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Naming of short words is (almost) the same as naming of alphanumeric symbols: Evidence from two orthographies

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ABSTRACT

Throughout reading development, a gradual shift is seen in the processes underlying word identification from serial decoding toward parallel processing or sight word reading. It has been argued that this shift can be detected in the correlations between serial and discrete naming of alphanumeric symbols (digits and letters) and words. In the current study, we examined the relations between alphanumeric symbol naming and reading of monosyllabic and multisyllabic words and nonwords in two languages that differ in orthographic consistency: English and Dutch. A sample of 92 English-speaking Canadian children and 101 Dutch children, all in Grade 5, were assessed on discrete and serial naming of digits and letters and on serial and discrete naming of monosyllabic and multisyllabic words and nonwords. Results showed that discrete naming of alphanumeric symbols closely resembled discrete reading of monosyllabic words, suggesting that these words are processed in parallel in both languages. Both serial and parallel reading processes were found to underlie identification of multisyllabic words as well as monosyllabic nonwords. However, differences between the two languages emerged when processing multisyllabic nonwords. Whereas English-speaking children relied more on parallel reading processes to read multisyllabic nonwords, Dutch-speaking children processed these items serially. Theoretical implications of these findings are discussed.

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Introduction

Rapid automatized naming (RAN), the ability to name as fast as possible a set of highly familiar stimuli (e.g., colors, objects, letters, digits), has been shown to be a strong concurrent and longitudinal predictor of reading performance across ages, languages, and ability levels (see Kirby, Georgiou, Martinussen, & Parrila, 2010, for a review). It has been suggested that the relation between RAN and reading is due to task similarities, such that "the seemingly simple task of naming a series of familiar items as quickly as possible appears to invoke a microcosm of the later developing, more elaborated reading circuit" (Norton & Wolf, 2012, p. 429). However, the cognitive processes underlying RAN performance, and consequently the nature of its relation with reading performance, are still under debate. Theoretical accounts proposed over the last three decades include, but are not limited to, factors such as speed of processing (Kail, Hall, & Caskey, 1999), working memory (Amtmann, Abbott, & Berninger, 2007), learning of arbitrary associations between symbols and their names (Manis, Seidenberg, & Doi, 1999), learning of orthographic codes (Bowers & Wolf, 1993), and the ability to access and retrieve phonological representations from long-term memory (Wagner & Torgesen, 1987).

Some findings concerning RAN, however, are largely undisputed. First, RAN predicts reading performance (particularly reading speed) even after controlling for other key predictors of reading such as phonological awareness (e.g., de Jong & van der Leij, 1999), letter knowledge (e.g., Kirby, Parrila, & Pfeiffer, 2003), phonological short-term memory (e.g., Parrila, Kirby, & McQuarrie, 2004), paired-associate learning (e.g., Lervåg, Bråten, & Hulme, 2009), orthographic knowledge (e.g., Moll, Fussenegger, Willburger, & Landerl, 2009), and speed of processing (e.g., Georgiou, Parrila, & Kirby, 2009). Second, although RAN is typically measured with objects, colors, letters, and digits, these four tasks load on two factors, namely alphanumeric naming (letters and digits) and non-alphanumeric naming (colors and pictures), of which alphanumeric RAN is the stronger predictor of reading performance (e.g., Närhi et al., 2005; Rodríguez, van den Boer, Jiménez, & de Jong, 2015; van den Bos, Zijlstra, & van den Broeck, 2003). Finally, several studies have shown that the format of RAN plays a role in the RAN–reading relation, such that the standard serial version of RAN is a stronger correlate of reading than discrete RAN, in which items are presented one at a time (e.g., Bowers & Swanson, 1991; Georgiou, Parrila, Cui, & Papadopoulos, 2013; Logan & Schatschneider, 2014).

More recently, however, de Jong (2011) argued that researchers should consider not only the format of the RAN tasks but also the format of the reading task because in his study discrete RAN emerged as a strong predictor of discrete word reading. Moreover, de Jong suggested that the relations of serial and discrete RAN with word reading may be used to delineate the underlying reading processes. If single words are read by sight, or processed in parallel, a high correlation should be found with discrete RAN because both tasks reflect a similar process of retrieving a pronunciation from memory. If, however, single words are read through serial decoding, a stronger correlation would be expected with serial RAN because both decoding and naming arrays of digits reflect a serial process.

In support of these hypotheses, de Jong (2011) found that for beginning readers in Grade 1, discrete reading of monosyllabic words was more strongly related to serial RAN, whereas discrete RAN was the strongest correlate among more advanced readers in Grades 2 and 4. These differences were confirmed through latent class analyses, which showed that children could be assigned to two classes of readers. For advanced readers, the relations between RAN and word reading were dependent on the format of both tasks, such that discrete word reading correlated most strongly with discrete RAN, whereas serial RAN correlated more strongly with serial word reading. In contrast, for beginning and poor readers, serial RAN was more strongly related to word reading than discrete RAN irrespective of the format in which words were presented. These results suggested that advanced readers processed words that were presented one by one in parallel, similar to naming of single digits, whereas beginning readers predominately relied on a decoding strategy more closely resembling serial naming of an array of digits.

