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Decomposing the Relation Between Rapid Automatized Naming (RAN) and Reading Ability

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The Rapid Automatized Naming (RAN) test involves rapidly naming sequences of items presented in a visual array. RAN has generated considerable interest because RAN performance predicts reading achievement. This study sought to determine what elements of RAN are responsible for the shared variance between RAN and reading performance using a series of cognitive tasks and a latent variable modelling approach. Participants performed RAN measures, a test of reading speed and comprehension, and six tasks, which tapped various hypothesised components of the RAN. RAN shared 10% of the variance with reading comprehension and 17% with reading rate. Together, the decomposition tasks explained 52% and 39% of the variance shared between RAN and reading comprehension and between RAN and reading rate, respectively. Significant predictors suggested that working memory encoding underlies part of the relationship between RAN and reading ability.

Keywords: reading, rapid automatized naming, RAN, latent variability, individual differences

The rapid automatized naming (RAN) test measures the speed and accuracy of naming an array of familiar stimuli on a page (Denckla & Rudel, 1974). When performing the RAN, participants typically view four or five letters, digits, colors, or simple object pictures presented in random order in a 5 row × 10 column grid, and name the entire grid of items as quickly and accurately as possible. RAN has generated considerable interest in the reading literature based on the observation that scores on this test are consistently correlated with reading ability in children and adults (Blachman, 1984; Bowers, 1995; Cornwall, 1992; Denckla & Rudel, 1974; Wolf, Bally, & Morris, 1986). A meta-analysis by Swanson, Trainin, Necochea, and Hammill (2003) that included children and adults, and both good and poor readers ($N = 1550$), observed the relationship between RAN times and reading performance to be .45. Powell, Stainthorp, Stuart, Garwood, and Quinlan (2007) observed a correlation of $-.53$ between reading comprehension and RAN in a sample of 1,000 7- to 10-year-old readers. Our own group has observed relationships of $-.52$ and $-.41$ (controlling for age) between RAN and the Test of Word Reading Efficiency (TOWRE) word and nonword reading, respectively, in a sample of 215 children aged 7 to 17 years with no neurological or developmental disorders (Joanisse et al., 2007). Indeed, the RAN is frequently used as a clinical instrument for diagnosing reading disorders in children (Bowers, 1995) and is often used to predict category membership in reading group subtypes. Nevertheless, there remains considerable uncertainty about why RAN predicts reading ability as well as it does.

A great deal of recent research has focused on the involvement of phonological factors in reading development and disability (Joanisse, Manis, Keating, & Seidenberg, 2000; Stanovich, 1988; Wagner, Torgesen, & Rashotte, 1994), and in this sense RAN appears to be an anomaly. Although the RAN measure can be thought of as tapping some phonological processing mechanisms—for instance, accessing the phonological representation of an object, and articulatory planning—many studies have now shown that phonological awareness and RAN scores account for independent variance in reading achievement (Blachman, 1984; Bowers, 1995; Bowers & Newby-Clark, 2002; Bowers & Swanson, 1991; Cornwall, 1992; McBride-Chang & Manis, 1996; Wolf et al., 2002). In addition, RAN tends to correlate rather weakly with phonological awareness skill in children (Blachman, 1984; Cornwall, 1992). It has also been argued that reading impaired children with rapid naming deficits and phonological awareness deficits might form distinct subgroups marked by subtly different reading problems (Bowers & Wolf, 1993; Manis, Seidenberg, & Doi, 1999). Finally, in developing readers, RAN performance has been shown to correlate significantly with read-

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ing ability even after the variance due to phonological awareness has been removed (Lovett, 1999; Wolfe et al., 2002). Thus, despite the strong emphasis that has been placed on understanding the role of phonology in reading, RAN appears to tap a neuro-cognitive mechanism that is independent of phonology but that nevertheless plays an important role in reading development. While urging a componential analysis of RAN performance, Klein (2002) suggested that both reading and RAN place particular demands on connections between the visual pattern recognition and vocal output modules, and that the unique contribution of RAN performance in predicting reading ability derives from these connections. In the present work, we explored this proposition by performing such a componential analysis.

One concern with RAN is that it is a broad measure, that is, it potentially assesses a wide range of cognitive skills. Speed and accuracy of rapid naming can be influenced by many different processing mechanisms. For instance, it is not surprising that individuals with reading disability and individuals with attention-deficit/hyperactivity disorder (ADHD) both show deficits compared to controls in RAN performance (Waber, Wolff, Forbes, & Weiler, 2000), even though it seems likely that the RAN deficits shown by these two groups have different underlying causes. In addition, there are in fact four different RAN tests, as there are four types of materials that are typically used (colour, digit, letter, and object), and so there is some question as to whether all RAN measures are equally related to reading skill. On the one hand, studies have found correlations between reading scores and each of the four rapid naming stimulus types (Denckla & Rudel, 1974), and different RAN measures tend to be highly correlated with each other (Bowers & Swanson, 1991). However, there is also evidence that rapid naming scores for letters and digits are more closely related to reading scores than are colors and objects scores (Blachman, 1984; Cornwall, 1992; Maya, Katzir, Wolf, & Poldrack, 2004; Spring & Capps, 1974). Evidence from genetics also points to stronger genetic covariance between reading skill and RAN scores for digits and letters than for colors and objects (Davis et al., 2001). Similarly, there is also emerging evidence showing that the development of rapid colour and object naming may diverge from rapid letter and digit naming, again suggesting that different cognitive processes may be involved in these different subtasks (e.g., Tannock, Martinussen, & Frijters, 2000; van den Bos, Zijlstra, & Spelberg, 2002; Waber et al., 2000).

Another significant challenge to understanding why RAN predicts reading ability lies in uncovering the cognitive mechanisms that it shares with reading. One hypothesis is that both reading and RAN tap orthographic processing, since both involve quasi-arbitrary relationships between visual objects and their names (Manis et al., 1999). However, the relationship between orthographic skill and RAN remains unclear. Tests of orthographic knowledge typically assess the ability to discriminate orthographically legal and illegal letter patterns (e.g., NUST vs. NSUT), and there is some evidence that performance on such tasks correlates with RAN scores (Bowers, Sunseth, & Golden, 1999). However, there is also evidence indicating that orthographic problems in individuals who score poorly on RAN are no greater than would be predicted by their ability to recognise and recall single letters or arbitrary letter strings (Conrad & Levy, 2007). Thus, the common underlying cognitive skill measured by RAN and word recognition remains unclear.

