Cascaded Processing in Naming and Reading: Evidence from Chinese and Korean

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Abstract

Previous studies have shown that the ability to simultaneously process multiple items when these appear in serial format (called "cascaded" processing) is an important element of reading fluency. However, most evidence in support of cascaded processing comes from studies conducted in European orthographies. Thus, the purpose of this study was to examine if the same findings generalize to non-linear and non-alphabetic orthographies (i.e., Korean and Chinese). Serial and discrete naming of digits and objects were measured in a sample of 610 Chinese and Korean children from Grades 1, 3, 5, and 6. Children were also assessed on discrete word reading and on word- and text-reading fluency. Results of hierarchical regression analysis showed that discrete naming was the main predictor of discrete word reading in both languages as early as Grade 1. Serial digit naming was the main predictor of word reading fluency across grades and languages. Finally, serial object naming made a unique contribution to word- and text-reading fluency in Chinese upper grades. Taken together, these findings suggest that, beyond accurate and fast word recognition, there is a universal, multi-item (or cascaded) processing skill involved in serial naming and reading fluency.

Keywords: cascaded processing, Chinese, Korean, rapid automatized naming, reading fluency, writing system.

Cascaded Processing in Naming and Reading: Evidence from Chinese and Korean

Rapid Automatized Naming (RAN), the ability of an individual to name as fast as possible highly familiar visual stimuli (e.g., letters, digits, objects, and colors), is a strong predictor of reading across languages (Araújo et al., 2015; Song et al., 2015). Even though the reason why RAN is a strong predictor of reading remains a subject of debate, researchers concur that the serial format of the RAN tasks (i.e., the stimuli are arranged in rows and are presented simultaneously), which resembles that of text reading, plays an important role in the RAN-reading relation (Kirby et al., 2010; Norton & Wolf, 2012; Wolf, 1991; Wolf & Bowers, 1999). This notion is supported by evidence showing that serial naming continues to predict reading even after controlling for discrete naming (e.g., Bowers & Swanson, 1991; Georgiou et al., 2013) and by evidence showing that children with dyslexia experience more difficulties in serial than discrete naming tasks (Gasperini et al., 2014; Zoccolotti et al., 2013; see also Araújo & Faísca, 2019, for a meta-analysis).

However, recent studies have suggested that the strength of the relation between serial/discrete naming and reading may also vary according to the format of the reading tasks. In his pioneering study, de Jong (2011) found that, among skilled Grade 4 readers, serial naming (operationalized with RAN digits and letters) was the main predictor of serial word reading and discrete naming was the main predictor of discrete word reading. De Jong concluded that the strong association between discrete naming and discrete word reading suggests that words are likely recognized as whole units (i.e., sight words). In turn, the higher correlations between serial naming and serial word reading are likely a product of the serial format of both tasks that requires sequential processing.

Since 2011, several studies with advanced readers have replicated de Jong’s findings in different languages with alphabetic orthographies (Dutch: van den Boer & de Jong, 2015; van den Boer et al., 2016; English: Altani et al., 2020a; Greek: Protopapas et al., 2013, 2018). However, they have also shown that the relations between serial/discrete naming and reading tasks change over time. Among beginning readers, serial word reading appears to correlate similarly with discrete and serial naming. Serial and discrete word reading also correlate strongly with each other, but their correlation decreases considerably as children become fluent readers. In addition, while the contribution of discrete naming to serial word reading is minimal among advanced readers, the contribution of serial naming to serial word reading remains strong. De Jong (2011) and Protopapas et al. (2013, 2018) have argued that these patterns of relations are indicative of different underlying processes gradually taking over during the development of reading fluency. More specifically, the strong relation between discrete and serial tasks in beginning readers reflects the fact that, at this phase of reading development, reading fluency largely depends on single word identification speed; thus, processing of a set of words presented in a list or a text is very similar to reading of words in isolation (i.e., presented one at a time on a computer screen). In contrast, in advanced readers, serial naming explains unique variance in serial word reading, even after controlling for discrete word reading and discrete naming (Altani et al., 2020a). This suggests that children take advantage of the serial format of the naming and reading tasks and process chunks of items in both tasks simultaneously. This has been called “cascaded” processing (or simply “cascading”; Altani et al., 2020a; Protopapas et al., 2018).

Researchers have also examined the relations between serial/discrete naming and discrete word reading. De Jong (2011) found that, among beginning readers, serial naming made a unique contribution to the reading of individual words after controlling for discrete naming; the latter having no unique significant effects. However, the opposite was found in advanced readers; discrete naming was the only significant predictor of discrete word reading. Based on these findings, de Jong concluded that beginning readers use a serial strategy in reading individual words and advanced readers use a parallel strategy (i.e., they process words as whole units). De Jong further argued that differences in intra-word processing strategies do not imply that there are two distinct stages in word reading development (serial vs. parallel). Instead, the use of serial or parallel strategies likely depends on both individual skill level and the linguistic characteristics of the particular set of words used in the experiments.