In a follow-up study, van den Boer and de Jong (2015) examined the relations of serial and discrete RAN with discrete reading of monosyllabic nonwords in addition to words. Surprisingly, the results for nonwords were very similar to those for words, such that, for beginning readers, discrete nonword reading correlated more strongly with serial RAN, whereas discrete RAN was the stronger correlate of nonword reading for more advanced readers. These findings indicate that the development seen in reading single words, from serial toward more parallel processing, is not item specific but rather reflects the development of processes that underlie reading of all monosyllabic letter strings irrespective of lexicality.

Interestingly, Protopapas, Altani, and Georgiou (2013a) found very similar patterns for word reading in Greek, a language with very few monosyllabic words. Second- and sixth-grade children were administered serial and discrete versions of a digit naming task and of a word naming task that included two- and three-syllable words. For beginning readers the correlations of serial and discrete RAN with word reading did not differ, whereas for advanced readers the correlations among the tasks of similar format were much higher than between formats. These findings indicate that serial and parallel reading processes can be distinguished not only in monosyllabic letter strings but also in multisyllabic words.

The current study aimed to extend these findings by providing a more complete overview of the relations between RAN and reading performance. So far, studies have focused specifically on the parallel processing of monosyllabic or multisyllabic words or of short words and nonwords. In the current study, the relations of serial and discrete RAN were examined with reading of both words and nonwords, of both monosyllabic and multisyllabic items, and in both serial and discrete formats. These materials were presented to young but advanced readers in Grade 5. At this grade level, children are expected to be able to read all of the items but still differ in their fluency, especially for the longer words and nonwords. Moreover, these relations were examined in two languages: English and Dutch. Previous studies in Dutch have examined monosyllabic word and nonword reading (de Jong, 2011; van den Boer & de Jong, 2015), but little is known about how Dutch children process multisyllabic words. To our knowledge, this is the first study to systematically examine the relations between serial and discrete RAN and reading tasks in English.

English and Dutch were selected because they differ in orthographic consistency (Seymour, Aro, & Erskine, 2003). In English, the mapping between graphemes and phonemes is ambiguous (onset entropy is .83; see Ziegler et al., 2010). In Dutch, in contrast, grapheme–phoneme mappings are more consistent and the few deviations are rule based (onset entropy is .23; see Ziegler et al., 2010). Despite these clear differences in orthographic consistency, it remains unclear how these differences may impact the development of reading processes.

Several studies have shown that reading acquisition proceeds faster in orthographies that are more transparent (e.g., Aro & Wimmer, 2003; Ellis et al., 2004; Seymour et al., 2003). For example, Seymour and colleagues (2003) found that, after 1 year of reading instruction, English-speaking children were able to read on average 34% of words correctly, whereas Dutch children's accuracy was 95%. The development of nonword reading in English has also been shown to differ greatly from Dutch (Aro & Wimmer, 2003). Whereas Dutch children in Grade 1 were able to read nonwords with more than 85% accuracy, English-speaking children did not reach the same level of accuracy until Grade 4. These early differences in decoding abilities might affect reading performance even in older children given that successful phonological decoding facilitates the development of orthographic representations (Share, 1995). These orthographic representations, in turn, facilitate the transition from slower serial reading processes toward faster parallel retrieval. Children learning to read Dutch are able to successfully decode sooner, due to the greater transparency of Dutch, and thus would be expected to move from serial to parallel reading processes sooner than children learning to read English. If this is true, serial RAN should correlate more strongly with discrete reading in English than in Dutch, whereas discrete RAN should be a stronger correlate of discrete reading in Dutch than in English.

Alternatively, it has been argued that exactly because of the ambiguity of the grapheme–phoneme mappings in English, serial letter-by-letter decoding strategies are less efficient (Ziegler & Goswami, 2005). Instead, children rely on larger units or letter patterns such as rimes, which are generally more consistent. In other words, whereas serial decoding is a successful reading strategy in transparent orthographies such as Dutch, English orthography encourages readers to focus on units larger than the phoneme. In terms of reading processes, it might be expected that English children rely more on parallel processing than Dutch children, for whom serial grapheme–phoneme conversion is also an efficient reading strategy. These differences might be especially obvious in reading nonwords, which need to be decoded because orthographic representations are not available. If this is true, we should find the opposite pattern; serial RAN should correlate more strongly with discrete reading in Dutch than in English, whereas discrete RAN should be a stronger correlate of discrete reading in English than in Dutch.