Studies so far have tended to focus on the extent to which RAN correlates with or predicts specific aspects of reading ability (e.g., Blachman, 1984; Conrad & Levy, 2007; Cornwall, 1992; Manis et al., 1999). Although informative, such investigations offer limited insights into the underlying source(s) of the association between RAN and reading ability. In the present work, we take a different approach to understanding the connection between rapid naming and reading by seeking to identify specific components of the RAN task that explain the variability shared by RAN and reading. We used a task decomposition methodology to tease apart the different elements of RAN and tested how these explained the shared variance between RAN and reading ability. In our view, the rapid naming task, like reading itself, involves multiple subcomponents and task demands, and it should be possible to assess each of these independently, to determine the degree to which they correlate with RAN, and whether they account for the connection between RAN and reading ability.

The most obvious elements of RAN tasks are the speeded identification and naming of individual, familiar objects. These include visual sensory processes, stimulus identification, and response retrieval and vocal production. However, what makes RAN unique is its rapid, sequential nature. Wolf and Bowers (1997) have suggested that a critical aspect of the task is the emphasis on focusing sustained attention over time; controlling eye movement sequences in order to fixate on consecutive stimuli; and coordinating these eye movements with the cognitive and articulatory processes involved in naming each item. To this list we would also add the dynamic cognitive suppression of previous and upcoming responses as the current response is being planned.

With respect to these component processes, there is some disagreement as to whether the key to RAN's effectiveness at predicting reading skill lies in the sequential nature of the task. RAN differs from general object naming because it involves continuous lists rather than items presented in isolation. It has been suggested that the continuous nature of this task taps not only speed, but automaticity of retrieval, and that, as in skilled reading, this characteristic is critical because of the need to direct attentional resources to higher-level processes such as comprehension (LaBerge & Samuels, 1974). Consistent with this, a number of studies have found that, unlike RAN, speed of naming letters or digits in isolation correlates only relatively poorly with reading scores (Perfetti, Finger, & Hogaboam, 1978; Stanovich, 1981; Stanovich, Feeman, & Cunningham, 1983). In addition, studies that have found effects of single item naming on reading have done so only in prereaders (Walsh, Price, & Gillingham, 1988) and in early readers with reading difficulties (Bowers & Swanson, 1991). These results suggest that single letter or digit naming speed might reflect individuals' familiarity and experience with print rather than the speed and automaticity of memory retrieval.

The use of the term "automatized" in RAN also implies that it directly measures the automaticity in the process of linking names with objects (Nicolson & Fawcett, 1990). However, the claim of automaticity derives not from response speed alone, but is based on converging operations including the absence of dual task interference (e.g., Posner & Snyder, 1975). Therefore, one goal of this research is to link RAN performance with the concept of automaticity in identifying objects. For instance, it is possible that RAN diverges from single-letter naming exactly because naming objects in sequence introduces a secondary task that can interfere with naming if this capacity is not properly automatized.

The present study seeks to address the relation between rapid naming and reading. The RAN task was "decomposed" into its various cognitive subcomponents. We examined whether these components accounted for the relation between RAN and skilled reading in adults, using a novel latent variable approach in which the variability shared between RAN and reading ability was predicted by the decomposition tasks. That is, unique from previous studies examining the RAN task, our primary interest was in understanding the source(s) of the linkage between RAN and reading performance, based on a decomposition of the RAN task into its hypothesised cognitive components.

Although much of the existing literature focuses on RAN-reading relationship in children, the present study focused on college- age adults. The advantage of studying adults in the present study was the expectation that adults would tend to provide cleaner reaction time and accuracy data on the computerized testing measures used here. This should in turn help to more accurately determine how performance on these measures is associated with individual differences in reading and rapid naming. RAN has previously been observed to be predictive of reading in reading impaired adults, even when controlling for education level and adult IQ (Felton, Naylor, & Wood, 1990), although less is known about this relationship in typical adult readers. Thusly, an added benefit of the present study is to provide evidence about whether RAN continues to correlate with reading ability into adulthood for normal readers, and which of the four RAN stimulus types (letters, digits, colours, and objects) are useful predictors of reading ability in skilled adult readers.

Participants were given a computerized RAN task, the reading rate and comprehension portions of the Nelson-Denny reading test (Brown, Nelson, & Denny, 1973), and six computer tasks, each designed to tap a subset of the mental processes that are seemingly required while performing the RAN. A speeded vocal naming task was used in which participants were shown a single RAN element (e.g., the letter "r") and were asked to vocally name it as quickly as possible. If the time taken to identify the item and produce a spoken name can explain some of the relationship between RAN performance and reading ability, then one would expect that some of the variability shared by RAN and reading performance can be explained by vocal naming time. However, if RAN's predictive ability is not related to the speed of naming an item in isolation, then the variability shared between RAN and reading performance would be independent of vocal naming time.

A manual response time task was also used as one of the six decomposition tasks. During this task participants were shown a single RAN element just as in the vocal naming task, but this time they were instructed to press a labelled key that matched the identity of the stimulus. This task also required rapid identification of the stimulus, but instead of requiring vocal production, it required response selection operations (mapping from stimulus identity to a response) and manual response execution operations. If vocal production is necessary for the relationship between RAN and reading performance, then one would expect that variability shared by RAN and reading performance would not be explained by manual response time. If, however, identification and/or response selection demands do underlie part of the relationship between RAN and reading ability, then one would expect that some of the variability shared by RAN and reading performance would be accounted for by manual response time.

A delayed manual response time task was also used as a control task. This task was the same as the manual response time task, except that the participant was told not to press the key matching the identity of the RAN element until after a tone had sounded. The tone was presented at least 1,500 ms after the onset of the stimulus, so that the participant would have time to identify the stimulus and perform response selection operations to isolate the correct key press response prior to the tone. Thusly, the response time should be a purer measure of response execution operations which would not be expected to correlate with RAN or reading performance, or to explain the relationship between RAN and reading—unless better readers simply have faster central nervous systems more generally.

It is possible that RAN predicts reading ability because both tasks require individuals to quickly and accurately identify stimulus units in the context of other stimuli. We have devised three tests that seek to isolate different elements of response encoding and selection in the context of conflicting distractor stimuli. The first of these was a modified version of Bowers and colleagues' Quick Spell Test (QST; Bowers & Newby-Clark, 2002; Bowers et al., 1999). Using the QST task, Bowers et al. (1999) found that the ability of young children to identify four letters presented briefly for 250 ms predicted reading performance levels. The QST task was not speeded and accuracy was the dependent variable. The task required rapid encoding of the letters, but not rapid phonological production. The QST task also relied on visual short-term memory abilities and required maintenance of order information. The QST results are important as they suggest that at least some of the relationship between RAN and reading ability may be in the encoding stage (as opposed to the response production stage), and/or in the ability to coordinate information in visual working memory.

The version of the QST that was used here was adapted for use with adults and used all four RAN stimulus categories (colors, digits, letters and objects). In the present work, all four items from a given RAN category (e.g., four different colors) were presented briefly in a row at the centre of the screen. After the offset of the display a probe appeared at one of the locations, prompting an unspeeded response indicating the identity of the item that had appeared at that location. As in the original Bowers et al. QST task, the time allowed for stimulus encoding was limited, but no speeded output, vocal or otherwise, was required from the participant.

