

## **On a test for predicting success in reading skill development: Anatomy of the RAN Task**

Eugene Borokhovski, Norman Segalowitz & Guy L. Lacroix  
Psychology Department and The Centre for the Study of Learning and Performance  
Concordia University, Montréal

Reading is a fundamental ability required of everyone by modern society. To become literate is the first step to all other academic achievements, and to be illiterate or a poor reader can result in life-long professional barriers and social challenges. No wonder, then, that so many psychologists, educators, and health professionals share in their determination to learn more about the factors associated with success and failure in reading development. Their goals are to determine, in a timely manner, who is at risk of developing reading problems and to devise efficient ways to either prevent or to overcome reading impairments.

There are a number of diagnostic tools that are capable of reliably predicting the development of reading skills (see Rayner, Foorman, Perfetti, Pesetsky & Seidenberg, 2001; Stanovich, 2000, for a general review in the area of reading). One popular task is the Rapid Automatized Naming task (RAN) (Denckla, 1972; Denckla & Rudel, 1974). In this task, the individual is required to say aloud, as quickly as possible, the names of 50 items (e.g., letters) presented in a 5 x 10 display. This test is well known for its ability to predict reading acquisition: the better (faster) a person performs on the RAN task, the more favorable is the prognosis for that person's reading development. Psychologists and educators use the RAN task to predict reading outcomes in children who are in the process of mastering reading skills or to diagnose certain difficulties in reading development from childhood up to adulthood.

While the RAN task seems to have strong predictive ability (Wolf, Bowers, & Biddle, 2000; Wolf, O'Rourke, Gidney, Lovett, Cirino, & Morris, 2002), it turns out that the nature of the cognitive processes underlying performance on this test has not yet been fully established (Savage, 2004). The RAN task exists in several different formats, all of which require participants to name aloud, as fast as possible a large sequence of simple stimuli (e.g., objects, colors, digits, and letters).

The speed of naming is positively associated with future reading performance. One needs to ask, however, what the test is actually measuring. The view articulated within the framework of the "double-deficit hypothesis" (Wolf & Bowers, 1999) asserts that most or all of the cognitive components underlying RAN performance are highly speed-sensitive. That is, performing well on the RAN task overall requires that many of the underlying component activities—recognizing the item to be named, finding the name in memory, planning its articulation, etc.—be carried out in a relatively automatic way. According to this view, the RAN task measures the degree to which a person has automatized connecting symbols to their meanings. An alternative explanation of the success of the RAN task in predicting reading is that it assesses how efficiently the individual is able to coordinate the various underlying processes. Coordination of mental processes involves what psychologists call "executive control"—the control processes involved in working memory and attention (for example, Norman and Shallice, 2000).

The present study addressed the difference between these two views by asking: Is it the degree of automatic processing or the degree of attention control that underlies the predictive power of the RAN task? Put another way, the question could

be formulated as follows: What does the “A” in RAN actually stand for—“automatized” or “attention-based” processing?

### 1. RAN and reading in more details

Among reading impairments, developmental dyslexia occupies a special place because no obvious reasons are readily available to account for the impairment. Consider the classic consensus documented by Critchley (1970): “[Developmental dyslexia is] a disorder manifested in difficulty in learning to read despite conventional instruction, adequate intelligence and socio-cultural opportunity.” (cited by Snowling, 2000, p. 15). This definition is just one example in a vast collection of similar approaches including, for instance, Bishop (1997) and Kelly (1998), among others. This approach not only distinguishes developmental dyslexia from other forms of learning disorders, but also emphasizes that it derives from problems in cognitive development and is not associated with any particular intellectual setbacks or social or educational deprivation.

Two major factors are commonly believed to underlie successful reading and whose impairment can result in developmental dyslexia of different degrees of severity. The first is phonological awareness—the ability to understand and handle efficiently the relationships between graphemes and phonemes as elements of written and spoken language respectively. In tests of phonological awareness participants are usually asked to correctly pronounce written letter patterns (the list of typical PA tasks includes rimes, blending and segmentation, rhyme and onsets, and phoneme elisions) and/or to spell those patterns when presented auditorily. The view that phonological awareness is the strongest and most reliable predictor of successful reading skill development in children is supported by a long line of psychological, linguistic and pedagogical research (for example, Fawcett, 2001; Rayner et al., 2001; Snowling, 2000, Stanovich, 2000). Naming speed is also considered to be a strong and to be relatively independent of phonological awareness predictor of reading. According to the double-deficit hypothesis (Wolf & Bowers, 1999), the most severe cases of developmental dyslexia occur when both phonological awareness and naming speed are impaired at the same time in a child’s cognitive profile.