In general, very little is known about processes underlying reading of multisyllabic words. It has been shown that there are very few differences in the identification of mono- and multisyllabic words when the effects of lexical variables, such as frequency, neighborhood size, and consistency, are considered (Yap & Balota, 2009). It has also been shown that multisyllabic words, especially those of high frequency, can be processed in parallel, as evidenced by the absence of length effects in naming latencies (Duncan & Seymour, 2003; Ferrand, 2000; Valdois et al., 2006). For multisyllabic nonwords, in contrast, findings are different. The strong effects of the number of syllables have indicated that reading of multisyllabic nonwords relies on a serial mechanism. These findings would be in line with the multiple-trace memory (MTM) model (Ans, Carbonnel, & Valdois, 1998), according to which letter strings, irrespective of length, can be processed through two successive reading procedures. Words are first processed as a whole through the global procedure, but if the letter string does not match an orthographic representation in memory, the analytic procedure is activated and a word is read through serial activation of smaller orthographic units such as syllables, letter clusters, and letters. In line with these previous findings, as well as with the premises of the MTM model, we expected that parallel processes underlie reading of multisyllabic words, especially in advanced and fluent readers, whereas serial processes are more dominant in the reading of multisyllabic nonwords.

The correlations of serial and discrete RAN with discrete measures of reading are especially suited to examine reading processes. Correlations with serial measures of reading, in contrast, are more difficult to interpret because performance on a serial reading task depends on multiple processes (e.g., sequential and articulatory processes). Beginning readers are expected to decode the words in a serial reading task. Therefore, a correlation with serial RAN would be expected because serial reading processes underlie word identification. However, a correlation between serial reading and serial RAN would also be expected for more advanced readers, who process each word in parallel but process the items sequentially. In other words, a high correlation between serial reading and serial RAN could reflect both intra- and interword serial processes and, as a result, does not differentiate between serial and parallel reading processes. It is mainly the pattern in the correlations between serial and discrete RAN and reading that can distinguish between serial and parallel reading processes. If words are processed mainly in parallel, the relations between RAN and reading are expected to be highly format specific; that is, we should see high correlations between serial measures of RAN and reading and high correlations between discrete measures of RAN and reading. If, however, items are identified mainly through decoding, serial RAN is expected to correlate more strongly than discrete RAN with both serial and discrete measures of reading.

Method

Participants

A sample of 92 English-speaking Canadian children (45 boys; mean age = 10 years 7 months, *SD* = 4.05 months) and 101 Dutch children (50 boys; mean age = 11 years 1 month, *SD* = 5.82 months) participated in the study. All children attended Grade 5 in their respective country and were recruited from public inner-city schools on a voluntary basis following parental permission. All Canadian children were Caucasian and native speakers of English (7 children reported also speaking another language at home). All Dutch children spoke Dutch at home (74.3% as their native language and 25.7% as a second language). The ethnic background of the non-native speakers varied (10.8% African, 8.9% other European, and 6% other).

Word-reading norm scores indicated that both the Canadian sample (assessed with Test of Word Reading Efficiency; Torgesen, Wagner, & Rashotte, 1999) and the Dutch sample (assessed with One Minute Test [Eén Minuut Test]; Brus & Voeten, 1995) included a representative range of reading abilities (Canadian: mean standard score = 107.98, *SD* = 11.30; Dutch: mean standard score = 10.14, *SD* = 3.66). Furthermore, the average nonverbal intelligence of children in both groups (assessed with Nonverbal Matrices; Naglieri & Das, 1997) was within the normal range (Canadian: mean raw score = 16.65, *SD* = 4.16; Dutch: mean raw score = 18.30, *SD* = 4.35).

Measures

Nonverbal intelligence

The Nonverbal Matrices task from the Cognitive Assessment System (Naglieri & Das, 1997) was used to assess nonverbal intelligence. The children were presented with a pattern of shapes/geometric designs that was missing a piece and were asked to choose among five or six alternatives the piece that would accurately complete the pattern. A discontinuation rule of four consecutive mistakes was applied. A participant's score was the total number of items correct (maximum = 33). Naglieri and Das (1997) reported internal consistency for Nonverbal Matrices across ages to be .89.

Standardized reading tasks

In Canada, the Word Reading Efficiency task (Form A) from the Test of Word Reading Efficiency battery (Torgesen et al., 1999) was used to assess word reading fluency. The children were given a list of 104 words, divided into four columns of 26 words each, and were 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-s time limit was recorded and converted to a standard score (M = 100, SD = 15). Torgesen and colleagues (1999) reported test–retest reliability of .84 for ages 10 to 18 years. In the Netherlands, the children were administered the One Minute Test (Brus & Voeten, 1995), a list of 116 words divided into four columns of 29 words each. The children were asked to read the words as quickly and accurately as possible for 1 min. A child's score was the total number of words read correctly within the time limit converted to a standard score (M = 10, SD = 3). Brus and Voeten (1995) reported test–retest reliability for elementary school children to be between .82 and .92.

Rapid automatized naming

RAN digits and letters were administered in both serial and discrete formats.

Serial RAN. The children were asked to name as quickly and accurately as possible five digits (2, 4, 5, 7, and 9) or letters (a, d, o, p, and s) that were repeated eight times each and arranged in semi-random order in five rows of eight. A fluency score was calculated by converting the total naming time to the number of items named per second and multiplying this score by the proportion of items correct.