However, we also know that the strategy used in reading words is not only influenced by the linguistic characteristics of the stimuli, but also by the writing system children are learning to read (e.g., Perfetti & Harris, 2013; Share & Daniels, 2014; see also the Psycholinguistic Grain Size Theory by Ziegler & Goswami, 2005). To date, with one exception (Altani et al., 2017), all previous studies examining the relations of serial/discrete naming and reading have been conducted in European orthographies. Altani et al. (2017) included non-European orthographies (Korean and Chinese) in a four-language study (English, Greek, Korean, and Chinese) with Grade 3 children and found that serial digit naming was a significant predictor of serial word reading, equally across languages, after controlling for discrete word reading and discrete digit naming. Nevertheless, because their sample included only intermediate readers, no definite conclusions can be drawn about the relations of serial/discrete naming with reading in beginning or advanced readers.

Examining the relations between serial/discrete naming and reading in non-European orthographies offers a critical test of the cascaded processing hypothesis. Crucially, cascading applies to multi-element processing, both within words (intra-word) and between words (inter-word). In alphabetic orthographies like English, words are spelled with sequences of graphemes that map onto the corresponding phoneme sequences. In beginning readers (i.e., before words can be read by sight), graphemes are most often processed sequentially, one after the other. With increasing skill, the processing of successive graphemes can begin to overlap in time, gradually leading to parallel processing of multiple graphemes in larger chunks (i.e., intra-word cascading) and, eventually, sight-word reading (at least for words that are both familiar enough and short enough). Thus, the extent to which an orthography permits intra-word cascading is determined by the compositional structure of the orthographic forms: if words (and word parts) are represented by multiple elements that can be processed one by one and then combined, the gradual parallelization of this processing affords intra-word cascading. In contrast, in orthographies such as Chinese and, possibly, Korean, serial intra-word processing is expected to be limited, if the written syllables in these languages are recognized holistically rather than as a sequence of multiple individual elements.

For example, in Korean (an alphabetic syllabary), the core symbols are alphabetic but they are not arranged in a linear sequence. Instead, the letters are organized from top to bottom or from left to right within well-defined syllable blocks (Pae, 2020; Taylor & Taylor, 1995). Orthographic syllable blocks are taught to children before the individual letters that compose them and this, combined with the non-linear configuration, may lead to their processing as whole units early on, limiting the effective number of intra-word elements to the number of syllables. Similarly, in Chinese (a morphosyllabic orthography), the basic graphic unit (i.e., character) represents a syllable (Pae, 2020; Shu et al., 2003). Even though characters are composed of strokes arranged in radicals, there is no sense in which these character elements can be processed sequentially to derive their pronunciation. Instead, characters must be processed holistically. Therefore, the effective number of intra-word processing elements in Chinese is the number of syllables. Thus, in both Chinese and Korean, the potential for intra-word cascading is very limited and, therefore, serial naming should not be a unique predictor of discrete word reading in these languages even in early grades.

A second critical test of the cascaded processing hypothesis relates to the kind of stimuli used in RAN tasks. To date, previous studies have used only letters and digits in serial/discrete naming tasks (Altani et al., 2020a; de Jong, 2011; van den Boer et al., 2016). As pointed out by Protopapas et al. (2018), different materials are differentially amenable to cascaded processing. In their study, serial object and dice naming had the lowest loadings on a serial naming factor also including serial digit, word, and number word naming. This was attributed to "semantic mediation" involved in object naming, instead of direct access to phonological representations (see Georgiou, 2010; Jones et al., 2010; Poulsen & Elbro, 2013, for models of object naming). Semantic mediation precludes automatization (cf. Roelofs, 2003, 2006) and thereby reduces the loading of serial object naming on a serial naming factor that presumably captures cascaded processing. Thus, serial object naming should not explain unique variance in word- and text-reading fluency after controlling for serial digit naming. However, in Chinese, characters directly represent syllable-sized morphemes, that is, units of meaning. Advanced Chinese readers may rely on semantic efficiency for rapid lexical access (So & Siegel, 1997; Tong & McBride-Chang, 2010), in addition to orthographic processes. Thus, if the semantic mediation idea is on the right track, object naming may turn out to account for additional variance in Chinese word- and text-reading fluency, over and above serial digit naming, by virtue of shared semantic processes, in contrast to more phonologically transparent systems.

The Present Study

The purpose of the present study was to explore the relations of serial and discrete naming with serial and discrete reading in two non-European orthographies (Korean Hangul and Chinese). We asked the following three questions:

1) Does serial digit naming account for unique variance in discrete word reading beyond the effects of discrete naming (i.e., single item naming speed)? We expected that serial digit naming would not account for unique variance in discrete word reading after controlling for discrete naming in both languages and in all grade levels.
2) Does serial digit naming account for unique variance in word- and text-reading fluency beyond the ability to read single words (i.e., discrete word reading)? We expected that serial digit naming would account for unique variance in word- and text-reading fluency over and above discrete word reading and that its effects would increase with reading skill.
3) Does serial object naming, which involves semantic mediation, account for unique variance in word- and text-reading fluency, beyond serial digit naming? We expected that object naming would explain unique variance in both reading outcomes, especially in Chinese.