Naming speed is empirically measured by performance on the RAN task which, in its most commonly used format, is composed of four sub-tasks. These tasks require participants to name aloud as quickly as possible a long sequence of either linguistic (letters and numbers) or nonlinguistic (colors and object pictures) stimuli. As with phonological awareness, the RAN task has a rich history of applied research. During the past three decades, the connection between the RAN task and reading has been empirically studied cross-sectionally, longitudinally, and in cross-language examinations, providing ample evidence in support of the double-deficit hypothesis (see Wolf, Bowers, & Biddle, 2000, for review). Cross-sectional studies have attempted to determine how well RAN task performance distinguishes developmental dyslexia from other learning disabilities that are not reading-specific. Longitudinal studies have used RAN task performance in earlier stages of cognitive development as a predictor of reading outcomes later on in different age groups. Finally, cross-language studies have looked at the relationships between measures of RAN task performance and reading fluency in different languages. Remarkably, the more transparent the language grapheme-phoneme structure is (i.e., the more word pronunciation directly matches spelling), the better RAN test performance predicts reading (DeJong & Van der Leij, 2003; Korhonen, 1995; Landerl, 2003; Novoa, 1988; Van den Bos, 1998; Wimmer, 1993).

As Wolf et al. (2002) have emphasized, the greater orthographic regularity in more transparent languages reduces the demand for phonological analysis. Under such circumstances, RAN task performance overtakes phonological awareness as a leading predictive measure of reading outcomes. The importance of this observation is that it once again emphasizes relatively independent nature of naming speed among the set of cognitive components contributing to successful reading acquisition. There remain, however, many important questions about the cognitive nature of performance on the RAN task that underlies its association to reading skills.

Wolf and Bowers (1999) described many of the processes involved in reading (i.e., symbols recognition, meaning activation and memory retrieval, speech label attachment, etc.). They see these as highly speed sensitive and thus requiring an optimal level of automatization for successful implementation. None of the other components of RAN task performance (i.e., articulation rate or short-term memory capacity), according to the authors, could possibly affect naming substantially enough to explain the differences between normal and troubled readers (Wolf, Bowers, & Biddle, 2000).

Fluent performance on any task is most often presumed to be automatic, that is, carried out rapidly, efficiently, and protected from interference. For example, the classic work of Laberge and Samuels (1974) explained reading fluency in terms of automatic word-identification achieved through practice. Such automaticity is understood to result from a high level of exposure to and great familiarity with specific words. Automaticity in RAN task performance appears instead to be related to trait characteristics of the readers themselves. This latter automaticity reflects some of the dynamic characteristics of the organization of cognitive processes, namely, how fast and efficiently one can put together the appropriate operations to perform successfully upon a long sequence of relatively unpracticed and unrelated stimuli.

One question in particular about the cognitive nature of automaticity as measured by the RAN task performance was the focus of interest for the present study. Ever since it was first introduced to describe cognitive processes not requiring attentional executive control (Anderson, 1983; Kahneman, 1973, Schneider & Shiffrin, 1977), the idea of automaticity has become a central concept in the cognitive psychology literature. Automaticity is broadly recognized to be critically important for understanding the nature of skill acquisition, regardless of the particular area of expertise (Segalowitz & Hulstijn, in press, for a review with implications for second language learning).

Usually, automaticity is described in terms of the rapidity of responses, their effortlessness, the non-involvement of conscious control and the ballistic (unstoppable, difficult if not impossible to interrupt) nature of responses. Although these distinctive characteristics of automaticity have been emphasized in various conceptual and empirically-oriented definitions, it is now clear that automaticity cannot be reduced to a simple combination of “critical-features”. Each feature can be separately operationalized and, in principle, play relatively independent and substantial roles in RAN task performance.

Research on cognitive factors involved in the RAN task has not been entirely restricted to automatic mechanisms. Attention-based mechanisms have also been considered. However, attempts to link poor reading skills and RAN task performance through attention-based mechanisms have turned out to be somewhat inconclusive (for example, Moores, Nicholson & Fawcett, 2003; Nigg, Hinshaw, Carte, & Treuting,

1998; Semrud, Guy, Griffin, & Hynd, 2000; Tannock, Martinussen & Frijters, 2000). Nevertheless, there continues to be interest in such a possibility (e.g., Lacroix, Constantinescu, Cousineau, de Almeida, Segalowitz, & von Grunau, in press; Visser, Boden, Giaschi, 2004).

As Savage (2004) duly noted, the question about what cognitive factors underlie RAN-task performance is still very much up in the air. The present study aims to address this question further.

## 2. The present study

The research questions for this study were:

- a. What form of automaticity, if any, underlies RAN task performance?
- b. Do attention-based factors contribute to RAN task performance?

The general design of this study was the following. Participants were given various versions of the RAN task: a test that yielded two different measures of ability to process stimuli automatically (ballistic processing; rapid, stable processing); a test of attention skill (control of focus shifting); and a test of reading skill (speed of silent reading). The research questions were addressed by examining through multiple regression analyses the unique contribution of the two measures of automaticity and the measure of attention to participants' performance on RAN individual sub-tasks. Below is more detailed description of each measure employed.

*RAN Task.* Four versions of the RAN task were prepared using a sequence of 50 letters, digits, colors, or object pictures. In each case there were five stimuli used repeatedly in a randomized manner. The version using letter and digit stimuli assessed the participants' ability to name reading-related stimuli. The versions using color patches or object pictures assessed general naming speed (Denckla & Rudel, 1974). Naming in each sub-task was to be implemented in participants first language.