We also tested object recognition in a rapid serial visual presentation (RSVP) paradigm. Like the QST task, RSVP also requires rapid extraction of stimulus identities and coordination of items in visual working memory, but here items are presented sequentially rather than simultaneously. In RSVP tasks, items are presented one at a time in the same spatial location at a high rate of speed (e.g., approximately 10 items/second). In this study, participants performed a single-target RSVP task where they were asked to report whether a given RAN element was present or absent in an RSVP stream of similar distractor elements (e.g., "Was the picture of the dog present in the stream of pictures?"). Again, no speeded response was required, but target presentation time was limited and targets were presented in the context of a rapidly changing display.

Finally, participants also performed a dual-task RSVP experiment wherein they were asked to search for two targets in an RSVP stream of similar distractor elements. Previous research has shown that when participants must attend to two targets presented in RSVP streams, performance on the first target (T1) is quite good. However, performance on the second target (T2) is poor when it is presented within 500 ms of the first target—a phenomenon known as the attentional blink (AB, Raymond, Shapiro, & Arnell, 1992). The AB is generally explained in terms of the first target depleting attentional resources that are required for conscious stimulus consolidation for a period of about 500 ms (e.g., Chun & Potter, 1995; Shapiro, Arnell, & Raymond, 1997). It is possible that the AB may be larger and/or longer in poor readers if it takes more resources for them to process T1. It is also possible that overall target accuracy in the single target RSVP task, and/or in the dual-target AB task, will be related to reading and RAN performance if at least some of the relationship between RAN and reading ability is at the stimulus encoding stage, and/or due to coordination of information in visual working memory, where participants must extract identities in the face of competing stimulus information. If so, then we would expect that some of the variance shared by RAN and reading would be accounted for by RSVP performance.

To summarise, the primary goal of the present study was to examine the relation between rapid naming and reading in adults by "decomposing" the RAN task into various cognitive subcomponents that were expected to be shared with reading ability. We tested whether these components accounted for the shared variance between RAN and reading performance. To the extent that the components can explain this relationship, the variance shared between RAN and reading should be at least partially accounted for by the decomposition tasks. If, however, the decomposition tasks do not explain the relationship between RAN and reading, then the shared variance between RAN and reading should be independent of the decomposition tasks.

Method

Participants

Sixty-four undergraduate students from Brock University (n = 34) and the University of Western Ontario (n = 30) participated in the experiment in exchange for course credit or a small monetary payment. Participants ranged in age from 19 to 26 years. Each person participated individually in a single session lasting approximately two hours. All participants reported learning English before 8 years of age, and normal (or corrected to normal) visual acuity.

Design

In a single testing session each participant performed seven computer tasks and the reading comprehension and reading rate portions of the Nelson-Denny reading test (Brown et al., 1973). All participants performed the tasks in the following fixed order: (1) the computerized version of the classic RAN task, (2) the manual response time (RT) task, (3) the adaptation of Bowers' QST task, (4) the speeded vocal naming task, (5) the reading comprehension and reading rate portions of the Nelson-Denny reading test, (6) the delayed manual response time task, (7) the single-task RSVP task, and (8) the dual-task RSVP task where an AB was expected. Each computer task was performed four times in succession, once using each of the four RAN stimulus categories. All participants received the same stimulus order for each task (colors, digits, letters, and then objects). The decomposition tasks employed the same stimuli used to create the grid for the RAN task (e.g., blue square, dog picture), presented in the same sise, but instead of being aligned in a grid, the stimuli were presented as needed for the given decomposition task.

Apparatus

Computer experiments were controlled using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) running on a Windows XP-based desktop PC with a 17" CRT colour monitor. Participants made manual responses using the computer keyboard, and vocal responses using a voice key integrated into a serial response box (Psychology Software Tools, Pittsburgh, PA).

Stimuli and Procedures

RAN task. The classic RAN task was adapted to computer presentation. Although the RAN test has usually been performed using paper cards, our group has recently observed a correlation of .95 between this computerized RAN task and standard RAN using paper cards (Howe, Arnell, Klein, Joanisse, & Tannock, 2006), suggesting differences in paper and computer presentation are negligible. A 5-row $\times$ 10-column grid of RAN elements was presented on the computer screen. The grid contained either colours (red, green, blue, yellow), digits (2, 4, 6, 9), letters (g, k, m, r), or object pictures (dog, hand, book, chair). Each grid measured approximately 25 cm wide $\times$ 18 cm high, subtending approximately 26.6 degrees of visual angle at an unfixed binocular viewing distance of approximately 50 cm. The vertical centre of one row to the vertical centre of the next row measured approximately 4.5 cm for each grid. The horizontal centre of one column to the horizontal centre of the next column measured approximately 3.0 cm for each grid. Each individual RAN element was approximately 1.5 cm high and wide for a visual angle of approximately 1.7 degrees. Note that RAN tasks often use arrays of five items, although this number varies across studies. Here we chose instead to use four items of each stimulus type to facilitate the use of speeded manual responses on the manual RT task.

A key press by the participant initiated the grid presentation and the computerized RAN timing. Participants were instructed to accurately name each stimulus item as quickly as possible, beginning immediately after their key press. Participants were told to name the grid items starting in the upper left element and ending at the lower right element working their way across the rows from left to right. They were instructed to press a key immediately after naming the last item to stop the computer timing. Items were named out loud with an experimenter in the testing room so that errors could be recorded. Each participant performed four trials, one with each stimulus type. For each participant the time required to name all the items in the grid was recorded for each of the four stimulus types and an overall mean score was computed across stimulus type.

Manual RT task. On each trial a single stimulus from the RAN grid (e.g., a blue square) was presented in the centre of the computer screen. Participants were instructed to press the key matching the identity of the stimulus as quickly and accurately as possible. Each trial began with a 500 ms presentation of a fixation cross, a 500 ms blank interval, and then the stimulus was presented and remained on the screen until a response was made. A 500 ms intertrial interval followed the response. Labels with stimulus names were pasted to the “z”, “x”, “n”, and “m” computer keyboard keys to facilitate stimulus response mappings. For each of the tasks requiring an identification response the “z” key was mapped to the colour “red”, the number “2”, the letter “g”, and the picture of the hand. The “x” key was mapped to the colour “blue”, the number “4”, the letter “k”, and the picture of the chair. The “n” key was mapped to the colour “yellow”, the number “6”, the letter “m”, and the picture of the dog, and the “m” key was mapped to the colour “green”, the number “9”, the letter “r”, and the picture of the book. Each participant performed one block for each of the four RAN stimulus categories (colors, digits, objects and letters). Each block contained 48 trials, with each of the four stimulus exemplars presented 12 times each in random order (e.g., each of the 4 colors was presented 12 times in random order in the colour block). For each participant the mean RT was computed for each of the four stimulus types as was an overall mean RT across stimulus type.

