Colors time, age, sex, and phonological processing).

2. Is working memory associated with the relations amongst RAN task total time and type, reading skills (oral-reading fluency, single-word reading), and behavioral ADHD-symptoms after one-year? In general, from the regression analyses, none of the baseline working-memory variables was associated with measures taken one-year later. Performance on visual-spatial Finger Windows at 12 months was associated with scores on norm-referenced Reading Fluency, and teacher ratings of inattention. After working-memory variables were entered into the equation, RAN-Colors at baseline no longer predicted any 12-month reading or attention measures (however, *n* was also reduced by half because working-memory measures

were only administered to the subset of stratified participants selected for high, medium, and low ADHD-symptoms from screening the SWAN-T data). There were also no 12-month working-memory differences predicted by either RAN-Colors errors and self-corrections or RAN-Letters errors and self-corrections.

Altogether, these findings were similar to those of Pham, Fine, & Semrud-Clikeman (2011), and Leung et al. (2014)--Manuscript 2, who also found that working-memory measures did not account for a significant amount of variance in their regression models of RAN predicting reading outcomes and attention. Working-memory variables did not explain significant amounts of variance accounted for by RAN-task performance. Neither did they reliably or consistently predict reading or attention measures at baseline or one-year later. Furthermore, working-memory measures did not contribute additional information with regard to reading or attention measures not already available through teacher ratings or RAN measures.

3. Is the sex of the child associated with the relations amongst RAN-task total time and type, reading skills (oral-reading fluency, single-word reading, and behavioral ADHD-symptoms? Yes, it is. Sex was a significant predictor of teacher ratings of inattention, hyperactivity, and impulsivity, as well as silent reading fluency in the main regression model.

4. Is age associated with the relations amongst RAN task total time and type, reading skills (oral reading fluency, single-word reading), and behavioral ADHD-symptoms? Yes.

Answers to Secondary Research Questions (Errors and Self-Corrections)

1. Do error-makers or self-correctors on the RAN tasks differ from those who made no errors or self-corrections in oral reading fluency or reading-achievement scores (single-word reading) at 12-months? Yes, they do differ, and in the direction supporting a double dissociation.

The group of students who made errors on the RAN-Letters task had statistically significantly lower scores on passage oral-reading fluency, but not on reading fluency or single-word reading.

Are there sex differences? Yes, girls who made errors on RAN-Letters at baseline were more likely to have lower reading-outcome scores after 12 months than girls who did not. No differences were found for boys' errors or self-corrections in the prediction of reading achievement. Taken together, results of the analyses for boys and girls were found to support the existence of a RAN double dissociation one-year later.

2. Do error-makers or self-correctors on the RAN tasks differ from nonerror-makers in behavioral ratings of inattention or hyperactivity? Yes, and in the direction supporting a double dissociation. The group of students who made self-corrections on the RAN-Colors task had significantly lower ratings of attention, hyperactivity, or impulsivity one-year after baseline assessment (i.e., were considered more hyperactive or impulsive by their teachers). Boys who made self-corrections on RAN-Colors at baseline were rated significantly lower (on average) on hyperactive and impulse control by their teachers one-year later. This was a similar finding to that reported in Leung et al. (2014)--Manuscript 2. Girls who made baseline self-corrections on RAN-Colors were more likely to have lower teacher and parent ratings of attention. These findings differed slightly from those in Leung et al. (2014)--Manuscript 2, which reported that RAN-Colors errors were associated with teacher hyperactivity and impulsivity ratings, and self-corrections were also associated with teacher, but not parent ratings of inattention, hyperactivity and impulsivity.

Performance on RAN-Letters tasks at baseline predicted one-year reading outcomes on single-word and passage oral-fluency scores in a typically developing sample of children in grades 2 to 4. Also, performance on the RAN-Colors task predicted teacher inattention ratings as well as a measure of reading fluency. The dual relation of RAN task to differential behavioral outcomes is the RAN double dissociation.

3. Does removing 10% of participants with the lowest oral reading fluency scores or the 10% with the lowest teacher-rated ADHD-symptoms affect the predictive ability of RAN measures? When the poorest readers were excluded, children who made errors or self-corrections on RAN-Letters were not significantly different on any reading or attention variables measured after one-year. However, self-corrections on RAN-Colors performance at baseline remained sensitive to 12-month teacher ratings of attention, hyperactivity, and impulsivity in a typical classroom sample of children when poor readers were excluded from the analysis. When the poorest attenders were excluded, RAN-Letters errors performance at baseline remained predictive of 12-month reading outcomes, and RAN-Colors self-corrections performance at baseline remained predictive of 12-month teacher ratings of behavioral ADHD-symptoms. This result contrasted with the findings in Leung et al. (2014a)--Manuscript 2 that, when poor readers were excluded, children who made errors or self-corrections on RAN-Letters were still significantly different on passage oral-reading fluency, but not on single-word reading or any attention measures. Children who made errors or self-corrections on RAN-Colors were significantly different on single-word reading, and teacher ratings of hyperactivity. When poor attenders were excluded, RAN-Letters errors were significantly different on reading measures, but not on any attention measures. RAN-Colors self-corrections showed significant differences on teacher ratings. This implied that even when higher ratings of dysfunctional behaviors related to ADHD were excluded from the analysis, RAN-Letters errors performance at baseline still remained predictive of 12-month reading outcomes, and RAN-Colors self-corrections

performance at baseline still remained predictive of 12-month teacher ratings of behavioral ADHD-symptoms.