Methods

Participants

A total of 260 Korean children from Grades 1, 3, and 5, and a total of 350 Chinese children from Grades 1, 3, and 6 participated in the study. Within the Korean sample, 80 children (39 boys, 43 girls, M_{age} = 7.4 years) were attending Grade 1, 100 children (50 boys, 50 girls, M_{age} = 9.0 years) were attending Grade 3, and 80 children (32 boys, 38 girls, M_{age} = 11.4 years) were attending Grade 5. Within the Chinese sample, 128 children (67 boys, 61 girls, M_{age} = 7.0 years) were attending Grade 1, 113 children (65 boys, 48 girls, M_{age} = 9.0 years) were attending Grade 3, and 109 children (58 boys, 51 girls, M_{age} = 12.0 years) were attending Grade 6. Children were recruited from three public schools in Shanghai, China, and two public schools in Changwon, South Korea. Children were native speakers of Korean and Mandarin, respectively, and none were experiencing any intellectual, sensory, or behavioral difficulties (based on school records). Parental and school consent was obtained prior to testing. Ethics approval was also obtained from the Research Boards of East China Normal University and Kyungnam University.

Materials

Digits. Digit naming included nine repetitions of four digits (Arabic numerals). To control the naming demands among items and tasks (see Appendices B and C), we selected digits 2, 3, 5, and 6 for Chinese and 1, 3, 4, and 6 for Korean.

Objects. Object naming included nine repetitions of each of four drawings. The object words were matched on frequency, number of syllables, graphemes, and phonemes, and syllabic structure to the four number words (Korean: 입/mouth, 컵/cup, 무/daikon, 양/sheep; Chinese: 狗/dog, 树/tree, 羊 /goat, 花 /flower).

Words. In each language, word reading included two sets of 36 high-frequency monosyllabic words. The two sets were matched on frequency, number of graphemes and phonemes, and syllabic structure. The naming demands were also similar to number and objects words (see Appendices B and C).

Text. A brief meaningful text was created in each language. Each text included 36 words matched on psycholinguistic variables (e.g., phoneme/syllabic length and frequency) in agreement with the naming demands of all the other items (see Appendix B and C). The text was organized in four sentences to match the presentation of previous tasks.

Procedure

Serial tasks. All 36 items from each naming task were presented simultaneously in a matrix of four rows by nine on a computer screen. Children were instructed to name or read aloud all items as quickly as possible from left to right and from top to bottom. Instructions and practice items were provided prior to each trial.

Discrete tasks. Digits, objects, and words were presented individually, centered on the computer screen. The items followed a fixed quasi-random order precluding immediate repetitions. Children were instructed to name aloud each item as quickly as possible. Each item remained on the screen until a complete response was recorded and was followed by the next item without an intervening prompt. Instructions and practice items were provided prior to each task.

All children were individually tested in their schools during school hours by our trained experimenters. Testing took place in April-May in mainland China and in November-December in South Korea (this is 8–9 months after the beginning of the school year in each site) and lasted approximately 40 minutes. The administration and scoring procedures were identical in the two languages. Prior to collecting the current data, we ran a pilot study at each site with 15 children (not included in this sample) to make sure the equipment was working properly and the generated sounds were of good quality.

To present the items and record the responses, we used DMDX experimental display software (Forster & Forster, 2003) for both serial and discrete tasks. Items were presented in black 20-pt Consolas font on a white background and remained on the screen until the experimenter pressed a key to proceed to the next item, as soon as complete production of a response was registered. The tasks were presented in a randomized order to avoid systematic practice effects in the data.

Data Preparation

Response times were determined off-line using CheckVocal (Protopapas, 2007). For the discrete tasks of naming and word reading, response time included both onset latency and articulation time of individual items. For the tasks of serial naming and serial word/text reading, response time included the total time of naming or reading the entire array of stimuli. Response times were subsequently converted to number of items named or read per second (i.e., rate). For the discrete tasks, a single score per participant and task was computed by averaging the naming/reading rates across correctly named/read items. Serial naming and reading rate included both correct and incorrect responses. Both naming and reading tasks included high-frequency words, and error rate in the discrete tasks was low (mean accuracy scores across tasks ranged from 0.93 to 0.99 in both languages).