Delayed RT task. The delayed RT task was the same as the manual RT task with the exception that participants were told to delay their manual response until a tone sounded. The tone was randomly presented 1500 or 2000 ms after the onset of the stimulus element, thereby allowing the participant sufficient time to identify the stimulus, and select and prepare a response prior to the tone. Participants were instructed to prepare their response prior to the tone, and then make a speeded response as soon the tone was sounded. Each participant performed one block of 48 trials for each of the four RAN stimulus categories. Within a block each of the four stimulus exemplars was presented 12 times each in random order. For each participant the mean RT was computed for each of the four stimulus types as well as an overall mean RT across stimulus type.

Vocal naming task. The blocks, trials, and stimuli for the vocal naming task were identical to those for the manual RT task. However, in the vocal naming task participants reported the identity of the stimulus by vocally naming the stimulus instead of making a manual response. Vocal RTs were measured from the onset of the stimulus until the voice key was tripped by the onset of a vocal response. The stimulus remained on the screen until the vocal response had been detected. Participants made their responses aloud into a microphone, and were cautioned to speak clearly and not to spoil the trial by making noises prior to their response (e.g., saying “umm” before naming the item). An experimenter was present during vocal naming blocks and recorded the accuracy and any spoiled trials at the end of each trial. Each participant performed one block for each of the four RAN stimulus categories. Each block contained 48 trials, with each of the four stimulus exemplars presented 12 times each in random order. For each participant the mean RT was computed for each of the four stimulus types as well as an overall mean RT across stimulus type.

Modified QST task. On each trial the participant viewed all four exemplars from a given category (e.g., all four colors) presented in random order in a row in the centre of the computer screen. The horizontal interitem distance was approximately 2 cm from the vertical centre of one item to the vertical centre of the next item for a visual angle of just over 2 degrees between adjacent items. Each trial began with the presentation of a fixation cross for 500 ms, followed by a blank interval for 500 ms, and then the row of four stimuli for 125 ms. Immediately after the stimulus was removed from the screen a “^” probe was presented just below one of the four random stimulus locations and remained on the screen until a response was made. The participant was asked to make an unspeeded response indicating which of the four exemplars was presented in that location, guessing if unsure. Responses were made using the same keys and mappings used in the manual RT task. Each participant performed one block of 48 trials for each of the four RAN stimulus categories. For each participant mean accuracy was computed for each of the four stimulus types and an overall mean accuracy averaged across stimulus type.

Single RSVP task. Participants were instructed to look for a specific target RAN element (e.g., the dog) in RSVP streams of similar distractors, and report whether the target element was present or absent in the stream. Each trial began with a fixation cross that was presented for 500 ms, a 500-ms blank screen, and then an RSVP stream of 16 items was presented one-at-a-time in the centre of the computer screen. At the end of each stream, a sentence appeared which asked whether the target was present or absent in the stream. The participant made an unspeeded response pressing “1” for present and “0” for absent. The target was present in the RSVP stream on 2/3 of all trials and absent on 1/3 of all trials. When present, the target was always the sixth or the tenth item in the stream. For object and colour streams each RSVP item was presented for 33 ms and followed by a 17-ms blank interstimulus interval (ISI). For digit and letter streams each item was presented for 50 ms and followed by a 17-ms blank ISI. Pilot testing was used for both single and dual-task RSVP programs (described below) to achieve presentation durations that resulted in approximately 70% detection accuracy for target present/absent judgements.

Eight distractors were used in each stream, but the same distractor was never presented in two successive stream positions. All distractors were made using the same sise, colour, shading, and/or font as the targets, but did not consist of target items from the other cognitive tasks. For colour trials distractor colors included the colors purple, orange, pink, brown, olive, and plum. For digit trials distractors were the numbers 0,1, 3, 5, 7, and 8. For letters distractors were b, c, h, p, x, and y, and for objects the distractor pictures were a teddy bear, a hat, a table, a wheelbarrow, a cup, and a fan.

Each participant performed one block for each of the four RAN stimulus categories. Each block contained 48 trials, which were divided into 4 sections of 12 trials each such that every 12 trials the target changed to the next stimulus in the set (e.g., for the first 12 trials in the colour block participants searched for the red colour, in the next 12 they searched for the blue colour etc.). To inform participants when the target had changed, a sentence appeared on the screen telling them the identity of the target for the next 12 trials. This sentence remained on until a key was pressed. For each participant, mean target sensitivity (hits minus false alarms) was computed for each stimulus type, as was an overall mean sensitivity across stimulus type.

Dual RSVP task. RSVP streams used for the dual-task trials were the same as those used for the single-task RSVP trials, with the following exceptions. One of the RSVP items was singled out from the others in the stream by virtue of a unique feature that was meant to attract attention. For the colour RSVP trials, one of the colored squares contained an asterisk in the centre while all others did not. Participants were instructed to identify the colour of the square that contained the asterisk (blue, red, or yellow) for their first target task. For digit, letter, and object trials this first target was colored red while all other RSVP items remained black. Participants were instructed to identify the red item for their first target task (the red item could be 2, 4, or 6 for digits, g, k, or m for letters, and dog, hand, or chair for objects). After the RSVP stream participants were prompted by a sentence to report the identity of this first target by making an unspeeded button press using the labelled keys. Participants were told to guess if unsure.

The second task on each trial was to report whether the fourth RAN element on that block (i.e., the "green" colour, the "9", the "r," or the "book" that were not used for T1) was present or absent in the RSVP stream anytime after the first target. After making their first target response, participants were prompted by a sentence on the computer screen to report whether this second target was present (press "1") or absent (press "0") using an unspeeded response. Once the first and the second responses had both been entered, the next trial began after a 1-s blank intertrial interval. A first target was present on all trials as the sixth or eighth item in the RSVP stream. The second target was present on 2/3, and absent on 1/3, of all trials. When present, the second target was presented equally often either 2 items after the first target or 7 items after the first target in the RSVP stream. Each item in the colour RSVP stream was presented for 66 ms with a 17 ms blank ISI. Each item in the digit, letter, and object streams was presented for 83 ms with a 17 ms blank interval. Each participant performed one block of 48 trials for each of the four RAN stimulus categories. For each participant mean T1 accuracy was computed for each of the four stimulus types and overall across stimulus type. Mean T2 sensitivity (hits minus false alarms) was computed for each stimulus type as was an overall mean sensitivity across stimulus type. In addition, AB size was computed as the difference between T2 sensitivity at lag 7 minus T2 sensitivity at lag 2.