Discussion

Rapid automatized naming (RAN) tasks measured at baseline are differentially correlated with behavioral ADHD-symptoms (namely, inattention, hyperactivity, or impulsivity), with the RAN-Letters task correlating with measures of reading fluency and single-word reading outcomes measured a year later, and with the RAN-Colors task correlating with teacher-rated hyperactive symptoms and experimenter rated behaviors also measured a year later. Slower rapid naming of letters predicted poorer reading fluency and single-word reading scores. Slower rapid naming of colors predicted 12-month poorer reading fluency and teacher-rated symptoms of inattention. Age and sex were also significant predictors of the outcome variables. Errors and self-corrections on RAN tasks measured at baseline were also associated with their respective predicted outcomes: students who had RAN-Letters self-corrections also tended to have lower scores on passage oral-reading fluency, but not ADHD-symptoms, whereas students who made RAN-Colors self-corrections did not differ on any of the reading measures one-year after baseline assessment, but had statistically higher teacher ADHD-symptom ratings one-year after their initial assessment. This finding contrasts with and extends those of Cantor (2009), who found no evidence of a relation between nonalphanumeric RAN performance and behavioral outcomes of inattention, as measured by the Continuous Performance Test and parent ratings, by looking at teacher ratings one-year after baseline assessment.

Interesting discussion points arose based on these findings. First, our findings coincided with those of Arnett et al. (2012), who examined competing hypotheses about longitudinal associations between rapid-naming speed and symptoms of inattention in children. Symptom severity of inattention from kindergarten to grade 4 was consistently predicted by previous rapid naming, over and above autoregressive and correlational associations in the model. We found evidence for this as well. The use of RAN tasks within the context of ADHD to explore differentiation between learning difficulties related to attention or basic processes in reading appears to be in its infancy and yet should prove to be a promising area rich in research opportunities.

Also, the relations of RAN tasks to and even among the reading-achievement outcomes themselves provide some interesting points for discussion. The nature of the correlations and regression coefficients in relation to the scores on the Reading Fluency subtask from the Woodcock-Johnson indicated some important additional processes that may be in play during this complex task. Although the Reading Fluency subtest requires reading ability, it is likely to also require other skills such as semantic knowledge, automaticity of access to words and their meanings in the mental lexicon, simple sentence comprehension, and visual search skills related to attention and executive processing. Alphanumeric and nonalphanumeric RAN tasks, although they look to be quite similar in form, do not behave similarly in terms of tapping the cognitive resources necessary for quick and accurate time performance--hence the likely dissociation. Nonalphanumeric RAN-Colors performance likely reflects executive function, whereas performance on alphanumeric RAN may depend on highly automatized processes in which executive function (in the form of lexical decision-making) plays little or no role. Our use of the Reading Fluency task as an outcome measure appeared to play a role somewhere in-between a pure passage-reading task, paper-pencil processing speed task, and a semantic decision-making task, and interestingly was associated with both RAN-Colors time as well as RAN-Letters time performance.

Studies that have investigated the role of speed of processing, rapid naming, and phonological awareness in reading achievement may provide additional clues about the role of rapid naming in tasks such as Reading Fluency or processing speed in RAN performance (Catts, Gillispie, Leonard, Kail, & Miller, 2002). Catts et al. administered measures of rapid object naming, phonological awareness, and reading achievement to 279 children in grades 2 and 4. Poor readers were proportionally slower than good readers on the rapid object-naming task and response-time measures, and may reflect a general deficit in speed of processing. They also found that speed of processing explained unique variance in reading achievement when IQ and phonological awareness were accounted for. Thus, a speed-of-processing deficit may account for some explanatory characteristics in some reading difficulties.

Second, continuous RAN provides information about an individual's reading performance in excess of general level of automaticity, due to the predictive differences amongst RAN-types, after phonological processing was accounted for. For example, the processes involved in executive function likely provide some clues with regard to RAN performance. It is probable that a combination of phonological factors, visual-verbal connections, and executive aspects intrinsic to and within each RAN task are somehow interconnected (Denckla & Cutting, 1999).

We found no evidence to support the perspective that phonological-processing deficits overlap in children with reading difficulties and those with attention-based difficulties even after one-year. Our results coincide and extend those of Douglas and Benezra (1990) as well as Pennington, Groisser, and Welsh (1993), who found doubly dissociative relations of cognitive processing between ADHD and reading disorders, and contrast with those who have found that children with and without SLDR and ADHD were found to share a common problem in phonological processing, when other factors were partialled out of the analysis (McGee, Williams, Moffitt, & Anderson, 1989; Swanson, Mink, & Bocian, 1999).

Working Memory

In general, our findings of the baseline or one-year working-memory variables associations in the regression analyses as well as correlation analyses were unimpressive. Performance on visual-spatial Finger Windows at 12 months was associated with scores on norm-referenced Reading Fluency, and teacher ratings of inattention. None of the baseline working-memory measures predicted any outcome variables of reading, attention, hyperactivity, or impulsivity after a year. This could be the result of extensive development of working memory ability during the early school years, but this speculation would need to be studied explicitly. In addition, the development of working memory might not to be strictly linear; this would cause linear correlations to appear lower. We also do not know whether or not the development of reading or attention performance is linear. Future studies might explore curvilinear relationships.