Discrete RAN. The children were asked to name as quickly and accurately as possible the same digits and letters that were used in serial RAN (total of 40 in each task) that appeared in the same order one at a time on a 15.4-inch laptop screen. An item remained on the screen until a response was given by the child. A voice key registered the response latency from the onset of stimulus presentation until the onset of the response. A plus sign (+) appeared in the middle of the screen in between the items to draw the child's attention to the next stimulus. The next trial was triggered by the experimenter, who coded the response of the child as correct and valid, incorrect, or invalid on a response box. Again, a fluency score was calculated by multiplying the number of items named per second by the proportion of items correct.

Reading

Children were presented with both words and nonwords, four and eight letters long, in both serial and discrete formats (a total of eight reading tasks). Both the discrete and serial tasks were administered in the same way as the RAN tasks. The words were selected from the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). In both languages, words of relatively high frequency were selected (Z-score > 1). For both four- and eight-letter words, two sets of 40 words each were selected that were matched on onset, consonant–vowel (CV) structure, and frequency. One set was presented in the serial format and the other set in the discrete format of the task. In the serial format, words were presented in random order in five rows of eight, similar to the RAN tasks. Sets of nonwords were created that were matched to the word sets in onset and CV structure. The nonwords were created from the real words by interchanging onsets and rimes, interchanging syllables, or changing a few of the letters (e.g., English: part/parf, argument/aflugent; Dutch: stuk [piece]/stod, doorgaan [continue]/dookgaar). A fluency score was calculated for the serial reading task by converting the total naming time to the number of items named per second and multiplying this score by the proportion of items correct. A fluency score for the discrete reading task was calculated in a similar way by multiplying the number of items named per second (i.e., both correct and incorrect) by the proportion of items correct.

Procedure

In both countries, the children were tested individually in April/May by trained graduate students who received extensive training on how to implement and score the tests. Testing was conducted in a quiet room at school and lasted approximately 30 min. The tasks were presented in the following order: RAN digits, RAN letters, four-letter words, four-letter nonwords, standardized reading task, Nonverbal Matrices, eight-letter words, and eight-letter nonwords. All RAN and reading tasks were presented on a laptop computer. For the RAN tasks, the items were first presented in the serial format; for the reading tasks, the items were first presented in the discrete format.

Results

Data preparation and descriptive statistics

For the discrete RAN and reading tasks, reaction times were excluded from the analyses if the voice key was not validly triggered, if latencies were less than 200 ms or more than 6000 ms, or if latencies were more than 3 standard deviations from a participant's mean (6.4% in total). Due to high correlations between letter and digit RAN in both the serial format (English: $r = .742$; Dutch: $r = .705$) and the discrete format (English: $r = .847$; Dutch: $r = .712$), composite scores were calculated representing the average scores on the two RAN tasks.

From the Dutch sample, 1 child was left out of the analyses because of outlier scores on 6 of 10 RAN and reading tasks. As a result, the analyses included 100 Dutch children. In the English sample, nine outlier scores were identified (two for discrete RAN, one for discrete four-letter word reading, two each for discrete eight-letter word and nonword reading, and one each for serial reading of four- and eight-letter nonwords). Consequently, the analyses included between 87 and 90 English-speaking children.

Descriptive statistics on accuracy, reading rates (i.e., items correct per second), and fluency are presented in Table 1. Accuracy was high on all tasks except for eight-letter nonword reading and, to a lesser extent, four-letter nonword reading, especially so in English. Letters and digits were named faster than words and nonwords, although differences in fluency on the discrete RAN and four-letter word tasks were small, especially in Dutch.

Fluency scores on the reading tasks were subjected to analyses of variance (ANOVAs). The fluency scores on the four discrete and four serial reading tasks were analyzed separately. In both languages, the main effect of length on fluency was significant in both the serial format (English: $F(1,89) = 799.29$, $p < .001$, $\eta_p^2 = .90$; Dutch: $F(1,99) = 1312.28$, $p < .001$, $\eta_p^2 = .93$) and the discrete format (English: $F(1,88) = 738.62$, $p < .001$, $\eta_p^2 = .89$; Dutch: $F(1,99) = 959.15$, $p < .001$, $\eta_p^2 = .91$). The main effect of lexicality was also significant in both the serial format (English: $F(1,89) = 1777.79$, $p < .001$, $\eta_p^2 = .95$; Dutch: $F(1,99) = 1312.08$, $p < .001$, $\eta_p^2 = .93$) and the discrete format (English: $F(1,88) = 957.09$, $p < .001$, $\eta_p^2 = .92$; Dutch: $F(1,99) = 1412.76$, $p < .001$, $\eta_p^2 = .94$). The four-letter items were read faster than the eight-letter items, and words were read faster than nonwords. In English, the interactions between length and lexicality were also significant (serial: $F(1,89) = 6.55$, $p = .012$, $\eta_p^2 = .07$; discrete: $F(1,88) = 13.46$, $p < .001$, $\eta_p^2 = .13$). Surprisingly, when reading in serial format, the length effect was larger for words than for nonwords. The effect size, however, was small to medium. For the discrete reading task, the effect of length was larger for nonwords than for words. The interactions between length and lexicality were also significant in Dutch (serial: $F(1,99) = 8.23$, $p = .005$,

Table 1
Mean accuracy, reading rate, and fluency (and standard deviations) on the RAN and reading tasks.