Nelson-Denny reading test. The reading comprehension and reading rate portions from form D of the Nelson-Denny reading test (Brown et al., 1973) was given to each participant. Before beginning the test, participants were told that they would need to answer multiple-choice questions after reading paragraphs in the test booklet. They were warned that they would have a limited amount of time (the 15-min cut-time administration was used) and that they should work quickly to try to answer as many questions correctly as possible. The number of correct multiple-choice responses was used to calculate the reading comprehension score. Because the cut-time version of the test was used, scores were multiplied by $1.33 * 2$ to produce the reading comprehension score used in subsequent analysis (Brown et al., 1973).

The first minute of the reading test was timed to provide a measure of reading rate. Participants were instructed to read the first text passage as quickly as possible with good comprehension. Participants began reading when the experimenter said "go" and read for one minute until the experimenter said "stop." Participants then pointed to the word that they were reading when told to stop. The word count for that line of text was used to estimate their reading rate where a higher word count indicated a faster reading rate. Each participant completed the reading rate and reading comprehension test once.

Results

Preliminary Analyses

The variance-covariance matrices for the study measures did not differ significantly across testing site ($p = .95$ in *Box's M* test). Consequently, data from Brock University and the University of Western Ontario were combined into a single dataset for all analyses. Combining the data in this manner did not result in the creation or removal of any effects that were not also observed in the results from each lab.

For the manual RT, vocal RT, and delayed RT tasks, only responses from correct trials were analysed. Less than 4% of RTs were removed using the Van Selst and Jolicoeur (1994) modified recursive outlier elimination procedure with moving criterion. With the present sample size, the criterion was approximately 3.5 standard deviations from the mean on the first iteration. Mean RTs, mean accuracies, mean sensitivities, standard deviations, and error rates are presented in Table 1 separately for each task and stimulus category.

An attentional blink was observed in our data. As shown in Table 1, T2 accuracy at lag 2 was significantly lower than T2 accuracy at lag 7; $t(63) = 13.74$, $p < .001$. That is, attending to T1 impaired T2 performance when both targets were presented closely in time, but not when T2 was presented more than 500 ms after T1.

Correlations Amongst Stimulus Types

For RAN and each of the cognitive tasks, intercorrelations amongst scores for the four stimulus types on a given task were computed prior to averaging these scores into a composite score for each measure. Principle components analyses also were conducted for each task to estimate factor loadings for each stimulus type on a single principle component and the overall amount of variability explained in the stimulus types by the principle component. Results are shown in Table 2.

Overall, a strong degree of intercorrelation was found amongst the four stimulus types for RAN performance and amongst the four stimulus types for each of the cognitive tasks. Furthermore, for each task a single principle component had strong loadings from each stimulus type and explained a large proportion of variance across stimulus type. An exception was that responses to the colour stimuli were less consistently interrelated with the other stimulus scores for single task RSVP performance, T1 performance in the dual-task RSVP paradigm, and on the QST task. Given the overall consistency in scores across stimulus type, however, subsequent analyses were based on aggregated mean scores (averaged across stimulus type) for each measure. Internal consistency estimates (Cronbach αs) for each aggregate measure are shown in Table 2.

Correlations Between Reading Comprehension, Reading Rate, RAN, and Cognitive Tasks

Correlations amongst the reading comprehension, reading rate, RAN, and cognitive tasks were examined based on the overall mean scores for each task. Note that in these, and subsequent

Table 1
Mean Reaction Times (RTs), Mean Accuracies, Mean Sensitivities, SDs, and Error Rates by Cognitive Task and Stimulus Type

	Stimulus type				
Task	Overall average	Color	Digit	Letter	Object
Reading comprehension	42.85 (13.57)	—	—	—	—
Reading rate	227.20 (88.78)	—	—	—	—
RAN[a]	25,251 (3,717)	29,731 (6,465)	19,223 (3,100)	20,075 (3,181)	31,974 (4,806)
	0.2% (0.4)	0.2% (0.5)	0.1% (0.3)	0.2% (0.4)	0.4% (0.8)
Manual RT[a]	642 (113)	607 (113)	544 (80)	716 (171)	700 (159)
	1.4% (1.4)	1.3% (1.4)	1.4% (1.4)	2.0% (1.6)	1.2% (1.3)
Vocal RT[a]	454 (56)	488 (71)	414 (60)	412 (52)	504 (66)
	1.3% (1.7)	2.0% (2.6)	1.3% (1.7)	0.6% (0.8)	1.2% (1.8)
Delayed RT[a]	305 (76)	306 (89)	304 (82)	305 (78)	304 (84)
	0.1% (0.3)	0.1% (0.5)	0.1% (0.3)	0.1% (0.4)	0.1% (0.3)
Modified QST[c]	93.9% (3.4)	94.0% (4.5)	93.8% (5.8)	95.4% (4.1)	92.3% (6.1)
Single-task RSVP[b]	57.3% (11.5)	66.1% (15.8)	71.9% (16.9)	59.0% (16.5)	32.2% (20.5)
Dual-task RSVP, T1[c]	95.3% (4.3)	92.9% (10.5)	96.1% (4.4)	95.8% (4.6)	96.3% (5.0)
Dual-task RSVP, T2[b]	52.1% (18.3)	69.5% (27.2)	58.9% (22.7)	42.6% (24.3)	37.5% (20.2)
Dual-task RSVP, AB[d]	67.5%−36.7%	77.1%−61.9%	75.3%−42.6%	60.0%−25.2%	57.7%−17.2%
	=30.8% (17.9)	=15.2% (25.1)	=32.7% (27.1)	=34.8% (27.3)	=40.5% (27.4)

Note. $N = 64$. RAN = Rapid Automatized Naming; QST = Quick Spell Test; RSVP = rapid serial visual presentation.
[a] Mean RTs are shown in milliseconds along with *SD*s (in parentheses). Mean error rates and SDs also are shown. [b] Mean sensitivities (% correct) are shown along with *SD*s (in parentheses). [c] Mean accuracy (% correct) is shown along with *SD*s (in parentheses). [d] Mean sensitivities at lag 7 minus lag 2 are shown along with the mean AB size and *SD*s (in parentheses).

analyses, $ps < .05$ were considered statistically significant. Correlations are shown in Table 3.

RAN was negatively correlated with both reading comprehension and reading rate, such that participants with longer RAN naming times tended to have lower reading comprehension scores and slower reading rates. Of the cognitive tasks, RAN scores were significantly related to manual RTs, vocal RTs, single-task RSVP sensitivity, and both T1 accuracy and T2 sensitivity dual-task RSVP scores. RAN times were higher amongst participants with longer manual RTs, longer vocal RTs, lower single-task RSVP sensitivity, lower T1 accuracy in dual-task RSVP, and lower T2 sensitivity in dual-task RSVP. In contrast, RAN scores were not related to delayed RTs, modified QST task, and AB size.