Furthermore, baseline and one-year working-memory measures were significantly but not highly correlated from year 1 to year 2. We also reported variable changes in working memory from baseline to one year later: Digit Span did not change significantly, Finger Windows forward performance became worse, and Finger Windows backward was the only working-memory variable to improve significantly. After working-memory variables were entered into the equation, RAN-Colors at baseline no longer predicted any 12-month reading or attention measures (however, *n* was also reduced by half because working-memory measures were only administered to a subset of participants). There were also no 12-month working-memory differences predicted by either RAN-Colors errors and self-corrections or RAN-Letters errors and self-corrections.

Altogether, these findings were similar to those of Pham et al. (2011), and Leung et al. (2014)--Manuscript 2, who also found that working-memory measures did not account for a significant amount of variance in their regression models of RAN predicting reading outcomes and attention. Working-memory variables did not explain significant amounts of variance accounted for by RAN task performance, neither did they reliably or consistently predict reading or attention measures at baseline or one-year later. Furthermore, working-memory measures did not contribute additional information or predictive ability in regard to reading or attention measures not already available through teacher ratings or RAN measures. We found that working-memory measures were unreliable, redundant, and therefore, not terribly useful.

Two subconclusions arise from the findings on working memory. First, if working memory is not predictive of the same outcomes that RAN predicts, then working memory does not explain what makes RAN performance hold up. The explanation lies elsewhere. Processing speed and semantic knowledge might especially be worthy of further study. Second, our research suggests that RAN is a better indicator of reading or behavioral skills than working-memory measures, at least in children similar to our sample in the early elementary grades. For the purposes of reading and attention assessment, we encourage the use of RAN measures to replace measures of rote working memory such as Digit Span or Finger Windows.

Our findings about variable changes in working memory in early childhood somewhat coincide with others who have found that auditory and visual-spatial working-memory span increases throughout childhood and early adulthood (Gathercole, 1999; Hale, Bronik, & Fry, 1997; Klingberg, Forssberg, & Westerberg, 2002; Luciana & Nelson, 1998; Siegel & Ryan, 1989). With development, children are able to remember increasing amounts of auditory or visual information (Jenkins, Myerson, Hale, & Fry, 1999). Younger normally-achieving children and children with reading disabilities from the age of 7 to 13 in the study had significantly smaller memory spans than older normally achieving children or young adults (Siegel & Ryan, 1989; Jenkins et al., 1999). This increase in working-memory capacity is thought to be important for the development of a wide range of cognitive skills, including reading (Hulme, Roodenrys, Brown, & Mercer, 1995). However, our results challenge the premise that working memory is important for the prediction of reading or behavioral symptoms of ADHD after one year, at least in our sample of typical schoolchildren aged 6 to 9.

The skills involved in working memory may vary in importance at different stages of reading development. For example, working memory may assist early readers in developing oral reading fluency as they gain phonetic and orthographic knowledge, but then may play less of a role after fluency skills have been automatized. Working memory may also play a role in reading comprehension and other reading-related abilities at different stages of reading acquisition and development. Future investigations could look at a possible non-linear relation between working memory and either reading or behavioral symptoms of ADHD. As working memory has been shown to continue development into adulthood, it would be worthwhile to examine these interrelations over a wider range of ages and longer period of time.

Errors and Self-Corrections

Errors and self-corrections on the RAN tasks demonstrated a doubly dissociative relation to reading outcomes and ADHD-related behaviors when assessed a year later. Students who made no errors or self-corrections on the RAN-Letters task were more likely (on average) to have better single-word reading scores and oral reading fluency. Students who made no errors or self-corrections on the RAN-Colors task were more likely (on average) to have better (lower) teacher ratings of hyperactive and impulsive control. Errors and self-corrections on RAN tasks have never been studied before in the context of a longitudinal double dissociation in typically developing students. This finding echoes other RAN studies that have examined errors. For example, a group of students with a specific learning disorder in reading (SLDR) made significantly more errors on the RAN-Letters task than either the ADHD or control group, but no differences in errors were found between the ADHD and control group (Semrud-Clikeman, Guy, Griffin, & Hynd, 2000). Denckla and Cutting (1999) have suggested that certain error types within word list learning tasks link “dyslexic” and “dysexecutive” errors because such errors reflect (a) impaired phonological working-memory, as in self-repetitions, and (b) impaired specific word retrieval, as when over-categorical recall leads to some random color being recalled instead of the shown color.

Limitations

The results of the current study may be interpreted with the following possible additional limitations that were not addressed in Leung et al. (2014) [Manuscript 2].

Additional variables. Variables such as cognitive processing speed and additional measures of attention such as sustained attention and executive functioning could be useful to further explore the relations between RAN performance, reading outcomes, and behavioral symptoms of ADHD. Perhaps other reading outcomes such as reading comprehension or word attack could further provide insight into the double dissociation hypothesis. The inclusion of the other RAN tasks (i.e., digits and objects) or types of naming (e.g., discrete-trial RAN, rapid alternating stimulus (RAS) tasks) may additionally provide some further insight. Based on the findings of this study, and the literature review in Leung & Stringer (2014) [Manuscript 1], it could be hypothesized that strong relations may exist between RAN-Objects, semantic knowledge, cognitive processing speed, and the Reading Fluency subtest from the Woodcock-Johnson.

Sample size. Although we considered the use of a larger age range, the collection of data from larger within-grade samples would be beneficial to be able to look at RAN-Colors and RAN-Letters utility on a clearer, developmental level.