Results

Descriptive Statistics

Table 1 shows the descriptive statistics on each task for each grade and language with the final dataset after excluding outliers based on the examination of Q-Q plots or due to technical issues. Three data points in Chinese and four in Korean were missing due to technical problems (two values from serial digit in Grade 1 and one from text reading fluency in Grade 6 in Chinese; and two values from serial object, one from serial digit, and one from word reading fluency in Grade 5 in Korean). In addition, outliers in naming rate associated with extreme values were excluded based on the examination of Q-Q plots (Chinese: two full cases from Grade 6 and three individual data points from Grade 1, one from Grade 3, and three from Grade 6; Korean: one data point from Grade 3 and two data points from Grade 5). Finally, three individual data points from Grade 1 and one from Grade 3 in Chinese were excluded due to low accuracy in discrete naming (67% correct was used as a criterion based on Q-Q plots). After this cleanup procedure, our final dataset included a total of 342 complete cases in Chinese (123 in Grade 1, 111 in Grade 3, and 104 in Grade 6) and a total of 257 complete cases in Korean (80 in Grade 1, 99 in Grade 3, and 77 in Grade 5). Examination of Q-Q plots and Shapiro-Wilk tests indicated no significant deviations from normality except for a mild deviation of Grade 3 serial text reading in Chinese (see Table S1 and Figure S1 in the Supplementary Material). All analyses were conducted using R v.4.0.2 (R Core Team, 2020).

An inspection of the descriptive statistics shows some interesting patterns worth reporting. First, the serial format of the naming tasks produced higher naming rates than the discrete format of the same tasks, consistent with a “serial advantage” (Altani et al., 2017, 2020b). Second, across both orthographies, object naming (either in serial or discrete format) was slower than digit naming. Finally, there appears to be more growth in all tasks over grades levels in Korean than in Chinese. In Chinese, there was little (if any) growth in children's performance from Grade 3 to Grade 6.

Individual Differences Analyses

Table 2 shows the correlations between serial/discrete naming tasks (digits and objects) and serial/discrete reading tasks (word reading fluency, text reading fluency, and discrete word reading) per grade and language using pairwise complete cases. The full list of correlations among all measures is available in Table S2 of the Supplementary Material. An examination of these correlations in Table 2 reveals that, across both languages and grade levels, discrete naming tasks correlated more strongly with discrete word reading than with word- and text-reading fluency outcomes. In contrast, serial naming tasks correlated more strongly with serial reading (i.e., word- and text-reading fluency) than with discrete word reading. Finally, with one exception (i.e., the correlation of discrete object naming with discrete word reading in Grade 5 in Korean), the correlations of discrete digit naming with discrete word reading were numerically higher than the corresponding ones with discrete object naming.

RQ1: Does serial digit naming account for unique variance in discrete word reading beyond the effects of discrete naming (i.e., single item naming speed)?

To examine the unique contribution of the serial naming tasks (and associated processes involved in serial naming beyond single item processing), we performed hierarchical regression analyses. Serial and discrete digit naming were entered into the regression equation either in the first or in the second step of the regression equation in order to examine their effects on discrete word reading separately, after the predictor in the first step was controlled. The unique variance in discrete word reading accounted for by serial (or discrete) digit naming entered in the second step of the regression equation is displayed in Table 3.

The results of Table 3 show that discrete digit naming continued to account for unique variance (20-59%) in single word reading speed (discrete words) even after serial digit naming was entered first in the regression equation. This pattern of findings held true across grades in both languages as early as Grade 1. In contrast, the unique contribution of serial digit naming to single word reading was either decreased or eliminated, after controlling for the effects of discrete digit naming. More specifically, serial digit naming accounted for 2%-6% of unique variance in single word reading in Grades 1 and 5 in Korean; whereas, no unique variance in single word reading was left to be explained by serial digit naming in Grade 3 Korean and across grades in Chinese, after controlling for the effects of discrete digit naming.

RQ2: Does serial digit naming account for unique variance in word- and text-reading fluency beyond the ability to read single words (discrete word reading)?

A second set of hierarchical regression analyses was performed to examine the unique contribution of serial naming to reading fluency beyond the effects of discrete word reading. Discrete word reading and serial digit naming were entered into the regression equation either in the first or in the second step in order to examine their effects on word list and text reading fluency separately, after the predictor in the first step was controlled. The unique variance in the two reading fluency tasks accounted for by serial digit naming or discrete word reading entered in the second step of the regression equation is displayed in Table 4.

The results of Table 4 show that serial digit naming was a unique predictor of both reading fluency tasks after controlling for the effects of discrete word reading. This pattern was consistent across grades in both languages. In contrast, the effect of discrete word reading on both reading fluency outcomes became small or non-significant after controlling for the effects of serial digit naming. Serial digit naming was the main predictor of both reading fluency tasks, with the exception of word list fluency in Grade 5 and text reading fluency in Grade 1 Korean children, where serial digit naming and discrete word reading explained similar amounts of variance.

RQ3: Does serial object naming, which involves semantic mediation, account for unique variance in word- and text-reading fluency, beyond serial digit naming?