Task	English			Dutch		
	Accuracy[a]	Reading rate[b]	Fluency[c]	Accuracy[a]	Reading rate[b]	Fluency[c]
Serial						
RAN	1.00 (.01)	2.18 (0.39)	2.18 (0.39)	1.00 (.01)	2.17 (0.38)	2.17 (0.38)
Four-letter words	.99 (.02)	1.94 (0.38)	1.92 (0.39)	.99 (.02)	1.88 (0.39)	1.87 (0.39)
Four-letter nonwords	.82 (.11)	1.11 (0.40)	0.91 (0.31)	.97 (.03)	1.31 (0.32)	1.27 (0.32)
Eight-letter words	.96 (.07)	1.35 (0.38)	1.30 (0.37)	.97 (.03)	1.23 (0.31)	1.20 (0.31)
Eight-letter nonwords	.62 (.15)	0.61 (0.21)	0.38 (0.16)	.84 (.11)	0.62 (0.18)	0.53 (0.17)
Discrete						
RAN	.99 (.02)	1.72 (0.30)	1.70 (0.31)	.99 (.01)	2.05 (0.26)	2.04 (0.26)
Four-letter words	.98 (.03)	1.63 (0.30)	1.61 (0.33)	.99 (.02)	2.02 (0.26)	2.01 (0.27)
Four-letter nonwords	.86 (.14)	1.25 (0.26)	1.09 (0.35)	.95 (.06)	1.71 (0.28)	1.63 (0.30)
Eight-letter words	.90 (.11)	1.36 (0.32)	1.22 (0.39)	.98 (.03)	1.67 (0.34)	1.64 (0.35)
Eight-letter nonwords	.60 (.20)	0.93 (0.30)	0.58 (0.30)	.74 (.13)	1.10 (0.29)	0.82 (0.28)

[a] Proportion correct.
[b] Items per second.
[c] Items correct per second.

$\eta_p^2 = .08$; discrete: $F(1,99) = 236.32$, $p < .001$, $\eta_p^2 = .71$). In both the serial and discrete reading tasks, length effects were larger for nonwords than for words. The effect size, however, was much larger for the discrete reading task.

Correlational analyses

The correlations between the RAN and reading tasks in both countries are presented in Table 2. Differences in the correlations of serial and discrete RAN with the reading tasks were examined using Steiger's *Z* test (Steiger, 1980). In general, stronger correlations were found between the RAN and reading tasks of a similar format. For all serial reading tasks, serial RAN was a significantly stronger correlate than discrete RAN. For four-letter words presented in the discrete format, significantly higher correlations were found with discrete RAN than with serial RAN in both countries. For discrete reading of both eight-letter words and four-letter nonwords, the correlations with the different formats of RAN were equal. In English this was also true for the eight-letter nonwords, whereas in Dutch serial RAN was found to correlate significantly stronger with discrete reading of eight-letter nonwords than discrete RAN.

Table 2
Correlations between serial and discrete RAN and reading fluency.

	Words				Nonwords			
	Four-letter		Eight-letter		Four-letter		Eight-letter	
	Serial	Discrete	Serial	Discrete	Serial	Discrete	Serial	Discrete
	English							
Fluency								
RAN serial	.700	.463	.611	.565	.734	.565	.721	.570
RAN discrete	.422	.857	.355	.658	.447	.607	.386	.567
Steiger's *Z*	3.179**	5.675**	2.672**	1.120	3.432**	0.486	3.831**	0.034
	Dutch							
Fluency								
RAN serial	.756	.554	.572	.494	.722	.588	.593	.542
RAN discrete	.479	.802	.330	.553	.399	.634	.313	.340
Steiger's *Z*	3.963**	3.953**	2.860**	0.735	4.296**	0.635	3.324**	2.362*

Note. All correlations are significant at $p < .01$.
* $p < .05$.
** $p < .01$.

Eight-letter words and nonwords were read less accurately than the other items. To ensure that the patterns in the correlations between RAN and reading fluency are not solely caused by differences in accuracy, we also examined the correlations of serial and discrete RAN with the reading rate of items read correctly in the discrete reading tasks. The correlations with serial RAN were slightly lower, whereas the correlations with discrete RAN were slightly higher. However, the differences were small and, most important, the patterns in the correlations did not change.

Finally, we examined the correlations between serial and discrete naming of the same items. If items are processed serially, it is expected that the correlation between serial and discrete naming of the same items is high because both tasks mainly reflect serial processing. If items are processed in parallel, in contrast, the correlation is expected to be lower because the serial version of the task reflects serial processing, but the discrete version of the task does not. The correlations are presented in Table 3. Interestingly, the pattern was very similar across languages. Correlations were stronger for nonword reading than for word reading. Correlations also appeared to be somewhat stronger for eight-letter items compared with four-letter items, more so for words than for nonwords.