Implications

Practice. The use of RAN tasks as clinical tools to possibly tap processes related to inattention, hyperactivity, and impulsivity could provide valuable insight into basic-skills deficits that inhibit the acquisition of reading at an age-appropriate level and indicate areas for intervention. Evaluation and identification of inattention and reading difficulties at an early age allow educators and practitioners to intervene early, potentially improving the long-term academic achievement outcomes of children who are at-risk. Brief assessments such as RAN are useful in predicting reading performance, even among children who do not exhibit reading difficulties (Kirby, Georgiou, Martinussen, & Parrila, 2010; Neuhaus & Swank, 2002; Pham et al., 2011). Slower RAN speed, particularly in RAN-Colors, suggests difficulties with control of attention, likely related to abnormal fluctuations or breakdown of neural connections (Misra, Katzir, Eolf, & Poldrack, 2004). Although these fluctuations may provide a basis for understanding levels of inattention, they may also facilitate more direct assessment of contributors to specific reading skills, particularly fluency, among typically developing children. These findings contribute to the development of a model of how the domains of reading and attention are interrelated. Researchers and practitioners may also be able to identify, and intervene early with, children who are considered at risk for developing reading or attention problems, aided by the use of RAN tasks. The finding that RAN tasks' predictive utility of reading abilities and ADHD-symptoms persist, even after one-year after initial assessment, could provide valuable information for clinicians and educators in their assessment and intervention planning for students at-risk for learning difficulties. In previous longitudinal research on RAN, only one study showed a RAN--inattention relation (Arnett et al., 2012), and the present study reinforces that result. The outcomes of the present study are otherwise consistent with previous research about reading skill prediction from alphanumeric RAN performance (e.g., Catts et al., 2001; Kirby et al., 2003; Landerl & Wimmer, 2008; Schatschneider et al., 2004).

We found that, similar to the conclusions of Leung et al. (2014) [Manuscript 2], that the relations between teacher and parent ratings of children's ADHD-symptoms to be only moderately correlated, which corroborate a number of studies that have found low or no association between teacher and parent ratings of ADHD (Antrop, Roeyers, Oosterlaan, & Oost, 2002; Mitsis, McKay, Schulz, Newcorn, & Halperin, 2000; Wolraich et al., 2004). Our findings add support to the importance of implementing rating scales and interviews from multiple informants as well as the careful selection of a multimodal assessment battery in the assessment of children's attention and reading difficulties.

Theory. There has been limited research on subtypes of RAN within investigations of reading and inattention in typical classroom settings. Very few studies to date have incorporated longitudinal investigations of RAN in the prediction of attention variables. Furthermore, our study accounted for variables that may have not been accounted for in previous studies (e.g., phonological processing, errors, self-corrections, teacher ratings). The proposed model based on the research-based framework of the RAN double dissociation is the first known working model that examines the relations among reading performance and behavioral symptoms of inattention, hyperactivity, and impulsivity.

This research has contributed both to a theoretical understanding of how attention difficulties contribute to the development of reading, how they may impact academic progress in reading over time, and to a practical understanding for education professionals responsible for governing students with attention difficulties in the classroom context (Edmunds & Martsch-Litt, 2008). Multiple possible theoretical explanations for the relation between naming speed and reading have been proposed based on different conceptual analyses of what is involved in naming speed and reading: phonological processing, orthographic processing, general processing speed, and executive processes or domain general automaticity deficits (Kirby et al., 2010; Leung & Stringer, 2010). Even a year after RAN administration, total time, errors, and self-corrections had significant dissociative relations with reading and behavioral symptoms of ADHD, after phonological processing had been taken into account. This repeated finding of the RAN double dissociation indicated that some of these theoretical interpretations of RAN performance (namely, phonological processing, orthographic processing, and general processing-speed) were insufficient to explain RAN's relations with behavioral symptoms of inattention, hyperactivity, and impulsivity, although aspects of each theory may still be relevant to reading development. We explored the interpretation of RAN that points to the importance of executive processes to orchestrate successful RAN performance by considering variables such as working memory, attentional control, impulsive and inhibitory responses in RAN (likely represented by errors and self-corrections), and reading performance. Other researchers had concluded that RAN taps both visual-verbal (language domain) and processing speed (executive domain) contributions to reading (Denckla & Cutting, 1999). Wolf et al. (2000) argued that rapid-naming tasks are composed of attentional, visual, lexical, temporal, and recognition subprocesses that all contribute to naming speed performance.

This research has also contributed to a developmental understanding of reading and behavioral symptoms of inattention, hyperactivity, and impulsivity. We found that both curriculum-based measures of passage-reading performance (DIBELS oral reading fluency) as well as norm-referenced single-word reading achievement (WJ-III Letter-Word Identification) improved over a year in a classroom sample of typical children aged 7 to 10. However, teacher and parent ratings of behavioral inattention, hyperactivity, and impulsivity did not show significant differences between baseline and year one. This finding suggests that reading development occurs regardless of subclinical levels of inattention and hyperactivity, at least, to some degree.

In addition, RAN-Letters performance was still predictive of reading despite improvements in reading performance over the span of one year. Less can be speculated with regard to RAN-Colors performance and longer-term changes in behavioral ADHD-symptoms because those symptoms did not appear to change dramatically over the course of a year, but would provide an interesting area for future research. A wider range of ages and a longer time span would be necessary to understand these outcomes more thoroughly.

Future Directions

The merits of this study emphasize the practicality of brief assessments such as RAN to predict reading performance among typical children and among those who exhibit significant reading difficulties. RAN speed is uniquely associated with a range of reading tasks beyond that explained by phonological processing, and early identification of children at risk for reading failure would be improved by the inclusion of variable RAN measures. Poor response to instruction by students who have slow naming speed should be considered when designing interventions. Further research is required to specify the theoretical nature of naming speed and to determine how to help students with slow naming speed (Kirby et al., 2010).

