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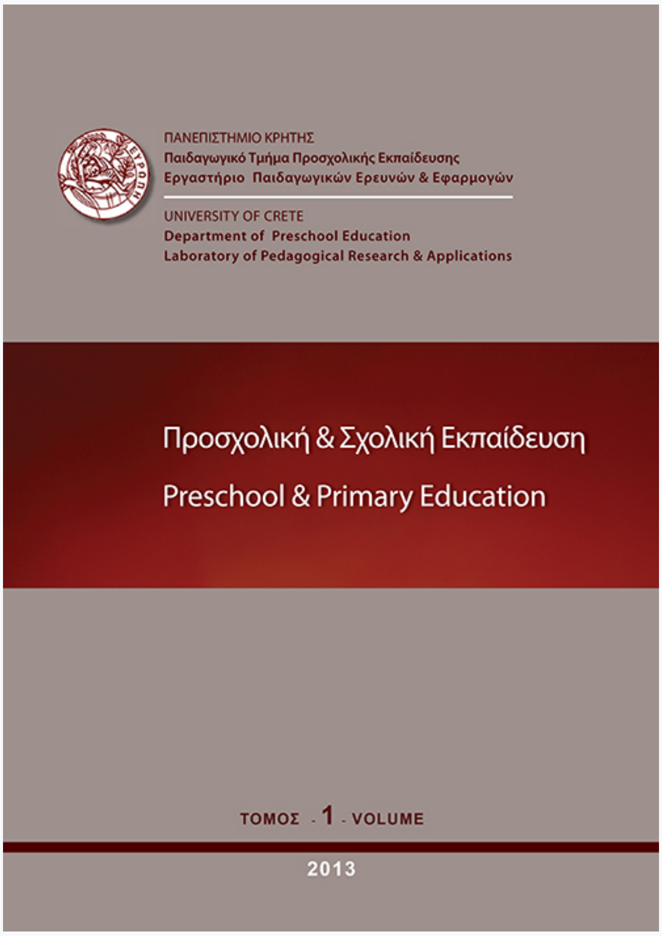

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Is rapid automatized naming automatic?

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Summary. According to Segalowitz and Segalowitz (1993), a process becomes automatic when the mean response time, its standard deviation, and the coefficient of variation (standard deviation/mean response time) decrease across time. To examine whether rapid automatized naming (RAN) reflects automatic processing, we retrospectively traced the development of RAN pause time, its standard deviation, and the coefficient of variation from Kindergarten to Grade 3. Twenty-five good readers and twenty-five poor readers were assessed on RAN Colors and Digits and their sound files were analyzed. The results indicated that there was a significant decrease across time in pause time and its standard deviation for both groups of readers. However, the coefficient of variation increased across time. In addition, the correlations between the pause time and the coefficient of variation were negative. These findings suggest that the observed improvement in RAN performance across time is not due to increased automaticity, but rather due to improved efficiency in the operation of each RAN sub-process.

Keywords: Rapid automatized naming, automaticity, reading, coefficient of variation

Introduction

There is little doubt that rapid naming speed, defined as the ability to name as fast as possible highly-familiar stimuli such as digits, letters, colors, and objects, is a strong predictor of reading acquisition (see Georgiou & Parrila, 2013, for a review). Likewise, rapid naming speed has been considered a second core deficit in reading disabilities (e.g., Wolf & Bowers, 1999) distinguishing between good and poor readers in childhood (e.g., Savage & Frederickson, 2006), in adolescence (e.g., Pennington, Cardoso-Martins, Green, & Lefly, 2001), and in adulthood (e.g., Parrila, Georgiou, & Corkett, 2007).

The history of rapid naming speed in relation to reading goes back to the early 70s (see Denckla & Cutting, 1999, for a historical account). Denckla (1972) demonstrated that dyslexic children were not significantly different from normal readers in color naming accuracy, but were significantly less proficient in color naming speed. Two years later, Denckla and Rudel (1974) developed three more rapid naming tasks with letters, digits, and objects, and used the term 'rapid automatized naming' (RAN) to describe them. Denckla and Rudel noted that the RAN performance time was not related to how early these symbols were learned, but instead to how "automatized" the naming process was. They showed that object or color names were learned much earlier in development, but children were much faster in naming letters and digits, which enjoyed a greater degree of automaticity. Since 1974, this finding has been replicated in several studies across languages (e.g., Albuquerque & Simões, 2010; Bowers, 1995; Di Filippo et al., 2005; Ding, Richman, Yang, & Guo, 2010;

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Georgiou, Parrila, & Kirby, 2006; van den Bos, Zijlstra, & Spelberg, 2002; Wolf, Bally, & Morris, 1986).