*Automaticity.* There were two indices of a person's ability to process stimuli automatically. The first addressed the degree to which participants were capable of recognizing simple stimuli—letters and digits—in a ballistic (unstoppable) manner. In the procedure based on a “primed decision” experimental paradigm (Favreau & Segalowitz, 1983; Neely, 1977) participants were given the task of judging whether a letter target stimulus was a vowel or a consonant, and whether a digit target was even or odd. Another stimulus preceded each target. This stimulus, to which the no overt response was required, prepared—or *primed*—participants to be ready for a letter or digit as the subsequent target stimulus. The design of the task made it possible to determine whether the prime had been processed in a ballistic manner or not.

Consider briefly the general idea behind the primed decision paradigm (see Favreau & Segalowitz, 1983, for a fuller discussion of the use of this technique). The prime stimulus in this study was a letter prime composed of five letters (*ABCDE*), a digit prime (*12345*), or a neutral prime (*\*\*\*\*\**). The prime influences the participants' responses to the target. If the prime prepares them for a letter target and a letter actually appears, then their response on that trial will be facilitated (faster) than if the prime had been neutral. If the prime wrongly prepares them, then the response will be interfered with (slower). There are, however, two factors that actually impact on how fast a participant's response will be—prime-target relatedness and prime-target expectancy. A prime and a target may be related (i.e., may belong to same category, digit or letter). A prime may, however, be unrelated to the subsequent

target but nevertheless correctly signal its category through expectancy. This is possible when the participant is given explicit instructions, with appropriate preliminary training, to expect a digit target after a letter prime and a letter target after a digit prime. Both relatedness and expectancy may result in facilitation or interference, depending on particular experimental conditions.

In general, when the target is expected given the prime that preceded it, there will be facilitation and when it is unexpected (surprise trials in which the expectation is violated) there is interference. However, there are exceptions to these general regularities depending on how much time separates the appearance of the prime and the target. Expectation can result in facilitation or interference effects, only when there is enough time for the individual to fully process the meaning of the prime. When the interval is too short, and if there is automatic (that is, ballistic) initial recognition of the prime as a string of letters or digits, then the individual will be primed for a related stimulus, regardless of whether the instructions were to expect a related stimulus or not.

Space does not permit discussion of all the possible outcomes of combining expectancy (expect a related target versus an unrelated target), interval (long versus short prime-target interval) and letter, digit and neutral primes with letter versus digit targets (see Favreau & Segalowitz, 1983; Neely, 1977). The logic of inferring ballistic processing of the prime can be explained as follows. Consider the condition where the participant is trained to expect an unrelated target (e.g., 12345–B), and there is a short prime-target interval. On a surprise trial the participant will see a target that is related to the prime (e.g., 12345 –4). This target is unexpected and so there should be interference and hence a slower response to it compared to baseline (e.g., \*\*\*\*\*–4). However, because the interval is short, there is no time for the expectancy instructions to override the automatic recognition of the prime as letters or digits and so in fact there will be facilitation. By contrast, in conditions with a long prime-target interval, there will be interference because the target is unexpected. The facilitation obtained on surprise trials in the short interval, expect-unrelated condition is thus evidence that the participant could not stop processing the prime in terms of how it was first recognized as digits, though otherwise must have been expected.

The second measure of automaticity assessed the degree to which participants were able to process stimuli efficiently. The technique for this was derived from a line of research addressing efficiency in performance (Segalowitz & Segalowitz, 1993, Segalowitz, Poulsen, & Segalowitz, 1999, Segalowitz, Segalowitz, & Wood, 1998). It is based upon the idea of distinguishing between rapid task performance that is due simply to a speeding up of all the underlying processing components and rapid task performance that is due to a restructured and more efficient deployment of underlying processing components.

In brief, the basic idea is this. Performance can appear to be automatic (very rapid) because all the underlying processing components responsible for the performance have become faster, even though the basic cognitive structure of the activity as a whole remains the same. This situation is referred to as simple "speed-up" by Segalowitz and Segalowitz (1993). Alternatively, performance can appear to be automatic because cognitive restructuring has occurred in which the slower components—those that tend to be highly variable in their time of execution and thus contribute lots of "noise" to the overall performance time—are now avoided or

eliminated. This situation is referred to as "restructuring" by Segalowitz and Segalowitz because it involves a new, more efficient activity structure. Segalowitz and Segalowitz proposed to distinguish speed-up from restructuring by examining changes in the coefficient of variability (CV) of the response time. The CV is the ratio of an individual's standard deviation (SD) of reaction time (RT) to the mean RT for that individual throughout the performance of the activity in question.

The basic logic of this measure is quite straightforward. If practice simply results in a speed-up of the processes underlying performance, then the variability (SD) in RT should decrease, at most, proportionally to the RT reduction itself. It leaves CV relatively unchanged (if all the components operate, for example, twice as fast, the RT should decrease by 50% and so should the SD). Suppose now that faster performance is achieved because of restructuring (more efficient organization) of the underlying cognitive processes, so that some of them became redundant, and hence unnecessary. Presumably, these would be the slowest component processes (decision making processes, inefficient search processes, etc.), those that require a larger amount of attentional control in the early phases of learning and practice. In this case overall response time variability should decrease by a much greater proportion than the reaction time itself, resulting in a significant reduction of the corresponding CV index.