Future studies should now focus on extending this research to other age and grade levels, a longer time span, as well as other variables to determine variables important to a model of RAN task performance in relation to reading skills and behavioral symptoms of ADHD. Variables such as processing speed, age, and cognitive processes of attention (e.g., sustained attention, visual search) could all be used in future investigations of RAN to clarify why RAN predicts reading development and some aspects of behavioral inattention, hyperactivity, and impulsivity. Further research could also provide additional information regarding the double dissociation hypothesis by considering the developmental framework of reading. This would elaborate what is currently a preliminary model of the relations among RAN, reading, and ADHD-symptoms.

Appendix N

Summary of regression analyses for variables predicting 12-month reading outcomes with working-memory variables excluded (n = 96)

	Reading Models														
	DIBELS ORF median correct					WJ-III Letter-Word ID					WJ-III Reading Fluency				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	9.68	4.89	.15	1.98	.05	.81	1.00	.06	.81	.42	3.98	1.72	**.18***	2.31	.02
Age	4.97	2.83	.14	1.76	.08	2.17	.58	**.29*****	3.76	.00	5.02	.99	**.40*****	5.05	.00
CTOPP Elision[1,2]	2.00	.56	**.30****	3.57	.00	.58	.11	**.41*****	5.07	.00	.51	.20	**.22***	2.59	.01
RAN-Letters[3]	-46.56	11.30	**-.36*****	-4.12	.00	-6.35	2.30	**-.23****	-2.76	.01	-8.05	3.97	**-.18***	-2.03	.05
RAN-Colors[3]	-26.06	11.98	**-.18***	-2.174	.03	-2.88	2.44	-.10	-1.18	.24	-8.43	4.21	**-.17***	-2.00	.05
R^2			.53					.56					.52		
Adj. R^2			.50					.53					.49		
F			**20.15*****		.00			**22.61*****		.00			**19.53*****		

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix O

Summary of regression analyses for variables predicting 12-month teacher-rated ADHD-symptoms with working-memory variables excluded (n = 96)

	Teacher-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	7.89	2.38	**.33****	3.31	.00	7.92	2.43	**.33****	3.26	.00
Age	-.82	1.38	-.06	-.60	.55	.04	1.40	.00	.03	.98
CTOPP Elision[1,2]	.48	.27	.19	1.76	.08	.13	.28	.05	.48	.63
RAN-Letters[3]	1.43	5.50	.03	.26	.80	.04	5.61	.00	.01	.99
RAN-Colors[3]	-13.12	5.83	**-.24***	-2.25	.03	-5.32	5.95	-.10	-.90	.37
R^2			.20					.13		
Adj. R^2			.16					.18		
F			**4.50****		.00			**2.70***		.03

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix P

Summary of regression analyses for variables predicting parent-rated ADHD-symptoms with working-memory variables excluded (n = 66)

	Parent-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	.84	2.20	.05	.38	.70	2.94	2.19	.17	.19	.19
Age	-1.09	1.27	-.12	-.85	.40	-.92	1.27	-.10	.47	.47
CTOPP Elision[1,2]	.33	.26	.19	1.29	.20	.06	.26	.03	.83	.83
RAN-Letters[3]	2.31	4.79	.07	.48	.63	-2.34	4.76	-.07	.63	.63
RAN-Colors[3]	-8.31	5.54	-.21	-1.50	.14	-5.45	5.50	-.14	.33	.33
R^2			.08					.08		
Adj. R^2			.00					-.00		
F			1.05		.40			.97		.44

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN = rapid automatized naming; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

Appendix Q

Summary of regression analyses for variables predicting 12-month reading outcomes with baseline working-memory variables included (n = 53)

	Reading Models														
	DIBELS ORF median correct					WJ-III Letter-Word ID					WJ-III Reading Fluency				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	10.80	7.71	.15	1.40	.17	-.83	1.63	-.06	-.51	.61	2.98	2.76	.12	1.08	.29
Age	-.11	4.69	-.00	-.02	.98	1.27	.99	.16	1.28	.21	2.80	1.68	.21	1.66	.10
CTOPP Elision[1,2]	1.26	.87	.16	1.45	.15	.57	.18	**.36****	3.10	.00	.48	.31	.18	1.53	.13
Digit Span forward[1,4]	.43	2.46	.02	.17	.86	.45	.52	.11	.87	.39	.64	.88	.10	.73	.47
Digit Span backward[1,4]	2.57	3.34	.09	.77	.45	.28	.70	.05	.40	.69	1.12	1.20	.11	.93	.36
Finger Windows forward[1,5]	-.52	1.43	-.05	-.36	.72	-.08	.30	-.04	-.27	.79	.21	.51	.06	.42	.68
Finger Windows backward[1,5]	1.44	.99	.18	1.46	.15	.16	.21	.10	.77	.44	.54	.35	.19	1.53	.13
RAN-Letters[3]	-54.98	17.97	**-.40****	-3.06	.00	-7.89	3.79	**-.28***	-2.08	.04	-6.26	6.44	-.13	-.97	.34
RAN-Colors[3]	-42.86	18.26	-.26	-2.35	.024	-3.55	3.86	-.11	-.92	.36	-11.35	6.54	-.20	-1.73	.09
R^2			.61					.59					.58		
Adj. R^2			.53					.50					.49		
F			**7.56*****		.00			**6.86****		.00			**6.54**		.00