According to Wolf and Bowers (1999), RAN (especially for letters and digits) requires a variety of cognitive and linguistic processes, which include:

> (a) attention to stimulus, (b) bihemispheric, visual processes that are responsible for initial feature detection, visual discrimination, and letter and letter-pattern identification, (c) integration of visual feature and pattern information with stored orthographic representations, (d) integration of visual information with stored phonological representations, (e) access and retrieval of phonological labels, (f) activation and integration of semantic and conceptual information, and (g) motoric activation leading to articulation. (p. 418)

Each one of these sub-processes operates within a specific time frame (Wolf, Bowers, & Biddle, 2000). For example, components responsible for lower spatial frequencies operate within 60 to 80 milliseconds following the stimulus presentation and components responsible for higher spatial frequencies operate within 150 to 200 milliseconds. As a result, slow RAN performance may reflect a breakdown within a specific sub-process or a failure to integrate information across sub-processes (Wolf & Bowers, 1999).

In order to examine which aspects of RAN drive its relationship with reading, researchers have decomposed RAN total time into its constituent components of articulation time and pause time (e.g., Araújo et al., 2011; Georgiou et al., 2006; Georgiou, Papadopoulos, Fella, & Parrila, 2012; Li, Cutting, Ryan, Zilioli, Denckla, & Mahone, 2009; Neuhaus, Foorman, Francis, & Carlson, 2001). According to Neuhaus et al. (2001), pause time for letters measures processing speed specifically associated with letters and pause time for objects measures a more general processing speed. The findings of the studies with RAN components suggest that pause time is more strongly related to reading (accuracy and fluency) than articulation time during the early school years. However, in upper grades, articulation time correlates equally well with reading (particularly when operationalized by fluency measures) as pause time. A few studies have also examined the role of consistency (or variability) of pause time in reading (see Li et al., 2009; Neuhaus & Swank, 2002; Parrila & Georgiou, 2006). The results are mixed, partly because of the discrepancy in the way consistency scores have been derived. In Neuhaus and Swank's (2002) study, consistency of pause time was the variance in the naming time across the five rows of stimuli after excluding the end of the line pause times. In contrast, Li et al. (2009) calculated the variability in pause time by dividing the standard deviation of pause time by the mean pause time.

An issue that has received much less attention by researchers is that of automaticity of RAN (Savage, 2004). Various definitions of automaticity have been proposed in the literature including attention-free processing, ballistic processing, effortless processing, and parallel processing (see Moors & De Houwer, 2006, for a review on automaticity). Traditionally, automaticity is inferred if cognitive processes are engaged unintentionally, involuntarily, with little or no expenditure of attention or cognitive resources, and outside of conscious awareness (Anderson, 1983; LaBerge & Samuels, 1974; Samuels & Flor, 1997).

For some researchers, RAN is synonymous to automaticity (e.g., Berninger, 2001; Samuels & Näslund, 1994; Spring & Davies, 1988; Schwanenflugel et al., 2006). Samuels and Näslund (1994), for example, viewed RAN as one of the indicators of automaticity of lexical access. The term "automaticity" is also one of the key concepts of RAVE-O (Retrieval, Automaticity, Vocabulary, Elaboration-Orthography), a fluency-based intervention program designed to address, among others, the naming speed deficits of poor readers (Wolf, Miller, & Donnelly, 2000). However, for some others, it is questionable whether RAN reflects automatic processing (e.g., Borokhovski, 2007; Savage, 2004), particularly if automaticity is defined in terms of processing speed.

Nicolson, Fawcett, and Dean (2001) proposed a causal chain linking automaticity to RAN. More specifically, Nicolson et al. (2001) argued that cerebellar abnormality at birth leads to motor and articulatory problems. Lack of articulatory fluency, in turn, leads to an impoverished representation of the phonological characteristics of speech, and subsequently to difficulties in phonological awareness that then cause problems in learning to read. Likewise, they argued that "naming speed difficulties are precisely those predicted by the cerebellar deficit hypothesis, given its established role in speech, inner speech, and speeded processing" (p. 511). In order to examine the automaticity hypothesis, Nicolson and Fawcett (1990) designed a dual-task paradigm, in which a secondary task was introduced (e.g., counting backwards from 50 in 2's) to divert attentional resources away from the primary task (e.g., balance on a beam with one leg). Unfortunately, several studies that followed failed to provide evidence in support of the hypothetical link between automaticity and RAN (e.g., Raberger & Wimmer, 2003; Savage et al., 2005; Wimmer, Mayringer, & Raberger, 1999).