*Attention.* Attention can be understood in terms of sustaining, focusing, dividing, suppressing, or shifting the concentration of conscious resources. In this study, we were interested in how efficient the attention shifting process in participants is, on the assumption that it is responsible for managing the complex processing of a large sequence of stimuli involved in the RAN task, that is, in attending to a stimulus, recognizing it, identifying its name, saying the name aloud, disengaging from the stimulus and attending to the subsequent one. The test used to assess attention control was the "Trail Making" test (Spreeen & Strauss, 1991). This test consists of two conditions in which requires participants connect a set of 25 circles randomly distributed across a page. In one condition, the circles are numbered from 1 to 25 and must be connected in numerical order. In the other condition half the circles are labeled with numbers (1-13) and half with letters (A-L). The participant must connect the circles by shifting from letters to digits and back in the standard order (1-A-2-B...etc.). The difference in time between the shifting and non-shifting conditions provides an index of attention control (the lower this difference, the lower is the burden of having to shift and hence the greater the degree of attention control).

Finally, to verify if the association between RAN task performance and reading is intact in young adults, a measure of reading skill was obtained, as well.

*Reading skill.* Reading skill was assessed by presenting participants a series of short texts, which they had to read silently and then answer simple multiple choice gist questions to ensure they had comprehended what they had read. The texts were presented on a computer screen, and the participants advanced through the texts by pressing a key. Reading speed and answers accuracy were recorded by the computer. Participants were tested in both their first language (English or French as appropriate) and in their second language (French or English), but only the first language data are considered here.

To summarize, data were collected on the RAN task, on automatic processing in terms of priming effects (ballistic processing) and the CV index (processing efficiency),

and on attention control. Reading skill was also assessed to see whether RAN task performance would be related to reading ability in the adult population tested here.

We assumed that whatever mechanisms are involved, their impact should be observable in fully developed normal adult readers, as well. Extensive practice in reading might moderate this impact somewhat, but it should not change the basic regularities in how adults perform both naming and reading activities. Moreover, the practice factor might even better explain the potential role different cognitive factors underlying RAN performance play in reading.

### 3. Method

*Participants.* There were 55 participants (39 women, 16 men, mostly undergraduate students of Concordia University, plus several off-campus volunteers who also responded to the call for participants). The mean age was 26.62 (ranging from 19 to 55, with the mode of 21). All had normal or corrected to normal visual acuity and reported no known learning disabilities. Thirty-nine indicated English as their first (dominant) language, and 16 indicated French.

*Procedure.* All participants completed the following: (a) The RAN task; (b) Primed decision-making tasks that tested automatic processing; (c) The Trail Making test of attention control; and (d) A reading speed test. After completing the tests, participants filled out a short biographical questionnaire.

*RAN Task.* Four RAN subtasks (letters, digits, colors, and objects) were administered. The following stimuli were used: in the letter condition - *a, d, o, p,* and *s*; in the digit condition - *2, 4, 6, 7,* and *9*; in the color condition - *red, yellow, green, blue,* and *black* squares, and in the objects condition line drawings of the following objects - *key, umbrella, watch, scissors,* and *comb*. In each condition the stimuli were presented on a computer screen in 5 rows of 10 items, using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) with a G4 iMac. Time required to say aloud the names of all 50 stimuli on each subtask was recorded.

*Automaticity.* A primed decision task was used to test automaticity. Participants saw a continuous set of trials consisting of a prime stimulus string followed by a target consisting of a single letter from the set "*a, e, i, u, b, c, d, p*" or a single digit from the set "*2, 3, 4, 5, 6, 7, 8, 9*". They had to judge whether the digit target was odd or even and whether the letter target was a vowel or consonant by pressing a response key. Targets were primed by either a string of digits ("*12345*"), a string of letters ("*ABCDE*"), or a string of asterisks (neutral prime). All information appeared in the center of an iMac standard monitor. Stimulus presentation was managed by a program written in HyperCard 2.3, which also registered reaction times and analyzed participants' responses.

Participants took part in two different conditions, several days apart. One of them was the Expect Related condition, in which participants were instructed that a letter string prime indicated that the upcoming target would be a letter, that the digit string prime indicated that the upcoming target would be a digit, and that neutral primes could be followed by either a letter or a digit. The other was the Expect Unrelated condition, in which a letter string prime predicted a digit target and a digit string prime predicted a letter target. Prior to each experimental session participants were given a detailed description of the activities to be performed and a training session, which lasted until criteria for full understanding of the instructions were met.

Both conditions consisted of 480 experimental trials of which 80 % were regular trials (primes and targets appearing as per instructions), 10 % were surprise trials (primes appearing with the "wrong" target) and 10 % were neutral prime trials. Within each condition half of the trials used a short prime-target stimulus onset asynchrony (SOA) interval of 150 ms and half used a long SOA of 1000 ms. These SOAs were distributed equally across regular, surprise and neutral trials.