Regression analyses

A series of hierarchical regression analyses was conducted to examine whether serial and discrete RAN were independent predictors of serial and discrete reading fluency. Serial RAN and discrete RAN were entered interchangeably into the regression equation in the first and second steps, respectively. The shared variance of serial and discrete RAN, as well as additional variance explained in the second step, is reported in Table 4. In general, the results of the regression analyses point to strong format-specific relations between RAN and reading fluency in both English and Dutch. For the serial reading tasks, serial RAN was clearly a stronger predictor. Discrete RAN accounted for a very small, and in most

Table 3
Correlations between fluency on serial and discrete versions of the RAN and reading tasks.

Task	English	Dutch
RAN	.399	.527
Four-letter words	.528	.571
Eight-letter words	.654	.635
Four-letter nonwords	.788	.737
Eight-letter nonwords	.803	.726

Note. All correlations are significant at $p < .01$.

Table 4
Shared variance and R^2 changes in hierarchical regression analyses using serial and discrete RAN to predict reading fluency.

	Serial				Discrete			
	Words		Nonwords		Words		Nonwords	
	Four-letter	Eight-letter	Four-letter	Eight-letter	Four-letter	Eight-letter	Four-letter	Eight-letter
	English							
Shared variance	.154**	.111**	.172**	.138**	.205**	.211**	.197**	.187**
RAN serial	.337**	.262**	.370**	.402**	.021**	.109**	.129**	.146**
RAN discrete	.024*	.015	.028*	.011	.530**	.222**	.171**	.135**
	Dutch							
Shared variance	.220**	.108**	.159**	.098**	.283**	.187**	.257**	.112**
RAN serial	.351**	.220**	.363**	.254**	.024*	.057**	.089**	.182**
RAN discrete	.009	.001	.000	.000	.360**	.119**	.145**	.004

* $p < .05$.
** $p < .01$.

instances nonsignificant, amount of unique variance in serial reading tasks (ΔR^2 values ranged from .000 to .028).

Discrete RAN was a stronger predictor of discrete reading of four-letter words. The amount of additional variance explained by serial RAN in discrete reading fluency increased for eight-letter words and even more so for nonwords. In English, the contribution of serial RAN was found to be substantial for eight-letter words (10.9%), even larger for four-letter nonwords (12.9%), and largest for eight-letter nonwords (14.6%). The same pattern was found in Dutch. However, the contribution of serial RAN to discrete reading of eight-letter words and four-letter nonwords was relatively small (< 10%), whereas for eight-letter nonwords serial RAN was the only significant unique predictor; discrete RAN did not explain any additional variance in fluency on this task.

Next, possible differences between languages were tested in a series of multiple regression analyses. Serial RAN and discrete RAN were entered into the regression equation, as were interaction terms of both RAN types with language. Reading fluencies of four- and eight-letter words and nonwords were the dependent variables. The results showed that none of the interaction terms was significant.

Discussion

Throughout reading development, a gradual shift is seen in the processes underlying word identification from serial decoding toward parallel processing or sight word reading (e.g., Marinus & de Jong, 2010; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003; Zoccolotti et al., 2005). In the current study, we examined the processes underlying word and nonword reading by inspecting the relations of serial and discrete RAN with serial and discrete reading. If words are mainly read by sight, the relations between reading and RAN should be highly format specific (de Jong, 2011; Protopapas, Altani, & Georgiou, 2013a; van den Boer & de Jong, 2015). In contrast, if words are mainly identified through decoding, serial RAN should be a stronger correlate of reading irrespective of the format of the reading task. We examined the relations of serial and discrete RAN with reading of both monosyllabic (four letters) and multisyllabic (eight letters) words and nonwords in two languages, English and Dutch, varying in orthographic consistency.

The patterns of correlations between RAN and reading were strikingly similar in English and Dutch. In general, the strongest correlations were found between RAN and reading measures of the same format. More specifically, for all serial measures of reading, serial RAN was a stronger correlate and predictor than discrete RAN, reinforcing the findings of previous studies in which serial RAN was found to be a stronger predictor of reading performance than discrete RAN (e.g., Bowers & Swanson, 1991; Georgiou et al., 2013; Logan & Schatschneider, 2014). Several aspects of serial RAN have been proposed to account for this stronger relation. In addition to lexical access, which is also captured by discrete RAN performance, both serial RAN and serial reading require left-to-right and downward visual scanning (e.g., Logan & Schatschneider, 2014). This is a plausible explanation, although Protopapas, Altani, and Georgiou (2013b) recently showed that a measure of RAN in which digits were named in right-to-left and upward directions correlated equally well with reading. Another explanation is that, in addition to foveal processing, serial tasks require parafoveal processing and, thus, capture differences between participants in their ability to process multiple items simultaneously (e.g., Jones, Branigan, & Kelly, 2009; Yan, Pan, Laubrock, Kliegl, & Shu, 2013; Zoccolotti et al., 2013).