Even among those who believe in RAN's automatization, there is disagreement on the time when automaticity is achieved. Cronin and Carver (1998), for example, followed two cohorts of typically developing children (one attending primary school and the other Grade 1) for a year and assessed them twice (fall and spring) on RAN objects, letters, and digits. They found that there were no significant differences on total time across the three RAN tasks and across the two measurement points for the younger cohort. However, for the older cohort, the RAN digits and letters were performed much faster than the RAN objects already by the Fall of Grade 1. Cronin and Carver (1998) concluded that "at the beginning of first grade symbolic stimuli had become automatized since they were named faster than the objects" (p. 456). In turn, Wolf et al. (1986) suggested that the time when letters and digits become automatic is around Grade 2. Specifically, in their longitudinal study that expanded from Kindergarten to Grade 2, Wolf and colleagues found that whereas in Kindergarten all RAN tasks were predictive of reading, by Grade 2, only RAN digits and letters continued to predict reading. Wolf et al. concluded that "by grade 2, there no longer exists a general relationship between retrieval speed and reading. From the time graphological symbols become automatic, only differentiated reading-retrieval speed relationships are found" (p. 998).

A different picture is obtained when automaticity is perceived as the time point when asymptotic performance in RAN has been reached (an asymptote is defined as the point when the curve becomes almost parallel to the X-axis). For example, Albuquerque and Simões (2010) demonstrated in a cross-sectional study that covered the developmental span from 7 to 15 years of age that for digit naming an asymptote was not reached until the age of 14. Likewise, in a study spanning an unusually large age range, van den Bos et al. (2002) found that performance in letter and digit naming reached an asymptote at the age of 16. No asymptote was reached for color and object naming even among the group of adults (36–65 years old).

Misra, Katzir, Wolf, and Poldrack (2004) further argued that the observed differences in the predictive value of the RAN tasks (the alphanumeric RAN tasks being more predictive of reading that the non-alphanumeric RAN tasks) may have to do in part with the extent to which the identification of these classes of stimuli becomes automatic (see also Cronin & Carver, 1998, for a distinction between automatized and non-automatized symbols). Although children are quite skilled at naming non-alphanumeric symbols (colors and objects), these items do not gain the same amount of practice as alphanumeric symbols (letters and digits). As a result, once letter and number naming become automatized, performance on these items differentiates groups of good and poor readers better than does performance on non-alphanumeric RAN tasks. Although this argument has received substantial empirical support (e.g., Badian, Duffy, Als, & McAnulty, 1991; Ho & Lai, 1999; Savage & Frederickson, 2006), there are still several studies showing that RAN Colors and Objects differentiate between poor and good readers equally well as RAN Letters and Digits even in adulthood (e.g., Felton, Naylor, & Wood, 1990; Parrila et al., 2007; Vukovic, Wilson, & Nash, 2004).

The automaticity of RAN tasks has also been blamed for the non-significant contribution of RAN to reading among average or good readers (e.g., McBride-Chang & Manis, 1996; Meyer, Wood, Hart, & Felton, 1998; Savage, Frederickson, Goodwin, Patni, Smith, & Tuersley, 2005; Scarborough, 2008). For example, Meyer et al. (1998), in a longitudinal study in which poor, average and good readers were assessed on RAN and reading in Grades 3, 5, and 8, found that RAN in Grade 3 was a significant predictor of reading, while in Grades 5 and 8 only in the group of poor readers. Because confrontational naming (naming of objects printed on separate pages) did not predict reading, Meyer and colleagues concluded that "it is the automaticity of retrieval of known items, not knowledge itself, that is involved in the predictive significance of rapid naming" (p. 114). In another longitudinal study, Scarborough (1998) found that RAN – assessed in Grade 2 – was a significant predictor of reading in Grade 8 only in the group of reading-disabled children. An interesting explanation of these findings has been given by Savage et al. (2005) who suggested that there is a "threshold" level of fluency that many children reach relatively early and beyond which additional naming speed advantages do not add to reading accuracy or fluency gains. Unfortunately, it was not specified when that threshold level is likely to be met by most children.

To summarize, there is skepticism among researchers whether or not RAN reflects automatic processing and disagreement among others on the time when automaticity is achieved. On the one hand, those who claim automaticity based on differences in the performance between alphanumeric and non-alphanumeric RAN or based on the relationship of different RAN tasks with reading, have picked up times in between Grades 1 and 3. On the other hand, those who claim automaticity on the basis of an asymptote performance in RAN have argued that this is not possible at least before the age of 14. It is clear from this discussion that a rigorous approach for the identification of automaticity is needed.

The coefficient of variation as an index of automaticity

Segalowitz and Segalowitz (1993; see also Segalowitz, 2000; Segalowitz, Segalowitz, & Wood, 1998) proposed an analysis that could help us distinguish between processing that is simply becoming faster across time and processing that has become automatic. This analysis can be applied to "any situation in which latencies and their variability can be measured over time as a function of practice or skill level" (p. 383). According to Segalowitz and Segalowitz (1993), performance on a given task may appear to be automatic because all the underlying processing components have become faster or because cognitive restructuring has occurred in which the slower components – those that tend to be highly variable in their time of execution – are either bypassed or eliminated.