***

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

[4] Measure of auditory working-memory

[5] Measure of visual-spatial working-memory

Appendix R

Summary of regression analyses for variables predicting 12-month teacher-rated ADHD-symptoms with baseline working-memory variables included (n = 53)

	Teacher-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	11.09	3.67	**.40****	3.03	.00	11.69	3.86	**.45****	3.03	.00
Age	-2.96	2.23	-.19	-1.33	.19	.82	2.35	.06	.35	.73
CTOPP Elision[1,2]	.58	.41	.19	1.40	.17	.49	.44	.17	1.12	.27
Digit Span forward[1,4]	1.10	1.17	.15	.95	.35	-.28	1.23	-.04	-.23	.82
Digit Span backward[1,4]	2.19	1.58	.19	1.38	.17	.92	1.67	.09	.55	.58
Finger Windows forward[1,5]	.29	.68	.07	.43	.67	-.13	.72	-.03	-.18	.86
Finger Windows backward[1,5]	.14	.47	.04	.30	.76	.31	.50	.10	.62	.54
RAN-Letters[3]	1.95	8.53	.04	.23	.82	-.21	9.00	-.00	-.02	.98
RAN-Colors[3]	-14.21	8.67	-.22	-.23	-1.64	-7.63	9.14	-.13	-.83	.41
R^2			.44					.30		
Adj. R^2			.32					.15		
F			**3.71****		.00			**2.01**		.06

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

[4] Measure of auditory working-memory

[5] Measure of visual-spatial working-memory

Appendix S

Summary of regression analyses for variables predicting 12-month parent-rated ADHD-symptoms with baseline working-memory variables included (n = 37)

	Parent-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	1.98	3.62	.11	.55	.59	5.51	3.84	.29	1.44	.16
Age	-2.44	2.38	-.24	-1.03	.31	-.52	2.52	-.05	-.21	.84
CTOPP Elision[1,2]	.16	.43	.08	.37	.72	-.12	.46	-.06	-.25	.80
Digit Span forward[1,4]	1.24	1.14	.25	1.08	.29	.42	1.21	.08	.35	.73
Digit Span backward[1,4]	-.65	1.61	-.09	-.40	.69	-1.35	1.7	-.17	-.78	.44
Finger Windows forward[1,5]	-.14	.78	-.05	-.19	.85	-.35	.82	-.11	-.43	.68
Finger Windows backward[1,5]	.12	.45	.06	.26	.79	.20	.47	.10	.42	.68
RAN-Letters[3]	-4.76	8.79	-.14	-.54	.59	-8.68	9.31	-.24	-.93	.36
RAN-Colors[3]	.68	9.64	.02	.07	.95	4.17	10.22	.09	.41	.69
R^2			.13					.12		
Adj. R^2			-.16					-.18		
F			.44		.90			.40		.92

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.
[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Appendix T

Summary of regression analyses for variables predicting 12-month reading outcomes with 12-month working-memory variables included (n = 43)

	Reading models														
	DIBELS ORF Median Correct					WJ-III Letter-Word ID					WJ-III Reading Fluency				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	12.17	7.64	.17	1.59	.12	-1.06	1.85	-.07	-.57	.57	3.71	2.71	.15	1.37	.18
Age	-.18	5.08	-.00	-.04	.97	1.34	1.23	.16	1.09	.29	1.98	1.80	.13	1.10	.28
CTOPP Elision[1,2]	.82	1.01	.10	.81	.43	.55	.24	**.33***	2.26	.03	.46	.36	.16	1.27	.21
Digit Span forward[1,4]	-.21	2.23	-.01	-.09	.93	.10	.54	.03	.18	.86	.79	.79	.12	1.00	.33
Digit Span backward[1,4]	4.14	2.96	.17	1.40	.17	.75	.72	.15	1.05	.30	1.51	1.05	.17	1.44	.16
Finger Windows forward[1,5]	1.94	1.38	.16	1.40	.17	.42	.34	.17	1.26	.22	1.11	.49	**.25***	2.25	.03
Finger Windows backward[1,5]	.97	1.20	.11	.81	.43	-.12	.29	-.06	-.42	.68	.60	.43	.18	1.41	.17
RAN-Letters[3]	-71.00	18.23	**-.49*****	-3.89	.00	-9.87	4.42	**-.33***	-2.23	.03	-10.90	6.47	-.21	-1.68	.10
RAN-Colors[3]	-20.72	19.68	-.13	-1.10	.30	-1.59	4.77	-.05	-.33	.74	-2.64	6.99	-.05	-.38	.71
R^2			.68					.56					.68		
Adj. R^2			.59					.44					.60		
F			**7.78*****		.00			**4.65*****		.00			**7.90**		.00

***

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

[1] Raw score

[2] Measure of phonological processing

[3] Total time

[4] Measure of auditory working-memory

[5] Measure of visual-spatial working-memory

Appendix U

Summary of regression analyses for variables predicting teacher-rated ADHD-symptoms with 12-month working-memory variables included (n = 43)