A third set of hierarchical regression analyses was performed to examine the unique contribution of serial object naming beyond serial digit naming. Serial digit and object naming were entered into the regression equation either in the first or in the second step. The unique variance in word list and text reading fluency accounted for by serial digit or object naming entered in the second step of the regression equation is displayed in Table 5. We see that both serial digit and object naming were significant predictors of both fluency outcomes when entered in Step 1 in the regression equation. Serial object naming had a significant and unique contribution mainly in the upper grades in Chinese, accounting for 4%-9% of unique variance, beyond the effects of serial digit naming. In Korean, the unique contribution of serial object naming was as low as .01, with the exception of word list fluency in Grade 3. Overall, serial digit naming accounted for a greater amount of unique variance (5%-34%) in word- and text-reading fluency than serial object naming and this was true across grades and languages. However, it is worth noting that both serial digit and object naming accounted for a similar amount of unique variance in text-reading fluency in Grade 6 in Chinese.

Discussion

The goal of this study was to explore whether previous findings in European orthographies (e.g., Dutch, English, and Greek) regarding the relations between serial and discrete naming with reading generalize to non-European orthographies with non-linear or non-alphabetic writing systems (e.g., Korean Hangul and Chinese). To achieve this goal, we examined: a) whether serial naming of digits predicts *discrete* word reading after controlling for discrete naming; b) whether serial naming of digits predicts *serial* reading (i.e., word list and text reading) after controlling for discrete word reading, and c) whether serial object naming predicts word- and text-reading fluency after controlling for serial digit naming. Our results showed that: a) serial digit naming generally did not account for unique variance in discrete word reading across grades and languages; b) serial digit naming predicted word- and text-reading fluency beyond discrete word reading across grades (except text-reading fluency in Grade 6) and languages; and c) serial object naming accounted for unique variance in word- and text-reading fluency in Chinese Grades 3 and 6.

Individual Word Processing in Non-Alphabetic Languages

Based on the findings of previous studies in alphabetic orthographies (Dutch: de Jong, 2011; English: Altani et al., 2020a; Greek: Protopapas et al., 2018), serial naming – reflecting serial multi-element processing – should be the main predictor of discrete word reading in early grades. In contrast, discrete naming – reflecting rapid whole-word processing – should be the main predictor of discrete word reading later in reading development, when word reading becomes more automatized, and all elements within a single word are recognized as a whole entity. In contrast to the findings of previous studies, we found that, in both Chinese and Korean Grade 1, discrete word reading was strongly related to discrete naming of both digits and objects (see Table 2) and only moderately related to serial naming. The results of regression analyses (see Table 3) further showed that when discrete naming was entered at the first step of the regression equation, the amount of variance explained by serial naming was mostly non-significant. Thus, our findings suggest that in orthographies such as Korean and Chinese, children adopt a holistic word processing strategy in reading already by Grade 1.

This finding aligns with the Psycholinguistic Gran Size Theory (PGST) (Ziegler & Goswami, 2005). PGST stipulates that consistent orthographies favor word processing through small linguistics units (e.g., phonemes). However, inconsistent orthographies require readers to rely on larger units (e.g., rimes in English). In the case of Chinese, even though characters contain a phonetic and a semantic radical (providing cues to sound and meaning, respectively), only one fourth of them can be read accurately using the phonetic radical (Chung & Leung, 2008); thus, parallel processing of whole word-sized units is preferred from the very beginning of learning to read.

In Korean, smaller units are in fact reliable, as the writing system is alphabetic with relatively high orthographic consistency (Pae, 2020; Taylor & Taylor, 1995); however, an effect of the instructional approach may be underlying this finding. In contrast to other alphabetic orthographies in which children start to learn letter names/sounds first, literacy policies and curricula in Korean emphasize the use of whole-word methods (Cho, 2017). As a result, Korean children are first taught Hangul syllables, particularly CV syllables around the age of 4 (see Cho, 2009; Wang et al., 2017). Cho (2009), for example, showed that 4- and 5-year-old Korean children were able to identify 78% and 96% of CV syllables, but only 54% and 76% of consonant letter names, and 29% and 68% of consonant sounds, respectively. This suggests that Korean children develop knowledge about CV first, then letter names, and finally letter sounds. One of the reasons Korean children learn the alphabet letter names after learning CV syllables might be related to the features of Korean letter names. Whereas English letter names are mostly mono-syllabic, the names of Korean basic consonants consist of two syllables in a CV VC or CV CVC form (Cho, 2009).

Our findings may also reflect the fact that we used short, high frequency words in each language, as short, high frequency words are typically recognized as whole units across languages once sufficiently familiar (see van den Boer et al., 2016, for a similar finding). To resolve the issue and identify the source of the discrepancy, a future study should explore the same relations using longer and less frequent words in early elementary grades.