To ensure that the expectancy instructions were effective, each condition began with an extensive training period with only regular and neutral trials under the long SOA condition. Training continued until no errors were made in 12 consecutive trials and the average response time for regular trials was at least 10 % faster than for neutral trials.

*Attention.* Attention control was measured using the "Trail Making" test (Spreen & Strauss, 1991). This test is comprised of two forms. Form A required participants to connect 25 numbered circles in sequence, and Form B to connect 25 lettered and numbered circles in sequence, but alternating between letters and digits (1-A-2-B-etc.). Both forms were to be completed as fast and as accurately as possible and time to complete each form was recorded.

*Reading speed.* Participants' silent reading rate and comprehension in both their first and second languages were measured. Seventeen 250-350 word passages, about 2-3 paragraphs each, were used for this test. These passages were adapted from Davy and Davy (1992), a TOEFL practice book for university level second language English. Seventeen translations of these passages were prepared in French by a professional translator who matched the texts for register and difficulty level. Each participant was tested on 8 randomly selected passages from the English set and the 8 complementary passages in French, with a common warm-up passage at the start of each language block. Associated with each passage was a simple 3-option multiple-choice question that tested for text comprehension. Reading time and accuracy in answering the questions were recorded.

*Questionnaire.* A short demographic survey elicited data about the participants' age, gender, basic academic background, absence/presence of learning disabilities or problems with visual perception, and about their history, expertise, actual use and the degree of comfort in the first and second language.

All participants signed a consent form prior to the experiment and upon completion were paid \$20. Each participant took part in two sessions on two different days. Experimental tasks and conditions were counterbalanced and pseudo-randomized across participants.

#### **4. Results**

For all the analyses reported here, the alpha level for significance testing was set at .05.

Of the 55 participants originally tested, the data from eight were excluded. Five failed to meet the inclusion criteria on the primed decision task. Three other participants performed the reading task with insufficient accuracy on the comprehension tests (not different from chance, which was 33 %), raising doubts whether their reading data were meaningful.

The results are presented and discussed below, first in terms of the basic findings for each set of measures, and then in terms of the study major research questions.

*RAN Task.* Table 1 presents the naming times for each of the four subtasks of the RAN task. Indices of linguistic RAN performance were calculated by combining results from the letters and digits sub-tasks and of non-linguistic by combining results from the colors and objects sub-tasks.

*Automaticity.* Table 1 also presents the mean RTs for the each of the conditions in the primed decision making task. Preliminary results showed that in the long SOA condition there were significant facilitation effects for expected targets and interference effects for unexpected targets and in the short SOA condition there were facilitation effects for related targets only. Importantly, there was a significant facilitation effect on surprise trials in the short interval, Expect-Unrelated condition, indicating that the test was able to demonstrate ballistic processing. We used the relative value of this facilitation effect (i.e., divided by the mean RT for the neutral trials in this condition). Table 1 also shows the CV indices (the individual's standard deviation of reaction time divided by that person's mean reaction time. Of special interest is the CV obtained from the short interval baseline trials in the Expect-Related condition because it could serve as an indicator of efficiency-based automaticity for recognizing letters and digits uncontaminated by either expectancy or relatedness factors.

*Attention.* The Trail making attention test yielded two basic measures of performance: time required to complete Forms A (involving numbered circles only) and Form B (requiring attention shifting between numbered and lettered circles). To assess the attention shift cost, time to complete Form B was residualized against the time to complete Form A. The residuals obtained in this way reflected those aspects of performance on the Form B that could not be predicted from performance on Form A (namely, the effect of shifting attention focus) and controlled for individual differences in other factors, such as spatial search and motor skills (see Table 1).

*Reading skill.* Silent reading rate was calculated as the average time spent on reading a single word (ms per word) in each of the participants' languages. Table 1 reports these mean reading times along with the mean comprehension scores. The second language data is not relevant to this study and will not be considered further.

Table 1. Descriptive statistics of the major variables in the study

Experimental Task	Variable	Mean	SD	
RAN task	1 Performance time on letters (sec.):	<b>17.66</b>	<b>2.79</b>	
	2 Performance time on digits (sec.):	<b>18.23</b>	<b>2.58</b>	
	3 Performance time on colors (sec.):	<b>29.85</b>	<b>4.79</b>	
	4 Performance time on objects (sec.):	<b>37.89</b>	<b>7.39</b>	
	5 Linguistic (letters & digits) performance combined (ms):	35.89	5.06	
	6 Non-linguistic (colors & objects) performance combined (ms):	67.74	11.16	
Primed decision task	7 Facilitation effect - xR, long SOA, regular trials (ms):	23.1	44.5	
	8 Facilitation effect - xU, long SOA, regular trials (ms):	10.1	33.3	
	9 Interference effect - xR, long SOA, surprise trials (ms):	-77.2	55.4	
	10 Interference effect - xU, long SOA, surprise trials (ms):	-69.8	83.0	
	11 Facilitation effect - xR, short SOA, regular trials (ms):	26.0	35.2	
	12 Facilitation effect - xU, short SOA, surprise trials (ms):	56.6	41.8	
	13 Facilitation (xU, short SOA, surprise trials) adjusted by base-line: <i>[Ballistic automaticity index]</i>	.079	.515	
	14 CV - xU, short SOA, neutral trials:	.1846	.0591	
	15 CV - xR, short SOA, neutral trials: <i>[Efficiency-based automaticity index]</i>	<b>.1772</b>	<b>.0682</b>	
	Trail making task	16 Form A performance time (sec.):	26.96	7.10
		17 Form B performance time (sec.):	56.19	16.74
		18 Standardized residual Form B: <i>[Primary attention shift cost index]</i>	<b>.08</b>	<b>1.04</b>
		Silent reading task (L1)	19 Reading rate (ms per word):	294.4
	20 Accuracy (% correct responses):		73.7	15.3

In bold: Variables that are used in the hierarchical multiple regression analyses.