Turning to discrete RAN, it was found to be a strong correlate and predictor of discrete measures of reading. Thus, it is important to consider the format of both RAN and reading tasks when interpreting their relation (see de Jong, 2011). The correlations of serial and discrete RAN with discrete measures of reading are especially suited to examine reading processes. Discrete RAN was found to correlate more strongly than serial RAN with discrete reading of four-letter words. The correlation of discrete RAN with discrete reading fluency was .802 in Dutch and .857 in English. Because discrete RAN can be regarded as a measure of individual differences in the retrieval speed of verbal codes, these high correlations suggest that the four-letter Dutch and English words were processed as a single unit in parallel.

For the discrete reading of eight-letter words and four-letter nonwords, the differences in the correlations with serial and discrete RAN were not significant, and the correlations between discrete RAN and discrete reading were lower than for the four-letter words. The same patterns were found for discrete reading of eight-letter nonwords in English. In Dutch, however, discrete reading of eight-letter nonwords correlated more strongly with serial RAN than with discrete RAN, indicating that mainly serial reading processes underlie identification. For English, this is the first study that systematically examined the relations between serial and discrete RAN and reading. For Dutch, however, previous studies also showed that short words are processed mainly in parallel, whereas both serial and parallel reading processes underlie identification of short nonwords (de Jong, 2011; van den Boer & de Jong, 2015).

These findings indicate that individual differences in both serial and parallel reading processes contribute to variation in the reading fluency of longer words and nonwords. These results might be in line with those of previous studies showing that readers of English are able to flexibly use a variety of word identification strategies (Decker, Simpson, Yates, & Locker, 2003; Goswami, Ziegler, Dalton, & Schneider, 2003) and indicate that children process some items serially and others in parallel. Alternatively, some children might process the items in parallel, whereas others rely on serial reading processes (see also Orsolini, Fanari, Tosi, De Nigris, & Carrieri, 2006). Finally, parts of the items might be processed in parallel (i.e., letters in letter clusters or syllables), whereas other parts are processed serially (i.e., consecutive clusters or syllables). Overall, we see a smaller contribution of parallel reading processes to nonwords as opposed to words and to items that are longer. However, based on the current results, we cannot say whether this is due mainly to variations in the contribution of serial and parallel processes within items, within participants, or between participants.

We have interpreted the correlations between reading and serial RAN mainly in terms of decoding or intraword serial processes. Protopapas and colleagues (2013a), who reported format-specific relations between RAN and reading for multisyllabic words in Greek sixth graders, offered a slightly different interpretation. They proposed that whereas beginning readers process items in serial tasks one by one, more advanced readers are able to process multiple items at the same time in a cascaded manner. This cascaded processing, which emerges in both serial RAN and serial reading, means that individual items are not processed one after the other but that processing of the next item begins before processing of the current item is complete. In other words, items pass through the processes of word identification (e.g., visual recognition, mapping to phonology, articulatory planning) in a serial manner, but multiple items can go through various stages simultaneously. As a result, format-specific correlations emerge because of increasing differentiation of the processes underlying discrete and serial RAN and reading. Importantly, Protopapas and colleagues (2013a) ascribed the relation between serial RAN and serial reading mainly to inter-item (symbols or words) serial processes.

In previous studies, differences in the patterns of correlations between RAN and reading across age groups could be ascribed to developmental changes in the processes underlying both RAN and reading performance (Protopapas et al., 2013a; van den Boer & de Jong, 2015). In the current study, only one age group was included, and students were tested only once. Therefore, differences in the correlation patterns can be ascribed only to the characteristics of the items in the reading tasks. The correlation of children's RAN performance, at a specific point in development, was found to vary across reading tasks, indicating that cascaded processing does not emerge to the same extent in all serial tasks.

Whether or not items in a serial reading task can be processed in a cascaded manner could be hypothesized to depend on intraword processing or the speed and ease with which single items are processed. Short, high-frequency words, which are processed mainly in parallel, are more amenable to cascaded processing than long nonwords, which are processed more serially. Accordingly, serial RAN, which given the age and reading level of the participants would be highly amenable to cascaded processing, would be expected to correlate most strongly with serial reading tasks of items that are processed in parallel. The current findings are only partly in line with this hypothesis. Serial RAN was found to correlate especially strongly with short items, but this relation was not stronger for words than for nonwords. The correlations of serial RAN with reading of longer items were somewhat lower, but again the difference in the correlation between words and nonwords was not found. Thus, based on the current data, we cannot fully support the hypothesis that only when individual items are no longer processed serially, but are identified in parallel, can multiple items be processed simultaneously in a cascaded manner. Future studies are needed to distinguish between intra- and interword serial processes.

The many similarities in the reading processes underlying word and nonword identification in English and Dutch indicate that early differences in the acquisition of word and nonword reading accuracy (Aro & Wimmer, 2003; Seymour et al., 2003) do not result in differences in reading processes near the end of primary school. Differences were found, however, in the reading processes underlying identification of multisyllabic nonwords. These findings are in line with those of previous studies showing that children learning to read a transparent orthography (i.e., Dutch, Greek, or Spanish) rely on relations between orthography and phonology at the phonemic level when reading nonwords, whereas children reading an opaque orthography such as English code phonology of larger units such as rimes (e.g., Goswami, Gombert, & de Barrera, 1998; Goswami, Porpodas, & Wheelwright, 1997; Marinus, Nation, & de Jong, 2015). These findings could be explained through the psycholinguistic grain size theory (Ziegler & Goswami, 2005). Because of the irregularities in English grapheme-to-phoneme mappings, children are encouraged to process in parallel units larger than a letter to accurately identify nonwords. In Dutch, in contrast, serial decoding of letters into sounds is a successful reading strategy for nonwords.