Reading comprehension was significantly associated with manual RT and dual-task T2 performance. That is, reading comprehension was higher amongst individuals who also produced faster manual RTs and higher sensitivity to T2 in the dual-task RSVP paradigm. In contrast, in the pairwise correlations, reading comprehension was not significantly related to delayed RT, vocal RT, QST, single-task RSVP sensitivity, RSVP dual-task T1 accuracy, and AB magnitude. Reading rate was not significantly associated with performance on any of the decomposition tasks.

To isolate the variance in manual RT that was not attributable to simple motor execution speed, a residual manual RT score was computed by regressing manual RT on delayed RT and saving the standardised residuals. This residual manual RT score was significantly correlated with RAN and reading comprehension ($rs = .25$ and $-.29$, respectively), but not with reading rate ($r = -.11$). Furthermore, in light of the moderate to strong intercorrelations amongst the single-task RSVP sensitivity, RSVP dual-task T1 accuracy, and RSVP dual-task T2 sensitivity measures shown in Table 3, a composite RSVP performance measure was computed by standardising and averaging across these three measures ($\alpha = .81$). Higher scores indicated better RSVP performance (i.e., greater sensitivity and accuracy). This composite RSVP performance measure was significantly correlated with RAN ($r = -.47$),

Table 2
Results From Principle Components Analyses by Cognitive Task

	RAN	Manual RT	Delayed RT	Vocal RT	QST	Single-task RSVP	Dual-task RSVP T1	Dual-task RSVP T2	Dual-task RSVP AB
Intercorrelations[a]	.48 to .73	.56 to .72	.75 to .83	.70 to .81	.16 to .51	.04 to .53	.05 to .72	.35 to .65	.11 to .36
Standardized loadings									
Color	.85	.87	.90	.90	.57	.37	.41	.65	.58
Digit	.87	.87	.92	.92	.54	.77	.90	.86	.76
Letter	.86	.89	.93	.91	.81	.81	.86	.79	.69
Object	.80	.81	.92	.90	.75	.63	.64	.82	.65
% variance explained[b]	71%	74%	84%	82%	46%	45%	53%	61%	45%
Cronbach α	.82	.85	.94	.92	.57	.62	.53	.78	.59

Note. RAN = Rapid Automatized Naming; RT = reaction time; QST = Quick Spell Test; RSVP = rapid serial visual presentation.
[a] Range in correlations (r values) are shown. [b] Percent of total variance explained by a single principle component.

Table 3
Correlations Between Reading Comprehension, Rapid Automatized Naming (RAN), and Cognitive Tasks

Measures	1	2	3	4	5	6	7	8	9	10	11
1. Reading comprehension	—	.53*	−.31*	−.27*	.01	−.12	.00	.16	.15	.22*	−.04
2. Reading rate		—	−.41*	−.11	−.03	−.11	−.01	.08	.17	.20	−.01
3. RAN			—	.28*	.17	.49*	−.18	−.40*	−.41*	−.39*	.00
4. Manual RT				—	.26*	.49*	−.05	−.46*	−.31*	−.56*	−.01
5. Delayed RT					—	.46*	−.13	−.09	−.11	−.18	−.03
6. Vocal RT						—	−.15	−.49*	−.43*	−.40*	−.05
7. Modified QST							—	.10	.32*	.24	.12
8. Single-task RSVP								—	.54*	.66*	.19
9. Dual-task T1									—	.58*	.37*
10. Dual-task T2										—	.23
11. Dual-task AB size											—

Note. RT = reaction time; QST = Quick Spell Test; RSVP = rapid serial visual presentation. $N = 64$.
* $p < .05$.

but not with reading comprehension or reading rate (*r*s = .21 and .18, respectively).

Predicting RAN, Reading Comprehension, and Reading Rate Using the Decomposition Tasks

Three multiple regression analyses were computed to estimate the amount of variance in RAN, reading comprehension, and reading rate explained by the set of decomposition tasks, and to identify which of the decomposition task measures explained unique variance. To do so, RAN, reading comprehension scores and reading rate were regressed onto residual manual RT, vocal RT, modified QST, composite RSVP performance, and AB magnitude.

The regression model explained a total of 32% of the variability in RAN. As shown in Table 4, of the five decomposition task measures, vocal RT and composite RSVP performance each explained a significant amount of unique variability in RAN. Longer RAN naming times were predicted by longer vocal RTs and lower RSVP performance. When the decomposition task measures were entered as simultaneous predictors of reading comprehension, 9% of the variability was explained. The overall regression model was nonsignificant and no predictor explained a significant amount of unique variability in reading comprehension. Similarly, the overall regression model for reading rate was not significant, and none of the individual task measures were significant, unique predictors of reading rate ($R^2 = .04$).

Table 4
Results From Regression of Rapid Automatized Naming (RAN), Reading Rate, and Reading Comprehension on Decomposition Tasks

Predictors	RAN	RComp	RRate
Residual manual RT	−.06	−.24	−.01
Vocal RT	.32*	.04	−.02
Modified QST	−.06	−.02	−.06
Composite RSVP	−.36*	.14	.20
AB size	.13	−.08	−.06
Model R^2	.32*	.09	.04
Adjusted R^2	.26	.02	.00

Note. $N = 64$. RComp = reading comprehension; RRate = reading rate; RT = reaction time; QST = Quick Spell Test; RSVP = rapid serial visual presentation. Standardized regression coefficients are shown by criterion (column) variable.
* $p < .05$.

Predicting the Shared Variance Between RAN and Reading Comprehension, and Between RAN and Reading Rate Using the Decomposition Tasks

The correlation between RAN and reading comprehension ($r = -.31$), and RAN and reading rate ($r = -.41$) indicated that RAN shared 10% and 17% of its variance with reading comprehension and reading rate, respectively. To assess whether this shared variance was explained by the decomposition tasks, two latent variable models were estimated.

First, RAN and reading comprehension were specified as indicators of a latent variable. This latent variable reflected the latent source of the shared variance shared between RAN and reading comprehension. To statistically identify this latent variable, loadings for RAN and reading comprehension scores were constrained to −1 and 1, respectively, consistent with the negative correlation between these scores. The set of decomposition measures were specified as having direct paths to this latent variable, and correlations were estimated amongst each pair of cognitive tasks. In light of differences in measurement scales and magnitudes of the variances between RT and accuracy-based measures (see Table 1), all scores were standardised prior to these analyses including RAN and reading comprehension. The latent variable model was estimated using AMOS software and maximum likelihood estimation.

The decomposition tasks explained a total of 52% of the shared variance between RAN and reading comprehension (model $\chi^2 = 10.70$, $df = 5$, $p = .06$; CFI = .92; RMSEA = .14, $p = .10$). Of the decomposition tasks, the latent shared variance (reflecting better reading comprehension and faster RAN times) was uniquely predicted by greater RSVP performance (see Figure 1). Note that of the remaining predictors, the unique effect of vocal RT approached statistical significance (i.e., $p = .10$).