	Teacher-rated ADHD Symptom Models									
	SWAN Inattention Subscale					SWAN Hyperactivity and Impulsivity Subscale				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	17.21	3.87	**.56*****	4.45	.00	16.97	3.62	**.59*****	4.69	.00
Age	-1.44	2.57	-.08	-.56	.58	1.07	2.41	.07	.45	.66
CTOPP Elision[1,2]	.82	.51	.23	1.60	.12	.59	.48	.18	1.24	.22
Digit Span forward[1,4]	.44	1.13	.06	.39	.70	-1.3	1.05	-.18	-1.24	.22
Digit Span backward[1,4]	.83	1.50	.08	.56	.58	1.97	1.40	.20	1.40	.17
Finger Windows forward[1,5]	1.43	.70	**.27***	2.04	.05	1.11	.66	.22	1.69	.10
Finger Windows backward[1,5]	-.10	.61	-.03	-.16	.87	-.35	.57	-.10	-.62	.54
RAN-Letters[3]	-.069	9.23	-.00	-.01	.99	-3.08	8.64	-.05	-.36	.72
RAN-Colors[3]	-6.70	9.96	-.10	-.67	.51	-3.91	9.32	-.06	-.42	.68
R^2			.55					.55		
Adj. R^2			.43					.43		
F			**4.54****		.00			**4.50****		.00

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

[*] $p < .05$; [**] $p < .01$; [***] $p < .001$.
[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Appendix V

Summary of regression analyses for variables predicting parent-rated ADHD-symptoms with 12-month working-memory variables included (n = 27)

	Parent-rated ADHD symptom models									
	SWAN Inattention					SWAN Hyperactivity and Impulsivity				
Variable	*b*	*SE b*	β	*t*	Sig. (*p*)	*b*	*SE b*	β	*t*	Sig. (*p*)
Sex	10.10	4.30	**.55***	2.35	.03	12.46	4.26	**.64****	2.92	.01
Age	-2.93	2.72	-.28	-1.07	.30	-4.76	2.70	-.43	-1.76	.10
CTOPP Elision[1,2]	.73	.59	.35	1.24	.23	.44	.58	.20	.75	.47
Digit Span forward[1,4]	1.80	1.42	.39	1.27	.22	1.16	1.41	.24	.82	.42
Digit Span backward[1,4]	.22	1.78	.04	.13	.90	.75	1.77	.12	.43	.68
Finger Windows forward[1,5]	.32	.90	.09	.35	.73	-.21	.89	-.06	-.23	.82
Finger Windows backward[1,5]	-.17	.71	-.08	-.24	.82	.68	.71	.29	.96	.35
RAN-Letters[3]	2.64	8.60	.08	.31	.76	-1.07	8.52	-.03	-.13	.90
RAN-Colors[3]	11.46	12.53	.25	.92	.37	11.42	12.42	.24	.92	.37
R^2			.33					.42		
Adj. R^2			-.03					.11		
F			.91		.54			1.36		.28

Note. CTOPP = Comprehensive Test of Phonological Processing; RAN(L or C) = rapid automatized naming (letter or color); DIBELS = Dynamic Indicators of Basic Early Literacy Skills; ORF = Oral reading fluency; WJ-III = Woodcock-Johnson III Tests of Achievement, with Normative Update; WISC-III = Wechsler Intelligence Scale for Children III; WRAML = Wide Range Assessment of Memory and Learning; SWAN = Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (Teacher or Parent form).

* $p < .05$; ** $p < .01$; *** $p < .001$.
[1] Raw score
[2] Measure of phonological processing
[3] Total time
[4] Measure of auditory working-memory
[5] Measure of visual-spatial working-memory

Final Overall Conclusions for the Three Manuscripts

Continuous rapid automatized naming (RAN) tasks are simple assessment tools that have been demonstrated to be strongly related to reading development. Emerging evidence has additionally linked some RAN tasks to attention and behavioral concerns, such as ADHD. The reasons why RAN performance is associated with reading ability or behaviors such as inattention, hyperactivity, and impulsivity are not yet well understood. The primary objective was to link a predictor of reading performance, RAN, to English-reading achievement and behavioral symptoms of ADHD in boys and girls of elementary school age in a general school sample. Our central research questions sought to explore the relations between RAN-task total time, reading outcomes (single word identification and reading fluency), and behavioral ratings of inattention and hyperactivity from different informants (teacher, parent, and examiner). Does the type of RAN task differentially predict behavioral ADHD-symptoms (namely, inattention and hyperactivity or impulsivity) and reading skills? In the first manuscript, a model of the RAN double dissociation based on a review of pertinent RAN theory literature was presented, outlining the relations between RAN performance, reading, and behaviors. Two contrasting patterns of differences were found based on the RAN literature: (a) Typical students and students with attention difficulties are similar in alphanumeric (A-RAN) performance but differ on nonalphanumeric (N-RAN) tasks, thus indicating that N-RAN tasks appear to be more closely associated with attentional processes, and (b) A-RAN appears to be more closely associated with reading. Students with reading difficulties only would exhibit similar N-RAN performance as shown by typical controls but would differ on A-RAN tasks. This led directly to an empirical investigation of differences between alphanumeric RAN (specifically, RAN-Letters) and nonalphanumeric RAN (specifically, RAN-Colors), the main research goal of Leung et al. (2014)--Manuscript 2.

A cross-sectional, exploratory study into the relations of RAN-Letters and RAN-Colors among reading and attention revealed that RAN-Letters total time, errors, and self-corrections were all predictors of concurrent single-word reading and passage oral-reading fluency. RAN-Colors total time was a predictor of examiner-rated behaviors, but not of reading outcomes, teacher, or parent ADHD-ratings. Errors and self-corrections on the RAN tasks supported the double dissociation more clearly. In other words, the participants who made errors or self-corrections on RAN-Letters also tended to have lower scores on reading outcomes, and participants who made errors or self-corrections on RAN-Colors tended to have poorer inattention, hyperactivity, and impulsivity ratings by their teachers.