Cascaded Processing as a Universal Inter-Word Processing Skill

The second goal of our study was to examine the relation of serial naming with word- and text-reading fluency. Previous studies in linear alphabetic orthographies have shown that serial and discrete reading are highly associated in beginning readers (e.g., Altani et al., 2018, 2020; de Jong, 2011; Protopapas et al., 2013, 2018), so that reading fluency resembles reading of words in isolation. Then the serial-discrete reading association gradually diminishes in upper elementary grades until serial naming becomes the main predictor of serial reading by Grade 5 or so. In the present study we found, instead, that serial naming uniquely predicted both word- and text-reading fluency consistently across grades and languages. In contrast, discrete word reading was a relatively weaker predictor, compared to serial digit naming, even in Grade 1, especially for text reading fluency and more so in Chinese. Our results thus show that serial naming dominates the prediction of reading fluency performance in Korean Hangul and (especially) Chinese as early as Grade 1.

This finding appears to be in contrast with developmental perspectives where text-reading fluency in beginning readers is essentially a word-by-word reading task (e.g., Kuhn &

Stahl, 2013; Rasinski et al., 2012). Because Chinese and Korean children begin reading much earlier than North American children, it is possible that by Grade 1 they have reached a stage where high frequency words are recognized automatically, which, in turn, allows multi-word processing. This interpretation is consistent with the findings concerning RQ1 above, where we observed evidence for sight reading of the test words even in Grade 1, insofar as serial digit naming was mostly a non-significant predictor of discrete word reading once the effect of discrete digit naming was controlled for. Another explanation may relate to the compact nature of characters/words in Chinese and Korean Hangul. Because in Chinese we used single character words they are not occupying much space (at least not as much compared to single syllable words in alphabetic languages), and this allows children to process more than one character within their preview window. This seems to be supported by eye movement data showing that Chinese dyslexic children were processing stimuli one at a time compared to typically-developing readers who were processing chunks of items at a time (Pan et al., 2013). The two potential explanations are not mutually exclusive.

Still, our results are in line with those of Altani et al. (2020a) who showed that serial naming continues to predict fluency performance in both word lists and connected text beyond the effects of discrete word reading and regardless of the orthographic system. The unique contribution of the serial naming tasks to efficient inter-word processing indicates that reading fluency involves the ability to simultaneously process multiple items that are presented in serial order. Thus, our results are consistent with the cascaded processing hypothesis (Protopapas et al., 2013, 2018) according to which reading and serial naming are associated partly because they involve parallel processing of multiple items (e.g., words or digits) in a cascaded manner rather than discrete processing (processing one item before moving on to the next). More specifically, when confronted with a list of words or connected text, an efficient reader will process the visual information of an item at position $n + 2$ and access the phonological representation of item at position $n + 1$, while articulating the item at position n (see also Gordon & Hoedemaker, 2016; Kuperman et al., 2016, for evidence from eye tracking studies). To efficiently schedule the words in the cascade, a high degree of parallel processing is required (Protopapas et al., 2013). Since the words included in the naming tasks were most likely recognized as unitized symbols and processed automatically, the children in our sample were able to rely on this ability regardless of their grade level. This means that cascaded processing does not belong to a developmental framework of reading stages; rather, it is an endogenous process whose availability is facilitated by the linguistic characteristics of the words and the peculiarities of the writing system.

Finally, the unique contribution of serial digit naming to reading fluency was significantly larger than that of serial object naming, as expected from previous studies in other languages in which alphanumeric serial naming was found to predict reading more strongly than non-alphanumeric naming (e.g., Bowey et al., 2005; Poulsen et al., 2015; Wolf et al., 1986). Still, serial object naming did explain unique variance in serial reading of both word lists and connected-text in Grades 3 and 6 in Chinese – but only word lists in Grade 3 in Korean – after controlling for the effects of serial digit naming. This indicates that serial object naming involves processes (e.g., semantic processing) that are independent of the serial nature of the task (already accounted for by serial digit naming). This effect was expected in Chinese due to the semantic component of Chinese characters. The role of semantic processing in reading development in Chinese has already been documented (e.g., So & Siegel, 1997; Tong & McBride-Chang, 2010). The fact that Chinese characters convey meaning may also explain why the correlations of object naming with reading fluency are closer to those between digit naming and reading fluency than previously reported in studies with alphabetic orthographies (see Araújo et al., 2015; Chen et al., 2021).