In the second latent variable model, RAN and reading rate were specified as indicators of a latent variable following the same model specifications described above, but replacing reading comprehension with the reading rate measure. Together, the decom-

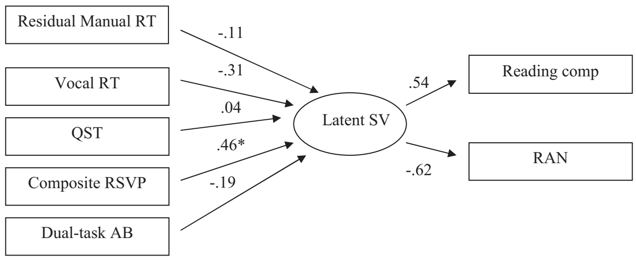

Figure 1. Results from the prediction of the latent shared variance between Rapid Automatized Naming (RAN) and reading comprehension. Standardised path coefficients are shown from the decomposition tasks to the latent shared variance ("latent SV") factor. Standardised factor loadings for reading comprehension ("reading comp") and RAN also are displayed. To simplify presentation, correlations amongst the cognitive task measures and residual error terms for the latent SV variable, RAN, and reading comprehension are not shown. * $p < .05$.

position tasks explained a total of 39% of the shared variance between RAN and reading rate (model $\chi^2 = 10.15$, $df = 5$, $p = .07$, CFI $= .93$, RMSEA $= .13$, $p = .12$). Here again, of the decomposition tasks, the latent shared variance (reflecting faster reading rate and faster RAN times) was uniquely predicted by greater RSVP performance (see Figure 2). Of the remaining predictors, the unique effect of vocal RT again approached significance (i.e., $p = .07$).

Discussion

Relationship Between RAN and Reading Performance

The relationship between RAN performance and reading ability in adults was investigated in the context of six computer tasks designed to decompose the RAN task into various mental processes. The primary goal of the study was to explore which aspects of the RAN task might underlie its connection to skilled reading performance. A wide range of studies has established a correlation between RAN and reading skill in both typically developing and reading impaired children (e.g., Blachman, 1984; Denckla & Rudel, 1974). However, studies of RAN and reading in adults have typically focused on reading impaired individuals (Felton et al., 1990). The present investigation focused specifically on college adults who were assumed to have normal-range reading abilities. Consistent with prior studies, the results revealed a clear relationship between reading rate and reading comprehension and RAN performance. This finding indicates that RAN is not simply diagnostic of very low reading scores in children, but can also explain distinctions in normal reading ability that can last into adulthood. Indeed, the present correlations of $-.31$ and $-.41$ between RAN and reading comprehension and reading rate respectively, are only slightly lower than the .45 relationship reported in the Swanson et al. (2003) meta-analysis of 1550 children and adults (including both normal and poor readers).

Interestingly, naming times for colour and object RAN predicted reading rate and comprehension as well or better than naming times for letter and digit RAN in the present study. This is the opposite of the pattern that is typically observed with normal and reading impaired children (e.g., Blachman, 1984; Cornwall, 1992; Maya et al., 2004; Spring & Capps, 1974). Indeed, Maya et al. (2004) contend that colour and object RAN are not predictive of reading performance in normal readers after first or second grade, but that letter and digit RAN continue to predict performance in normal reading until at least age 18. The present results argue against this assertion, showing clearly that colour and object RAN can predict reading performance for normal readers into young adulthood. Maya and colleagues suggest that the better prediction for letters and digits may result because good readers come to automatize letter and digit naming after Grade 1, whereas poor readers do not. This allows for greater variability in letter and digit naming performance across good and poor readers. They posit than colour and object naming never really get automatized for either good or poor readers, thus reducing their ability to discriminate amongst readers. The reverse may be true for relatively skilled young adult university student readers where all participants may have automatized letter and digit naming, but there was generally less automatization of colour and object naming. In support of this idea we observed faster naming times and smaller standard deviations for letter and digit RAN tasks than for colour and object RAN tasks. We therefore speculate that amongst more highly skilled adult readers object and colour RAN may capture the most useful variability in naming performance.

Relationships With RAN Decomposition Tasks

The key question in this study was which cognitive subcomponents of RAN explained its connection to reading performance. RAN is a complex task whose success in predicting reading ability could be due to one or several of the information processing abilities that must be coordinated for its successful performance. To this end, we devised a range of decomposition tasks that captured specific perceptual, processing and performance aspects of RAN. We found that manual RT, vocal RT, single-task RSVP, and dual-task RSVP (T1 and T2 performance) tasks were all significantly correlated with RAN performance, suggesting that the decomposition tasks did indeed tap some of the mental processes required for RAN. Collectively, these tasks explained roughly one third of the variability in RAN performance. However, from a task decomposition point of view, it was not the case that each was contributing unique variance to RAN ability.

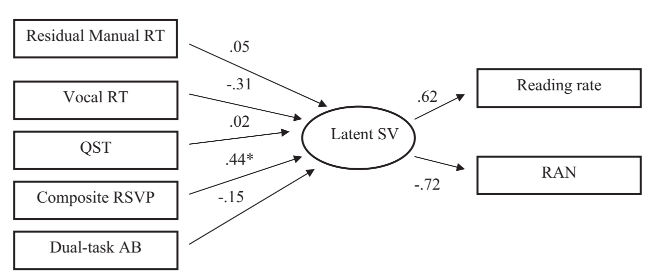

Figure 2. Results from the prediction of the latent shared variance between Rapid Automatized Naming (RAN) and reading rate. Standardised path coefficients are shown from the decomposition tasks to the latent shared variance ("latent SV") factor. Standardised factor loadings for reading rate and RAN also are displayed. To simplify presentation, correlations amongst the cognitive task measures and residual error terms for the latent SV variable, RAN, and reading rate are not shown. * $p < .05$.

Both vocal naming time and composite RSVP performance explained unique variability in RAN. The relation between vocal naming times and RAN performance suggest that variability in motor planning and/or vocal production contributes to variability in RAN times. While phonological awareness and RAN have often been suggested to account for independent variance in reading achievement (Blachman, 1984; Bowers, 1995; Bowers & Newby-Clarke, 2002; Bowers & Swanson, 1991; Cornwall, 1992; Wolf et al., 2002), the present data suggest that speed of phonological awareness and/or phonological production may represent one component of the RAN. The relation between composite RSVP performance and RAN suggests that better RAN performance may reflect, in part, more efficient stimulus encoding into working memory in the face of competing stimulus information. With regard to reading comprehension, however, although manual RT (and residual manual RT) and dual-task T2 sensitivity were significantly correlated with reading comprehension, none were uniquely predictive in the regression model. Similarly, none of the decomposition tasks were predictive of reading rate. Thus, of the cognitive processes assessed by the decomposition tasks, identification stimulus encoding demands, as indexed by RSVP performance, and vocal production times, as indexed by the vocal RT task, may be particularly relevant to predicting performance on the RAN.