To distinguish between speed-up (improvement without automaticity) and restructuring (improvement with automaticity) Segalowitz and Segalowitz (1993) proposed examining changes in the coefficient of variation (CV) of the response time (RT). The CV is the ratio of an individual's standard deviation of response time (SD_{RT}) to the mean RT for that individual throughout the performance of the task (CV = SD_{RT}/mean RT). In essence, the CV measures the proportionality between SD_{RT} and RT. The lower an individual's CV value, the more stable are the person's response times and hence more efficient the processing. The CV has been widely used in studies examining the automaticity of second language acquisition (e.g., Hulstijn, van Gelderen, & Schoonen, 2009; Segalowitz et al., 1998; Segalowitz, Trofimovich, Gatbonton, & Sokolovskaya, 2008).

In the case of speed-up, both mean RT and SD_{RT} are expected to decrease across time; however, the SDRT should decrease, at most, proportionally to the reduction of RT. This will leave CV relatively unchanged and the correlation between RT and CV not significantly different from zero. In contrast, in the case of automaticity, both components should become faster; however, the SDRT should decrease by a much greater proportion than the mean RT itself (because during the restructuring of processes those that were initially slow and more variable are eliminated or bypassed). This will be accompanied by a decrease in CV. In addition, given a set of RT and CV pairs, where the underlying reason for the RT differences is differential degrees of automaticity, the correlation between mean RT and CV should be positive, both in between- and within-subject data analyses (see Segalowitz & Sehalowitz, 1993, for examples).

The present study

The purpose of the present study was to examine whether RAN is automatic using a direct test of automaticity. This is theoretically important because if RAN is a "microcosm" of reading (Wolf & Bowers, 1999), then an examination of automaticity in RAN could reveal important information about automaticity in reading itself. To achieve our goal we traced the development of RAN Colors and Digits from Kindergarten to Grade 3 in two groups of readers. We also performed the same analyses for each half of the RAN tasks (the first two rows versus the last two rows). This was done to indirectly test Scarborough and Domgaard's (1998) hypothesis according to which, if poor readers have difficulty achieving automaticity in naming, then the correlations between the first half of RAN tasks and reading should be lower than the corresponding ones with the second half of RAN tasks. This hypothesis lies on the assumption that RAN becomes automatic during its execution because of the practice obtained from naming the same symbols. Therefore, for children who are fast in learning the visual-verbal associations, automaticity should be achieved within the first half of the RAN task and for those who are slow in learning the visual-verbal associations, automaticity should be achieved in the second half of the RAN task.

Method

Participants

Fifty English-speaking children from Edmonton (Canada) participated in the study. The children were selected from a larger group of children (n = 161) that took part in a longitudinal study examining the predictors of reading from Kindergarten until Grade 3. Twenty-five of them (14 girls, 11 boys; mean age = 100.59 months, SD = 4.18 months at the beginning of Grade 3) with a grade equivalent (G.E) score at least half a year above their grade level (G.E equal to or above 3.8) on both word identification and word reading efficiency were selected to be in the good readers' group. In turn, twenty-five children (15 girls, 10 boys; mean age = 100.87 months, SD = 4.02 months at the beginning of Grade 3) with a G.E score at least half a year below their grade level (G.E equal to or below 2.6) on both word identification and word reading efficiency were selected to be in the poor readers' group. We then traced the development of RAN pause time and its variability for both groups of readers from Kindergarten to Grade 3.

All participants were native speakers of English, attended school regularly, and came from middle- to upper-middle socioeconomic backgrounds (based on the location of the schools). Independent sample *t*-tests (see Table 1) confirmed that the two groups differed significantly on letter knowledge (assessed at the beginning of Kindergarten and Grade 1), word identification (assessed at all measurement points), and word reading efficiency (assessed at the beginning of Grade 2 and 3).

Table 1 Descriptive statistics on the reading measures for each group of readers

	Good Readers		Poor Readers		
	M	*SD*	*M*	*SD*	*t*
Kindergarten					
Letter Knowledge	48.50	6.72	32.76	14.96	-4.11***
Word Identification	16.56	12.95	0.86	1.53	-3.60***
Grade 1					
Letter Knowledge	53.33	0.77	49.62	7.94	-2.25*
Word Identification	29.67	19.74	7.52	8.06	-4.45***
Grade 2					
Word Identification	64.67	8.63	36.43	14.22	-7.34***
Word Reading Efficiency	60.67	7.67	32.29	12.88	-8.18***
Grade 3					
Word Identification	76.20	6.17	52.64	8.89	-10.88***
Word Reading Efficiency	72.80	5.27	45.36	9.66	-12.46***

Note. * $p < 0.05$; *** $p < 0.001$.

Measures

RAN-Colors (RAN-C). This task was adopted from the RAN/RAS battery (Wolf & Denckla, 2005) and required participants to name as fast as possible a set of five colors (blue, black, green, red, and yellow) that were repeated 10 times each and arranged in five rows of 10. Prior to beginning the timed naming, each participant was asked to name the colors in a practice trial to ensure familiarity. Wolf and Denckla (2005) reported test-retest reliability for Color Naming to be 0.90.