Some limitations of the present study should be reported. First, we examined the changes in the strength of the discrete-serial naming relationship using a cross-sectional design. Therefore, any relations reported here do not imply causation. More research with longitudinal data is required to confirm whether the same changes and patterns are visible over time. Second, the words in the reading tasks consisted of short, high frequency words, which may have facilitated cascaded processing. Thus, the role of multi-item or cascaded processing in reading fluency development seems to be true for reading fluency tasks that contain highly recognizable words. It remains unclear to what extent multi-item processing skills predict reading fluency performance in serial reading tasks that include longer and less frequent words. If there was any effect of syllabic length, that should be largest in the early stages of learning to read, because once automatized, syllables (and indeed whole words) would be processed as whole units. In this case, we would see results a bit more similar to those of previous studies in alphabetic orthographies, with some evidence for intra-word processing, at least in Grades 1 and 3. The use of high frequency monosyllabic words could also explain the lack of association between serial processing and discrete word reading in Korean. A possible explanation is that Korean is taught from a very early age and even at home well before children enter Grade 1 (Cho & McBride-Chang, 2005). Thus, future studies should study intra-word processing earlier in development (i.e., kindergarten). Third, we observed very little growth in the naming tasks in Chinese from Grade 3 to Grade 6. This was surprising in view of the findings of previous studies in Chinese showing a significant improvement in RAN from Grade 3 to Grade 6 (e.g., Ding et al., 2010; Liu et al., 2017). Because of the cross-sectional design of our study, it is possible that our Grade 3 sample had a larger representation of advanced readers and our Grade 6 sample a larger representation of poorer readers. Finally, although we use the term “non-alphabetic” to describe Chinese, our findings may not generalize to other non-alphabetic scripts with unique characteristics (e.g., Kana). Thus, the cascaded processing hypothesis should be explored in a wider spectrum of writing systems.

Conclusion

Our findings support previous arguments that discrete naming and serial naming rely, to some extent, on different cognitive demands. Specifically, discrete naming seems to reflect fast lexical retrieval (Näslund & Schneider, 1996), where words are recognized as unitized symbols and their pronunciation is directly retrieved from long-term memory (Ehri, 2005). On the other hand, while still related to efficient word recognition skills, serial naming also reflects an endogenous cognitive procedure in charge of handling multiple sequential items (Protopapas et al., 2013, 2018).

Importantly, our results provide support to the cascaded processing hypothesis as a unique element of reading fluency across languages. Specifically, the data from Chinese and Korean readers show that serial naming of digits was the main predictor of serial reading beyond discrete word reading across grades. Serial naming contributed not only to efficient processing of a list of unrelated words, but also to text reading fluency. Therefore, our findings complement those of previous studies in alphabetic orthographies (Altani et al., 2020a; de Jong, 2011; Protopapas et al., 2018; van den Boer et al., 2016) and suggest that the effect of cascaded processing is independent of orthographic transparency and the linearity of the script.

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Table 1

Descriptive Statistics Across All Naming and Reading Tasks per Grade and Language with the Final Datasets

Chinese	Grade 1					Grade 3					Grade 6				
Task	*N*	*M*	*SD*	Skew	Kurt	*N*	*M*	*SD*	Skew	Kurt	*N*	*M*	*SD*	Skew	Kurt
d_digits	127	1.15	0.19	0.31	0.11	112	1.40	0.18	0.28	–0.33	107	1.35	0.15	0.05	–0.49
d_objects	126	0.92	0.13	0.29	0.66	113	1.09	0.13	0.14	–0.18	107	1.11	0.11	0.08	–0.43
d_words	125	1.05	0.18	0.42	0.14	113	1.25	0.15	0.20	–0.54	105	1.24	0.10	0.33	–0.43
s_digits	126	1.71	0.38	0.19	–0.45	113	2.36	0.41	0.38	0.88	106	2.47	0.46	–0.19	0.14
s_objects	128	1.20	0.23	0.43	0.31	113	1.44	0.21	0.11	–0.59	107	1.56	0.28	0.03	–0.53
s_words	128	1.33	0.32	–0.23	0.18	113	1.88	0.33	0.25	0.37	107	1.91	0.38	0.05	0.08
s_text	128	2.21	0.73	0.19	–0.09	112	3.71	0.79	0.52	–0.20	107	3.65	0.62	0.24	–0.09
Korean	Grade 1					Grade 3					Grade 5				
Task	*N*	*M*	*SD*	Skew	Kurt	*N*	*M*	*SD*	Skew	Kurt	*N*	*M*	*SD*	Skew	Kurt
d_digits	80	1.07	0.15	–0.03	–0.22	100	1.25	0.16	0.26	–0.38	79	1.41	0.15	–0.02	–0.43
d_objects	80	0.90	0.11	0.09	–0.55	100	1.07	0.14	–0.15	–0.56	80	1.19	0.14	–0.37	–0.35
d_words	80	1.04	0.15	–0.45	0.22	100	1.23	0.15	–0.04	–0.10	79	1.37	0.13	–0.23	0.22
s_digits	80	1.64	0.36	–0.07	–0.12	100	1.97	0.42	–0.06	–0.24	79	2.29	0.47	0.19	0.64
s_objects	80	1.05	0.23	0.33	–0.25	100	1.23	0.23	0.05	–0.38	78	1.45	0.26	–0.26	0.15
s_words	80	1.44	0.33	–0.05	–0.10	99	1.64	0.31	0.10	–0.12	79	1.91	0.38	–0.02	0.17
s_text	80	1.52	0.46	0.15	0.13	100	2.07	0.39	0.13	–0.26	80	2.45	0.45	–0.12	0.25

Note. d = discrete; s = serial; Skew = skewness; Kurt = kurtosis. All naming and reading measures are reported in items per second (i.e., rate); thus, higher values represent faster performance.