Reading processes were further examined through the correlations between serial and discrete reading of the same items. If items are processed serially, this correlation is expected to be high because performance in both tasks mainly reflects serial processing. If, however, items are processed in parallel, the correlation should be lower because the serial task reflects serial processing, but the discrete version does not. An unexpected finding was that the correlation between serial and discrete RAN was higher in Dutch than in English. Logan and Schatschneider (2014) reported estimates from .42 to .58 in their meta-analysis of studies that included discrete and serial RAN. In this respect, it is the correlation between serial and discrete RAN in English that was rather low. We have no clear explanation for this finding. Apart from this correlation, the results were very similar for both English and Dutch. The correlation between the serial and discrete forms was moderate for four-letter words and resembled the correlation between serial and discrete RAN in Dutch. The correlation was higher, but still moderate, for eight-letter words. For nonwords, in contrast, the correlations were high and did not differ for short and longer nonwords. In fact, the correlations found for nonwords were higher than expected given that parallel reading processes also play a role in nonword identification. From the current study, it is not clear what reason, other than serial reading processes, explains this finding. Perhaps, the ability to assemble phonological output for nonwords affects the performance on both the discrete and serial reading tasks. In reading both words and nonwords, letters need to be converted into sounds either serially or in parallel. For words, these sounds can be mapped onto a phonological representation. For nonwords, in contrast, a phonological code needs to be assembled. It has been shown that the ease of obtaining a phonological form (e.g., “woz” [was]) from the spelling pronunciation of a letter string (e.g., “w. . .a. . .s”) contributes to word reading performance of beginning readers (Elbro, de Jong, Houter, & Nielsen, 2012). Possibly, assembling a phonological code from activated letter sounds is an important process in nonword reading as well even for these more advanced readers. Assembling phonology is a process that does not contribute to performance on the RAN task. Therefore, it could explain the high correlation among reading nonwords in the two task formats and, at the same time, the lower correlations with both serial RAN and discrete RAN.

Finally, the mean fluency scores on the reading tasks were examined more closely. As expected, words were read more fluently than nonwords, and monosyllabic items were read more fluently than multisyllabic items. Differences across languages could not be tested because the items in the reading tasks were not matched. Differences between serial and discrete tasks also could not be tested due to differences in the measures of fluency. In serial reading tasks, the time taken to read all words was recorded. This measure included identification and articulation of all items as well as the time needed to switch from one item to the next. The naming latencies recorded for the discrete reading tasks, in contrast, reflected only the time needed to identify the item and to initiate articulation. Because discrete naming with and without articulation time has been shown to correlate similarly with reading fluency (Georgiou et al., 2013), these differences in measurement are not expected to have greatly affected the correlations between RAN and reading.

The findings regarding the monosyllabic items, which suggest parallel reading processes for words and both serial and parallel reading processes for nonwords, could fit current models of word reading. Within the framework of the dual route cascaded model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), for example, parallel reading processes are expected for monosyllabic words. Although parallel reading processes are not necessarily expected for nonwords, they could be explained as an effect of the lexical route that is simultaneously active with the nonlexical route and, thus, can affect processing of nonwords as well as words. Alternatively, according to the parallel distributed processing model (Plaut, McClelland, Seidenberg, & Patterson, 1996), both words and nonwords should be read through a reading system based on parallel activation of interconnected orthographic, phonological, and semantic units. Here, the same reading processes would be expected to underlie both word and nonword identification, although the semantic units should influence processing of words more than nonwords, resulting in an advantage of word processing over nonword processing. For multisyllabic items, our findings seem to fit well with the MTM model (Ans et al., 1998). Multisyllabic words can be processed in parallel through the global procedure. Words that are not represented in the lexicon, as well as nonwords, are subsequently processed through the analytic procedure. In the analytic procedure, phonology is activated through serial activation of smaller orthographic units. These units could consist of letters or letter clusters, but they could also consist of syllables or rimes. In line with our findings and with the psycholinguistic grain size theory (Ziegler & Goswami, 2005), it is expected that the units that are activated through the analytic procedure are larger in English (i.e., rimes or syllables) than in Dutch (i.e., letters or letter clusters).

To conclude, the results of the current study indicate that in both English and Dutch, naming of alphanumeric symbols and monosyllabic words was very similar because both are processed in parallel. Both serial and parallel reading processes underlie identification of multisyllabic words, monosyllabic nonwords, and English multisyllabic nonwords. In Dutch, multisyllabic nonwords were processed serially. Overall, the similarities between the two languages in processing short and long words and nonwords far outweigh the differences.

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