Table 2 presents all the inter-correlations between variables in this study.  
Table 2. Correlation coefficients

VARIABLES:	1	2	3	4	5	6	7	8	9	10	11	12
1. Letter-RAN	-											
2. Digit-RAN	.773***	-										
3. Color-RAN	.486**	.505***	-									
4. Object-RAN	.259**	.245**	.664***	-								
5. Linguistic RAN	.946***	.937***	.526***	.268*	-							
6. Non-linguistic RAN	.380**	.379**	.869***	.947***	.403**	-						
7. Ballistic automaticity index	-.216	-.216	-.089	-.073	-.230	-.086	-					
8. Efficiency-based automaticity	-.152	-.172	.071	.239	-.172	.189	.138	-				
9. Attention (Form A)	.233	.223	.363**	.447**	.242*	.451**	-.077	.157	-			
10. Attention (Form B)	.345**	.233	.416**	.603***	.310*	.578***	.113	.090	.536***	-		
11. Attention shift cost	.263*	.136	.265*	.434** *	.215	.401**	.182	.008	.007	.848***	-	
12. Reading rate (L1)	.401**	.396**	.223	.119	.423**	.175	-.136	-.122	.205	.186	.092	-

\* -  $p < .05$ , \*\* -  $p < .01$ , \*\*\*  $p < .001$ . All - one-tailed

The list of variables:

1 - RAN performance time on letters task; 2 - RAN performance time on digits task; 3 - RAN performance time on colors task; 4 - RAN performance time on objects task; 5 - RAN performance time on letters and digits tasks combined; 6 - RAN performance time on colors and objects task combined; 7 - Facilitation effect (xU, short SOA, surprise trials) - relative value (adjusted by the corresponding base-line condition); 8 - CV index (xR, short SOA, neutral trials); 9 - Trail making test (Form A) performance time; 10 - Trail making test (Form B) performance time; 11 - Standardized residual (Form B performance time) as an attention shift cost index; 12 - Reading rate (ms/word) in L1.

**RAN Task performance and Reading.** Performance on the letter and digit RAN subtasks were significantly correlated with performance on the reading ability task, whereas on the color and digit subtasks it was not (see Table 2).

The main question that motivated this study was addressed through hierarchical multiple regression as follows. RAN task performance on individual subtasks served as criterion variables and measures of automaticity and attention served as predictive variables. The results of these analyses are given in Tables 3-6.

Table 3

Results from a hierarchical regression analysis of RAN (letter sub-task) performance by index of ballistic automaticity, CV-index of automaticity, and attention shift index

Variable:	$r^a$	R	$R^2$	$R^2$ change	F change	Final $\beta$	Model F
Ballistic automaticity	-.216	.216	.047	.047	2.210	-.256	2.210
CV index of automaticity	-.152	.249	.062	.015	.716	-.119	1.465
Attention shift index	.263*	.394	.155	.093	4.736	.310	2.632

<sup>a</sup>Zero-order correlation. \* $p < .05$ .

Table 4

Results from a hierarchical regression analysis of RAN (digit sub-task) performance by index of ballistic automaticity, CV-index of automaticity, and attention shift index

Variable:	$r^a$	R	$R^2$	$R^2$ change	F change	Final $\beta$	Model F
Ballistic automaticity	-.216	.216	.047	.047	2.203	-.229	2.203
CV index of automaticity	-.172	.259	.067	.021	.971	-.142	1.586

Attention shift index	.136	.313	.098	.031	1.479	.179	1.562
ªZero-order correlation. * $p < .05$ .							

Table 5

Results from a hierarchical regression analysis of RAN (color sub-task) performance by index of ballistic automaticity, CV-index of automaticity, and attention shift index

Variable:	$r^a$	R	$R^2$	$R^2$ change	$F$ change	Final $\beta$	Model $F$
Ballistic automaticity	-.089	.089	.008	.008	.359	-.155	.359
CV index of automaticity	.071	.123	.015	.007	.318	.090	.336
Attention shift index	.265*	.312	.098	.082	3.931	.292	1.549
ªZero-order correlation. * $p < .05$ .							

Table 6

Results from a hierarchical regression analysis of RAN (object sub-task) performance by index of ballistic automaticity, CV-index of automaticity, and attention shift index

Variable:	$r^a$	R	$R^2$	$R^2$ change	$F$ change	Final $\beta$	Model $F$
Ballistic automaticity	-.073	.073	.005	.005	.238	-.194	.238
CV index of automaticity	.239	.262	.069	.063	2.999	.262	1.624
Attention shift index	.434*	.529	.280	.211	12.579	.467	5.561*
ªZero-order correlation. * $p < .05$ .							