The third central research question that was posed in Manuscript 3 asked if RAN tasks can be used to predict reading ability and behavioral ratings by teachers or parents after one year. This question was posed to observe longer-term predictive value of the RAN-Colors and Letters tasks and to examine the possible clinical utility of this basic reading indicator in the assessment of problems related to reading difficulties and inattention occurring in the classroom setting. First, RAN-Letters total time significantly contributed to the variance on all reading tasks (passage oral-reading fluency, norm-referenced single-word reading and silent-reading fluency) when age, sex, and phonological processing were taken into account. In our regular school sample of children age 6 to 9, reading was found to improve significantly over the course of a year in both passage oral reading fluency and single-word reading measures and RAN-Letters performance was demonstrated to be strongly associated to reading performance both at baseline and the following year, providing additional support to the notion that RAN-performance is not just associated with reading performance, but it is associated with reading development. RAN-Colors total time at baseline was a significant predictor of 12-month oral-reading fluency, silent reading fluency, and teacher ratings of inattention. Participants who took more time on RAN tasks were more likely to have lower one-year reading scores. What was even more interesting about the longer-term predictive value of RAN was in the role of errors and self-corrections. Students who made errors on the RAN-Letters task had statistically lower scores on passage oral-reading fluency, but not teacher ratings, or parent ratings of inattention or hyperactivity or impulsivity. Conversely, students who made self-corrections on the RAN-Colors task did not differ on any of the reading measures one-year after baseline assessment, but they had statistically significantly worse teacher ratings of inattention, hyperactivity or impulsivity one-year after their initial assessment. More research needs to be undertaken to assess the practicality of RAN-Color measures to detect changes in ADHD-symptoms over time, which would provide additional insight into our developmental understanding of relations between RAN performance and behavior.

For example, developmental research suggests that the behavioral symptoms of hyperactivity decrease as children age, but difficulties with restlessness, inattention, poor planning, and impulsivity persist into adolescence and adulthood (Turgay et al., 2012). According to the DSM-5, the main manifestation of ADHD is motoric hyperactivity at young ages, inattention becomes more prominent during elementary school, and during adolescence, signs of hyperactivity (e.g., running and climbing) become less common and may manifest as fidgetiness, restlessness, or impatience (American Psychiatric Association, 2013a). In adulthood, along with inattention and restlessness, impulsivity may remain problematic even when hyperactivity has diminished. Thus, it will be important to clarify and assess symptoms separately rather than in combination, in order to further our developmental understanding of behavioral ADHD-symptoms in relation to RAN performance.

Overall, the three separate research questions provided supportive evidence for the anticipated outcomes as posited by the RAN double dissociation, even after one-year. The double dissociation model as described in this paper was presented as a useful guide, or measuring device like a thermometer or barometer, to document RAN associations with reading performance and symptoms of ADHD, namely, inattention, hyperactivity, and impulsivity. The relative strengths of associations as described and summarized in this paper signal clues to which clinicians or researchers may use specific types of RAN to measure the existence of attention or reading phenomena in children. For example, one basic finding of this paper supports the notion that the use of RAN-Letters would be useful in an assessment battery to predict reading performance or reading difficulties, rather than inattention, hyperactivity, or impulsivity. The corollary would be that RAN-Colors could be useful as a quick measure or tool in an assessment battery as an indicator of possible inattention, hyperactivity, or impulsivity symptoms in the classroom setting, and not to predict reading performance or reading difficulties, particularly in school-aged children 6 to 9.

Future investigations should now focus on extending this research to other age and grade levels as well as other variables to determine aspects important to a model of RAN task in relation to reading ability and behavioral symptoms of ADHD. Variables such as processing speed, increased age range, vocabulary, and cognitive processes of attention (e.g., sustained attention, visual search) could all be used in future investigations of RAN and to clarify why RAN predicts reading development and some aspects of behavioral inattention, hyperactivity, and impulsivity.

Original Contribution to Knowledge

There has been limited research on subtypes of RAN within investigations of reading and inattention in typical classroom settings. Very few studies to date have incorporated longitudinal investigations of RAN in the prediction of attention variables. Furthermore, our study accounted for variables that may have not been examined together in previous studies (e.g., phonological processing, errors, self-corrections, teacher ratings, examiner ratings). The proposed model built on the research-based framework of the RAN double dissociation is the first known working model that simultaneously examines the multiple relations among reading performance and behavioral symptoms of inattention, hyperactivity, and impulsivity.

This research has contributed both to a theoretical understanding of how attention difficulties contribute to the development of reading and how they may impact academic progress in reading over time, and to a practical understanding for education professionals responsible for governing students with attention difficulties in the classroom context (Edmunds & Martsch-Litt, 2008). Specifically, the research has contributed to our understanding of the role of rapid automatized naming on reading development as well as ADHD-symptoms of inattention, hyperactivity, and impulsivity.

Currently, the diagnosis of ADHD may not lead to specific implications for any type of educational support in the classroom; this project informs policy makers regarding the long-term impact of attention on academic achievement. Perhaps self-monitoring, self-reflective strategies, and regulation skills might be useful contributors to dealing with ADHD or reading problems, and our results add support to what is likely a key area of intervention for children in the primary school age, and could be easily diagnosed with the aid of RAN tasks.

Most importantly, it provides further clues regarding the cognitive similarities and differences between children with attention difficulties and reading problems, which, in isolation or in combination, may lead to being at risk for poor academic outcomes, decreased motivation at school, and dropping out.

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