RAN-Digits (RAN-D). This task was adopted from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) and required participants to name as fast as possible a set of six digits (4, 7, 8, 5, 2, 3) that were repeated six times each and arranged in four rows of nine. Prior to beginning the timed naming, each participant was asked to name the digits in a practice trial to ensure familiarity. Wagner et al. (1999) reported test-retest reliability of 0.91 for Digit Naming for children ages five to seven.

Letter knowledge. Letter knowledge was assessed with the Letter Identification test (Clay, 1993). Participants were asked to name each of the upper and lowercase letters. Two lowercase letters, *a* and *g*, were presented in two different fonts, so the total possible score was 54. Cronbach's alpha reliability coefficient in our sample was 0.93 in Kindergarten and 0.85 in Grade 1.

Word identification. The Woodcock Reading Mastery Tests-Revised (WRMT-R; Woodcock, 1998) was used to assess word identification. The test required participants to read isolated words aloud. A discontinuation rule of six consecutive errors was applied. A participant's score was the number of correctly read words. Woodcock (1998) reported split-half reliabilities of 0.98 across ages.

Word reading efficiency. The Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) was used to assess reading efficiency. The children were given a list of 104 words, divided into four columns of 26 words each, and asked to read them as fast as possible. A short, 8-word practice list was presented first. The number of words read correctly within a 45-second time limit was recorded. Torgesen et al. (1999) reported test-retest reliability of 0.95 for ages six to nine.

Procedure

All participants were tested individually in their respective schools during school hours by trained experimenters (two graduate research assistants). Testing was conducted at the beginning of each grade level and was divided into two sessions lasting roughly 40 minutes each (this included tasks that are not considered in the present study). RAN Colors was administered at all measurement points and RAN Digits from Grade 1 onwards. Both RAN tasks were presented on a Dell Latitude 800 laptop computer and the responses on the RAN tasks were digitally recorded on mini-CD disks with the help of a portable minidisk recorder.

Manipulation of sound files

The sound files containing the color and digit naming responses for each participant were analyzed using the GoldWave 4.26 digital audio– editing program (GoldWave Inc., St. John's, Canada). Data extraction for each child was completed following the procedure described by Georgiou et al. (2006). In order to establish the onset and offset of articulation and pause time, a volume level of 0.15 of the absolute value of the sound file amplitude was used as a cutoff. The beginning of an articulation was defined as the point when meaningful acoustical energy exceeded the 0.15 noise level threshold; conversely, offset was determined to be the point where the meaningful acoustical energy dropped below the 0.15 noise level.

Four types of cleaning of RAN components took place. First, if there was an incorrect articulation, the preceding pause time, the incorrect articulation, and the following pause time were removed. Second, if there was a self-correction, then everything between the two correct articulations was removed. Third, if the child skipped a stimulus, then the pause time between the two correct articulations and the articulation time that followed the skip were removed. Fourth, in cases in which off-task behavior (e.g., coughing, talking to the experimenter, self-encouragement) was observed between two articulations, the specific pause time was removed.

In this study, we worked only with pause times (49 for RAN Colors and 35 for RAN Digits) for two reasons: first, articulation is an integral part of RAN and cannot be eliminated or bypassed. Consequently, it cannot be affected by a possible restructuring of the underlying sub-processes. Second, pause time involves several sub-processes that could possibly be eliminated or bypassed.

Data cleaning

Before calculating the mean pause time and SD_{RT} for each individual, we first eliminated the pause times that were associated with errors (see the cleaning procedures described above). Second, we eliminated the pause times at the end of each row (four pause times for RAN Colors and three for RAN Digits). Finally, we winsorized any values that were higher or lower than 2 *SD*s from an individual's mean pause time (< 4% of the number of pauses).

Data analysis

After cleaning the data, we calculated the mean pause time and the standard deviation of the pauses for each individual and at each measurement point (four data points in RAN Colors and three in RAN Digits). Next, we calculated the mean pause time and the mean standard deviation across individuals of each group (these are the values reported in Table 2). Three sets of repeated measures ANOVA (one for mean pause time, one for mean standard deviation, and one for coefficient of variation) were then performed separately for each group and RAN task.