Together both indexes of automaticity and one of attention explained about 15.5 % (adjusted  $R^2 = .096$ ) of variability in the letters-based RAN (overall model's significance was .062). Results were even lower for the RAN digits and colors sub-tasks:  $R^2 = .098$  (adjusted  $R^2 = .035$ ) for both, not significant as well. Quite a different picture was observed for the object-based RAN sub-task. The overall model was highly significant ( $p = .003$ ) explaining about 28 % (adjusted  $R^2 = .229$ ) in RAN performance. Individual contributions of each factor varied across models with some of them approaching or achieving significance. For example, attention in RAN letter-naming ( $\beta = .310$ ,  $p = .035$ ), RAN color-naming ( $\beta = .292$ ,  $p = .054$ ), and RAN object-naming ( $\beta = .467$ ,  $p = .001$ ), as well as CV index in RAN object-naming ( $\beta = .262$ ,  $p = .051$ ) and the index of ballistic automaticity in RAN letter-naming ( $\beta = -.256$ ,  $p = .082$ ) (see Tables 3-6 for details).

## 5. Discussion

There were several interesting results obtained in this study. First, there was a statistically significant connection between the RAN task performance (especially on a letter-naming “linguistic” sub-task) and the rate of silent reading. Numerous studies have reported analogous findings (for example, Wolf et al., 2002; Neuhaus et al., 2001; Van Daal & Van der Leij; 1999, among others). With practice, in reading this association remains intact (or even gains strength), while the predictive power of so-called “non-linguistic” RAN sub-tasks (like naming objects, for instance) noticeably

declines. Our results reflected this pattern as well. The tested sample was drawn from a population of well-educated young adults with substantial reading practice. Their performance on linguistic RAN sub-tasks was strongly associated with their reading performance, whereas the performance on non-linguistic RAN sub-tasks was not.

Second, in terms of what factors contributed to RAN task performance, there also was a difference between linguistic and non-linguistic RAN subtasks. Performance on the linguistic RAN subtask was not significantly predicted by either automaticity measure or by the attention measure. Performance on the nonlinguistic RAN tasks, however was significantly predicted by the attention measure. At first glance, this result seems puzzling. It would appear that in adults the RAN subtasks most related to reading (the linguistic component reflecting performance on the letter and digit subtasks), were not related to either automatic or attention-based processing, whereas the RAN subtasks least related to reading (the color and object naming subtasks) were related to attention-based processing only. It could be, however, that in highly literate adults, letter and digit recognition are so highly practiced that there is a ceiling effect, and automaticity variables will not serve as effective predictors. On the other hand, more complex naming (connecting color and object symbols to meanings) may not have reached ceiling effects across this population and so cognitive variables are able to explain some of the variance in this RAN task performance. If this is correct, then the interesting finding is that it is the attention-based processes, and not the automatic processes, that most successfully explain variance in RAN task performance.

The present results indicate, if anything, support for attention-based rather than for automatic processing as the underlying cognitive mechanisms addressed by the RAN tasks. However, these results may reflect effects specific to a highly literate and older reading population. Additional research should, therefore, continue to explore the mechanisms underlying RAN task performance by including various types of RAN stimuli differently associated with attention demands, as well as a greater age and levels of literacy in the population tested.

### **References**

- Anderson, J. R. (1983). *The architecture of cognition*. Mahwah, NJ: Erlbaum.
- Bishop, D. V. M. (1997). *Uncommon understanding: Development and disorders of language comprehension in children*. Cambridge, UK: Psychology Press Ltd.
- Cohen J.D., MacWhinney B., Flatt M., & Provost J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, and Computers*, 25(2), 257-271.
- Davy, E. & Davy, K. 1992. TOEFL: Reading and vocabulary workbook. New York, USA: Macmillan Inc.
- de Jong, P. F. & Van der Leij, A. (2003). Developmental changes in the manifestation of a phonological deficit in dyslexic children learning to read a regular orthography. *Journal of Educational Psychology*, 95 (1), 22-40.
- Denckla, M. B. (1972). Color-naming defects in dyslexic boys. *Cortex*, 8, 164-176.