Explaining the RAN–Reading Relationship

The finding that the decomposition tasks were more closely aligned with RAN performance than they were with reading comprehension and reading rate is not surprising. The decomposition tasks were chosen based on the hypothesised cognitive components of RAN, as well as the expected sources of the connection between RAN and reading ability, rather than the multiple components of reading comprehension. Thus, most critical for present purposes was demonstrating that the decomposition tasks could explain a substantial part of the *shared processing components* of RAN and reading comprehension. That is, a number of cognitive factors correlate with individual differences in reading performance, just as a number of (only partially overlapping) factors correlate with variability in RAN performance. Of interest in this study, however, were the factors that can explain the joint variability of reading and RAN.

To this end, the latent variable approach provided a novel method to examine this issue. Although less commonly applied in reading research, this latent variable approach allowed us to directly assess an important question that is not otherwise easily amenable to investigation. A substantial proportion of the shared variance between RAN and reading comprehension and between RAN and reading rate was explained by the decomposition tasks (52% and 39%, respectively). Only the composite RSVP performance, however, was a unique predictor in the latent variable models. RSVP performance has been posited to reflect the ability to identify a stimulus rapidly and encode it into working memory (e.g., Jolicoeur, 1998). Efficient updating of working memory also should be required for good reading comprehension (Norman, Kemper, & Kynette, 1992). Thus, the ability to encode information in the face of competing stimulus information might underlie, at least in part, the shared processing components of RAN and reading.

Vocal RT came close to being a significant unique predictor of the shared variability between RAN and reading, both with reading comprehension and reading rate. This suggests that motor planning and/or vocal production may also explain variability in the RAN-reading relationship that is independent of rapid identification and encoding into working memory. Phonological awareness and RAN have been suggested to account for independent variance in reading achievement (Blachman, 1984; Bowers, 1995; Bowers & Newby-Clarke, 2002; Bowers & Swanson, 1991; Cornwall, 1992; Wolf et al., 2002). It is possible that instead of phonological awareness and RAN contributing independently to reading performance, that stimulus identification/working memory encoding and motor planning/vocal production explain independent variance in the relationship between RAN and reading.

It is this shared variance between RAN and reading performance that was of primary interest in the present work. Although the total amount of variability in RAN explained by the decomposition tasks was moderate (and modest for reading comprehension and reading rate), it is important to emphasise that much of the attention given to the RAN task by researchers and clinicians has stemmed from the ability of this task to predict reading performance. However, not all of the variability in RAN performance is related to reading ability (Swanson et al., 2003). Therefore, in addition to understanding the sources of the variability between individuals in reading ability and RAN performance, there is much to be gained by isolating the common variance between RAN and reading, and investigating the nature of this linkage. To this end, the approach taken in the present work provides a valuable first step toward identifying *why* RAN and reading are linked. By systematically expanding the number and nature of the cognitive processes and mechanisms explored in future research, progress can be made both in explaining variability in RAN and reading performance, as well as accounting for the covariance between them.

While most research on the relationship between RAN and reading ability has been focused on children, the present work was based on a sample of university undergraduates. An important issue for future research, therefore, is determining whether the decomposition tasks identified in the present study as relevant to the connection between RAN and reading ability also are implicated amongst children and adolescents. For instance, there is evidence that although RAN continues to predict reading ability in both children and adults, this relationship can change in subtle ways as a function of age (e.g., van den Bos et al., 2002).

Also important, some of the variability in RAN was not explained by the decomposition tasks. Part of the variability in RAN may reflect a complex coordination of individual item recognition, eye movements, and speeded output that was necessarily stripped away in the individual decomposition tasks. However, the decomposition tasks did not include other cognitive components that likely are relevant to both RAN and reading ability, including word recognition and phonological awareness.

Similarly, although our study included a measure of text comprehension, the Nelson-Denny test provides only a partial view of the broader construct of interest. In future work, therefore, a multidimensional assessment of reading ability, incorporating aspects such as word recognition, decoding, phonological processing skills, phonemic awareness, and orthographic awareness, would provide a valuable extension of the present findings. Also, the

Nelson-Denny is a time-pressured reading comprehension test. It would be interesting to use the present approach to examine the factors that underlie the relationship between RAN and reading using a reading comprehension measure that was not time-pressured, as it is possible that a portion of the variability shared by RAN and the reading measures was related to the speeded nature of these tasks. We expect that the latent variable approach applied in the present work will be particularly useful in future research addressing these issues.

Finally, the moderate sample sise may have resulted in attenuated statistical power. Although the number of predictor variables relative to the number of study participants (i.e., 1 to 12.8) was within the recommended range for regression analysis (e.g., Cohen, Cohen, West, & Aiken, 2003), in both latent variable models, the unique predictive effect of vocal RT was substantive in magnitude, but failed to reach conventional levels of statistical significance. Given the moderate effect sizes observed in the present work, future investigations examining the sources of the covariation between RAN and reading would benefit from inclusion of a large group of respondents.

In conclusion, this study extended previous research in several ways. We showed a clear relationship between RAN and reading performance in skilled adult readers. Using a novel latent variable approach, we also sought to better understand the cognitive mechanisms underlying the relationship between RAN and reading in terms of perceptual, attentional, and motoric components. RSVP performance appeared to underlie part of the relationship between RAN and reading. These findings implicate working memory processes as a possible underlying source of the relationship between RAN and reading performance. However, part of the connection between RAN and reading remains unexplained—possibly reflecting the "cognitive overhead" necessary to coordinate the multiple subskills that operate during RAN and reading.

Résumé

Le test *Rapid Automatized Naming* (RAN) implique de nommer rapidement des séquences d'items présentés visuellement. Le RAN a suscité beaucoup d'intérêt, car la performance à ce test prédit les succès en lecture. Cette étude avait pour but de déterminer quels éléments du RAN sont responsables de la variance partagée entre ce test et la performance de lecture en utilisant une série de tâches cognitives et une approche de modélisation à variable latente. Les participants ont effectué les mesures du RAN, un test de vitesse et de compréhension de lecture et six tâches permettant de tester différentes supposées composantes du RAN. Le RAN partageait 10 % de variance avec la compréhension de lecture et 17 % avec la vitesse de lecture. Ensemble, les tâches utilisées pour la décomposition expliquaient respectivement 52 % et 39 % de la variance partagée entre le RAN et la compréhension de lecture et entre le RAN et la vitesse de lecture. Des prédicteurs significatifs suggèrent que l'encodage en mémoire de travail sous-tend une partie de la relation entre le RAN et les habiletés de lecture.

Mots-clés : lecture, dénomination rapide, RAN, variabilité latente, différences individuelles

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