Results

Table 2 presents the descriptive statistics and the results of repeated measures ANOVA for RAN Colors and Digits, separately for each group of readers (the results for poor readers appear in the top half of the table). The results indicated first that there was a significant decrease across time in the mean pause time (Color Naming poor readers: $F(3, 73) = 15.58$, $p < 0.001$; Color Naming good readers: $F(3, 73) = 15.56$, $p < 0.001$; Digit Naming poor readers: $F(2, 48) = 27.37$, $p < 0.001$; Digit Naming good readers: $F(2, 48) = 38.60$, $p < 0.001$) and mean SD_{RT} (Color Naming poor readers: $F(3, 73) = 6.44$, $p < 0.01$; Color Naming good readers: $F(3, 73) = 9.82$, $p < 0.001$; Digit Naming poor readers: $F(2, 48) = 19.67$, $p < 0.001$; Digit Naming good readers: $F(2, 48) = 42.05$, $p < 0.001$). The decrease in the mean SD_{RT} paralleled that of mean pause time (see Figures 1 and 2). Second, there was a significant increase in the coefficient of variation across time for each RAN task and for each group of readers (Color Naming poor readers: $F(3, 73) = 6.16$, $p < 0.01$; Color Naming good readers: $F(3, 73) = 8.02$, $p < 0.001$; Digit Naming poor readers: $F(2, 48) = 15.32$, $p < 0.001$; Digit Naming good readers: $F(2, 48) = 12.20$, $p < 0.001$). Finally, there were significant, but negative, correlations between mean pause time and CV. In the group of good readers, significant correlations were obtained for both RAN tasks already by Grade 1. In the group of poor readers, significant correlations in Color Naming were obtained in Grades 2 and 3 and in Digit Naming in Grade 3.

Table 2 Descriptive statistics and results of repeated measures ANOVA for each group of readers

	Variable	Mean RT	Mean SD	Mean CV	*r* CV-RT
			Poor Readers		
	CN_PT-Kindergarten	860.06	559.86	0.67	-0.23
	CN_PT-Grade 1	757.47	536.91	0.70	0.08
	CN_PT-Grade 2	571.05	463.23	0.88	-0.55**
	CN_PT-Grade 3	335.15	283.88	0.92	-0.65**
$F(3, 72)$		15.58***	6.44**	6.16**	
η_p^2		0.45	0.25	0.24	
	DN_PT-Grade 1	587.98	405.88	0.71	-0.24
	DN_PT-Grade 2	257.16	226.22	0.90	-0.11
	DN_PT-Grade 3	115.54	108.88	1.26	-0.72**
$F(2, 48)$		27.37***	19.67***	15.32***	
η_p^2		0.62	0.54	0.47	
			Good Readers		
	CN_PT-Kindergarten	653.91	452.73	0.72	-0.33
	CN_PT-Grade 1	455.61	319.93	0.75	-0.56**
	CN_PT-Grade 2	439.68	352.74	0.89	-0.61**
	CN_PT-Grade 3	228.29	219.12	1.08	-0.80**
$F(3, 72)$		15.56***	9.82***	8.02***	
η_p^2		0.46	0.35	0.31	
	DN_PT-Grade 1	247.93	187.55	0.86	-0.67**
	DN_PT-Grade 2	120.52	126.94	1.21	-0.65**
	DN_PT-Grade 3	58.65	64.59	1.28	-0.61**
$F(2, 48)$		38.60***	42.05***	12.20***	
η_p^2		0.64	0.66	0.36	

Note. CN = Color Naming; DN = Digit Naming; PT = Pause Time. ** $p < 0.01$; *** $p < 0.001$.

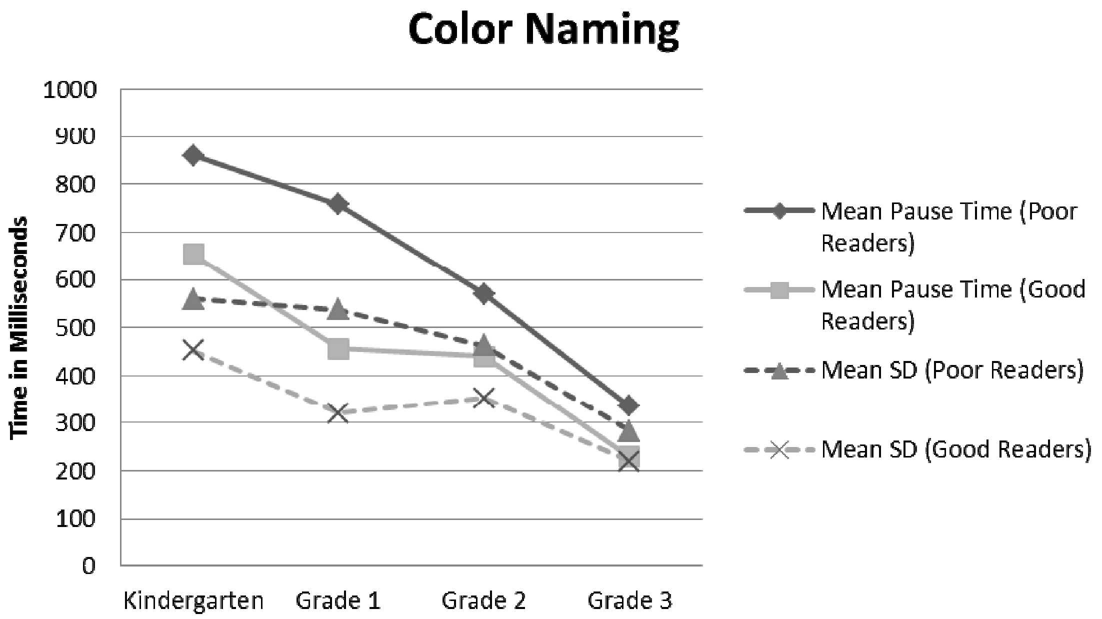

Figure 1 The development of mean pause time and mean SD across time for Color Naming