- Denckla, M. B., & Rudel, R. G. (1974). "Rapid automatized naming" of pictured objects, colors, letters, and numbers by normal children. *Cortex*, *10*, 186-202.
- Favreau, M., & Segalowitz, N. (1983). Automatic and controlled processes in the first- and second-language reading of fluent bilinguals. *Memory and Cognition*, *11* (6), 565-574.
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.
- Kelly, B. (1998). Dyslexia/reading difficulty: Reassessing the evidence for a developmental model. *Educational Research*, *40* (1): 3-16.
- Korhonen, T. (1995). The persistence of rapid naming problems in children with reading disabilities: A nine-year follow-up. *Journal of Learning Disabilities*, *28*, 232-239.
- Lacroix, G. L., Constantinescu, I, Cousineau, D., de Almeida, R. G., Segalowitz, N., von Grunau, M. (2004). Attentional blink differences between adolescent dyslexic and normal readers. *Brain and Cognition* (accepted 12.08.2004.)
- Landerl, K. (2003). Dyslexia in German-speaking children. In N. Goulandris (Ed.), *Dyslexia in different languages: Cross-linguistic comparisons* (pp. 15-32). London, England: Whurr Publishers, Ltd.
- Moore, E., Nicolson, R. I., & Fawcett, A. J. (2003). Attention deficits in dyslexia: Evidence for an automatization deficit? *European Journal of Cognitive Psychology*, *15* (3), 321-348.
- Neely, J. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited capacity attention. *Journal of Experimental Psychology: General* *106*, 226-254.
- Neuhaus, G. F., Foorman, B. R., Francis, D. J., & Carlson, C. D. (2001). Measures of information processing in rapid automatized naming (RAN) and their relation to reading. *Journal of Experimental Child Psychology*, *78* (4), 359-373.
- Nigg, J. T., Hinshaw, S. P., Carte, E. T. & Treuting, J. L. (1998). Neuropsychological correlates of childhood attention-deficit/hyperactivity disorder: Explainable by comorbid disruptive behavior or reading problems? *Journal of Abnormal Psychology*, *107* (3), 468-480.
- Norman, D. A. & Shallice, T. (2000). Attention to action: Willed and automatic control of behavior. In Gazzaniga, M. S. (Ed), *Cognitive neuroscience: A reader*, (pp.325-402). Malden, MA, US: Blackwell Publishers.
- Novoa, L. (1988). Word-retrieval process and reading acquisition and development in bilingual and monolingual children. Unpublished doctoral dissertation, Harvard University, Cambridge.
- Rayner, K., Foorman, B. R., Perfetti, C. A., Pesetsky, D., & Seidenberg, M. S. (2001). How psychological science informs the teaching of reading. *Psychological Science in the Public Interests (Special Issue)*, *2* (2), 31-74.
- Savage, R. (2004). Motor skills, automaticity and developmental dyslexia: A review of the research literature. *Reading and Writing: An Interdisciplinary Journal*, *17*, 301-324.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological review*, *84* (1), 1-66.

- Segalowitz, N., & Segalowitz, S. (1993). Skilled performance, practice and differentiation of speed-up from automatization effects : Evidence from second language word recognition. *Applied Psycholinguistics*, *14*, 369-385.
- Segalowitz, N., Poulsen, C., & Segalowitz, S. (1999). RT coefficient of variation is differentially sensitive to executive control involvement in an attention switching task. *Brain and Cognition*, *38*, 255-258.
- Segalowitz, S. J., Segalowitz, N. S., & Wood, A. G. (1998). Assessing the development of automaticity in second language word recognition. *Applied Psycholinguistics*, *19*, 53-67.
- Segalowitz, N., & Hulstijn, J. (2003). Automaticity in bilingualism and second language learning. In J. F. Kroll & A. M. B. De Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches*. London: Oxford University Press.
- Semrud, C. M., Guy, K., Griffin, J. D., & Hynd G. W. (2000). Rapid naming deficits in children and adolescents with reading disabilities and attention deficit hyperactivity disorder. *Brain and Language*, *74* (1), 70-83.
- Snowling, M. J. (2000). *Dyslexia*. Oxford, UK: Blackwell Publishers Ltd.
- Stanovich, K. E. (2000). *Progress in understanding reading: Scientific foundations and new frontiers*. New York: Guilford Press.
- Tannock, R., Martinussen, R., & Frijters, J. (2000). Naming speed performance and stimulant effects indicate effortful, semantic processing deficit in attention deficit/hyperactivity disorder. *Journal of Abnormal Child Psychology*, *28* (3), 237-252.
- Van Daal, V., & Van der Leij, A. (1999). Developmental dyslexia: Related to specific or general deficits? *Annals of Dyslexia*, *49*, 71-104.
- Van den Bos, K. (1998). IQ, phonological awareness, and continuous-naming speed related to Dutch children's performance on two word identification tests. *Dyslexia*, *4*, 73-89.
- Visser, T.A., Boden, C., & Giaschi, D.E. (2004). Children with dyslexia: evidence for visual attention deficits in perception of rapid sequences of objects. *Vision Research*, *44*, 2521-2535.
- Wimmer, H. (1993). Characteristics of developmental dyslexia in regular writing system. *Applied Psycholinguistics*, *14*, 1-34.
- Wolf, M., & Bowers, P. (1999). The question of naming-speed deficit in developmental reading disabilities: An introduction to the double-deficit hypothesis. *Journal of Educational Psychology*, *91*, 1-24. (???)
- Wolf, M., O'Rourke, A. G., Gidney, C., Lovett, M., Cirino, P., & Morris, R. (2002). The second deficit: An investigation of the independence of phonological and naming - speed deficits in developmental dyslexia. *Reading and Writing: An Interdisciplinary Journal*, *15*, 43-72.
- Wolf, M., Bowers, P., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities*, *33*, 387-407.