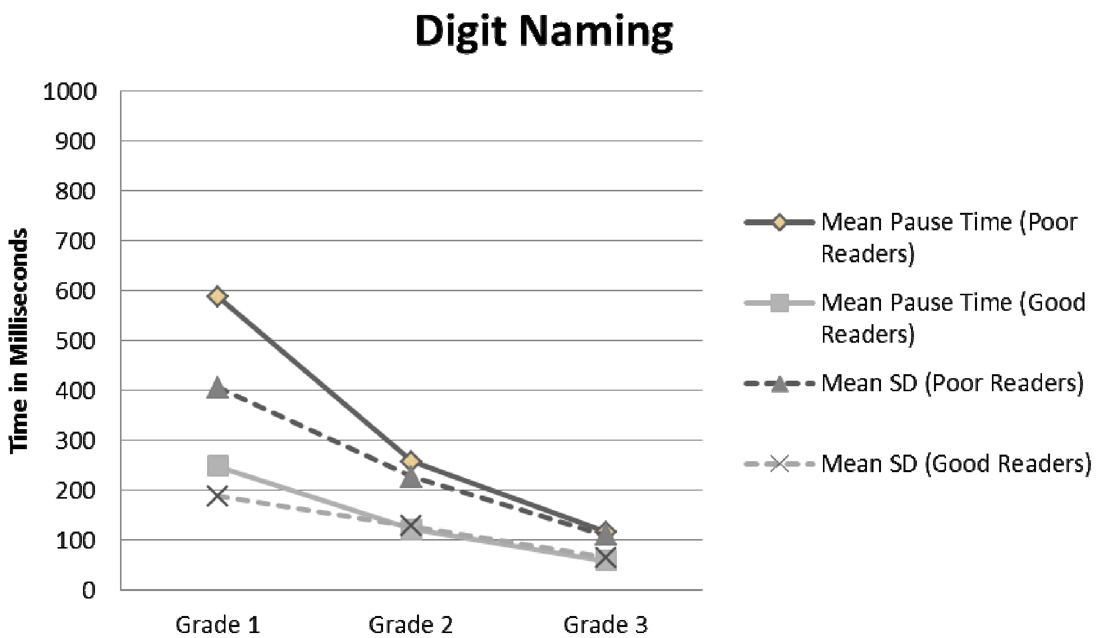

Figure 2 The development of mean pause time and mean SD across time for Digit Naming

We then repeated the analysis for the pause times in the first and the second half of the RAN tasks (see Tables 3 and 4). In regards to the first half, the results were similar to those observed when the analysis involved all pause times. In regards to the second half, the results revealed some deviations from the analysis with all pause times. First, the CV in Color Naming for poor readers did not increase significantly across time. Second, the correlation between the mean pause time and the CV in Color Naming in good readers did not reach significance in Grade 1. It is worth noting, that the mean pause times for the second half of the RAN tasks were in all instances higher than the corresponding ones for the first half. This pattern was true of both groups of readers.

Table 3 Descriptive statistics and results of repeated measures ANOVA for the first half of RAN

	Variable	Mean RT	Mean SD	Mean CV	r CV-RT
			Poor Readers		
	CN_PT-Kindergarten	781.30	534.41	0.68	-0.09
	CN_PT-Grade 1	583.50	402.83	0.73	-0.35
	CN_PT-Grade 2	438.51	339.64	0.89	-0.49*
	CN_PT-Grade 3	215.67	179.20	0.99	-0.68**
$F(3, 72)$		8.45**	4.16**	3.65*	
η_p^2		0.31	0.18	0.16	
	DN_PT-Grade 1	532.01	377.79	0.85	-0.20
	DN_PT-Grade 2	264.09	259.99	1.03	-0.18
	DN_PT-Grade 3	88.33	94.44	1.35	-0.53*
$F(2, 48)$		14.88***	10.78***	5.92**	
η_p^2		0.47	0.39	0.26	
			Good Readers		
	CN_PT-Kindergarten	493.00	307.34	0.67	-0.42
	CN_PT-Grade 1	302.43	217.14	0.80	-0.48*
	CN_PT-Grade 2	364.44	290.02	0.93	-0.56**
	CN_PT-Grade 3	127.18	139.92	1.25	-0.61**
$F(3, 72)$		13.46***	12.83***	10.00***	
η_p^2		0.46	0.42	0.36	
	DN_PT-Grade 1	225.04	196.17	0.94	-0.45*
	DN_PT-Grade 2	111.63	140.17	1.45	-0.46*
	DN_PT-Grade 3	49.78	69.45	1.54	-0.52**
$F(2, 48)$		29.26***	18.78***	10.55***	
η_p^2		0.57	0.46	0.33	

Note. CN = Color Naming; DN = Digit Naming; PT = Pause Time. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Discussion

The objective of the present study was to examine whether RAN becomes automatic between Kindergarten and Grade 3 in two groups of readers. To quantify automaticity we employed Segalowitz and Segalowitz's (1993) analysis according to which a process is considered automatic when the mean response time, its standard deviation, and the coefficient of variation decrease across time, and the correlation between the mean response time and the coefficient of variation is positive. Our findings showed that there was indeed a significant decrease across time for mean pause time and its standard deviation. However, in contrast to the assumptions of automaticity, the coefficient of variation increased across time and its correlations with mean pause time were negative. This is due to the fact that the mean SD_{RT} did not decrease proportionally to the mean pause time. Because SD_{RT} decreased much less, this resulted in an increase in the CV and in negative correlations between mean pause time and CV (see Hulstijn et al., 2009, for similar findings on sentence construction and sentence verification tasks). Taken together, these findings suggest that, for the time period covered in our study, only speed-up effects are present in RAN. The improved efficiency with which the RAN sub-processes operate took place earlier in good readers than in poor readers. If we consider the time point when the coefficient of variation correlated significantly with the mean pause time, then we see a two-year gap between the two groups in RAN digits and a one-year gap in RAN colors.

In his study with university students, Borokhovski (2007) asked what should the "A" in RAN really stand for because of his findings showing that the RAN tasks were more closely related to attention (operationalized with a Trail-Making task; *r*s ranged from .25 to .43) than to automaticity (operationalized with a primed decision task; *r*s ranged from .04 to

.24). We share his concern using a more direct test of automaticity. We also echo Savage's (2004) suggestion that we should perhaps look for evidence of asymptotic performance in RAN before we claim that RAN has become automatic. van den Bos et al. (2002) have nicely demonstrated that an asymptote in RAN Digits and Letters is reached at the age of 16 and in Colors and Objects in adulthood.

Table 4 Descriptive statistics and results of repeated measures ANOVA for the second half of RAN

	Variable	Mean RT	Mean SD	Mean CV	*r* CV-RT
			Poor Readers		
	CN_PT-Kindergarten	952.12	618.88	0.63	-0.16
	CN_PT-Grade 1	903.09	614.19	0.65	0.07
	CN_PT-Grade 2	680.79	522.14	0.80	-0.46*
	CN_PT-Grade 3	469.78	339.51	0.79	-0.49*
$F(3, 72)$		8.24***	3.35*	2.32	
η_p^2		0.30	0.15	0.11	
	DN_PT-Grade 1	683.68	479.08	0.64	-0.40
	DN_PT-Grade 2	280.05	232.97	0.85	-0.12
	DN_PT-Grade 3	148.15	116.90	1.12	-0.74**
$F(2, 48)$		30.00***	15.07***	12.66***	
η_p^2		0.64	0.47	0.43	
			Good Readers		
	CN_PT-Kindergarten	766.53	502.79	0.72	-0.35
	CN_PT-Grade 1	598.77	371.87	0.65	-0.39
	CN_PT-Grade 2	531.43	414.12	0.87	-0.50**
	CN_PT-Grade 3	354.91	281.07	0.94	-0.70**
$F(3, 72)$		7.79***	5.32**	3.21*	
η_p^2		0.30	0.23	0.15	
	DN_PT-Grade 1	286.99	188.12	0.77	-0.55**
	DN_PT-Grade 2	138.80	118.14	1.01	-0.61**
	DN_PT-Grade 3	71.84	63.07	1.15	-0.61**
$F(2, 48)$		28.07***	20.03***	5.27**	
η_p^2		0.56	0.48	0.19	

Note. CN = Color Naming; DN = Digit Naming; PT = Pause Time. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

RAN did not become automatized during its execution either. With one exception (the mean SD of good readers in Digit Naming), both the mean pause times and the corresponding standard deviations were larger in the second half than in the first half of RAN. In addition, the correlations between the coefficient of variation and the pause time continued to be negative. This may explain why Scarborough and Domgaard (1998) failed to find stronger correlations between the second half of RAN tasks and reading than between the first half of RAN tasks and reading. The assumption that RAN would be automatic in the second half was not likely met.

To conclude, the term 'rapid automatized naming', which has been used since 1974 to describe the speed of naming of familiar symbols, is likely a misnomer. We found no evidence that RAN tasks become automatized from Kindergarten to Grade 3 and this applies to both good and poor readers. The significant decrease in the pause time and its standard deviation across time reflects the fact that the sub-processes involved in RAN operated at a much faster rate. Future studies should replicate our findings either following the same children across a larger developmental span or by recruiting subjects of different ages.

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