Table 2

Correlations Between Naming and Reading Tasks per Grade and Language

Chinese	Grade 1			Grade 3			Grade 6		
Tasks	DWR	WRF	TRF	DWR	WRF	TRF	DWR	WRF	TRF
Discrete									
digits	0.76*	0.33*	0.27*	0.78*	0.38*	0.24	0.76*	0.16	0.19
objects	0.70*	0.25	0.15	0.66*	0.31*	0.22	0.59*	0.25	0.34*
Serial									
digits	0.29*	0.64*	0.64*	0.31*	0.53*	0.43*	0.24	0.53*	0.37*
objects	0.29*	0.38*	0.30*	0.09	0.36*	0.28	0.17	0.53*	0.41*
Korean	Grade 1			Grade 3			Grade 5		
Tasks	DWR	WRF	TRF	DWR	WRF	TRF	DWR	WRF	TRF
Discrete									
digits	0.75*	0.54*	0.51*	0.84*	0.42*	0.29	0.63*	0.51*	0.37*
objects	0.52*	0.42*	0.32	0.79*	0.39*	0.24	0.71*	0.58*	0.42*
Serial									
digits	0.54*	0.74*	0.61*	0.34*	0.68*	0.65*	0.52*	0.71*	0.62*
objects	0.44*	0.57*	0.44*	0.43*	0.55*	0.43*	0.47*	0.54*	0.50*

Note. Pearson's *r* correlation coefficients. DWR = Discrete word reading; WRF = Word reading fluency; TRF = Text reading fluency.
* Statistically significant coefficients at the adjusted level ($\alpha = .0025$) after Bonferroni correction for multiple comparisons.

Table 3

R^2 Change in Hierarchical Multiple Regression Predicting Discrete Word Reading Speed for Each Grade and Language

(Step) Predictor variable	Grade 1		Grade 3		Grade 6/5[a]	
	Chinese	Korean	Chinese	Korean	Chinese	Korean
(1) Serial digits	0.07*	0.29**	0.10*	0.12**	0.06*	0.30**
(2) Discrete digits	0.51**	0.30**	0.52**	0.59**	0.54**	0.20**
(1) Discrete digits	0.57**	0.56**	0.62**	0.70**	0.60**	0.44**
(2) Serial digits	0.01	0.02*	0.01	0.01	0.01	0.06*
Total R^2	.58	.58	.63	.71	.61	.50

Note. Discrete word reading speed was the dependent variable. Serial or Discrete digit naming was entered as a predictor at step 1 or at step 2, and vice versa, to examine its unique contribution (i.e., step 2) after controlling for the effect of the predictor variable entered at step 1.

[a] Grade 6 in Chinese and Grade 5 in Korean.

$*p < 0.05$, $**p < 0.0005$.

Table 4

R^2 Changes in Hierarchical Multiple Regression Predicting Word- and Text-Reading Fluency for Each Grade and Language

Language	(Step) Predictor variable	Grade 1		Grade 3		Grade 6/5[a]	
		WRF	TRF	WRF	TRF	WRF	TRF
Chinese							
	(1) Serial digits	.41**	.41**	.24**	.18**	.28**	.13**
	(2) Discrete words	.04*	.01	.05*	.01	.01	.02
	(1) Discrete words	.13**	.07*	.14**	.05*	.03	.06*
	(2) Serial digits	.33**	.36**	.15**	.13**	.25**	.10**
	Total R^2	.46	.43	.29	.18	.28	.16
Korean							
	(1) Serial digits	.55**	.38**	.46**	.44**	.48**	.38**
	(2) Discrete words	.07**	.13**	.07**	.01	.14**	.02
	(1) Discrete words	.39**	.41**	.23**	.09*	.48**	.21**
	(2) Serial digits	.23**	.10**	.30**	.36**	.14**	.19**
	Total R^2	.62	.51	.53	.45	.62	.40

Note. WRF = Word reading fluency; TRF = Text reading fluency. Serial digit naming or discrete word reading was entered as a predictor at Step 1 or at Step 2, and vice versa, to examine its unique contribution (i.e., Step 2) after controlling for the effect of the predictor variable entered at Step 1. Discrete words refers to discrete word reading.

[a] Grade 6 in Chinese and Grade 5 in Korean.

*$p < 0.05$, **$p < 0.0005$.

Table 5

R^2 Changes Predicting Word- and Text-Reading Fluency for Each Grade and Language

		Grade 1		Grade 3		Grade 6/5[a]	
Language	(Step) Predictor variable	WRF	TRF	WRF	TRF	WRF	TRF
Chinese							
	(1) Digits	.41**	.41**	.24**	.18**	.28**	.13**
	(2) Objects	.01	.00	.06*	.04*	.09**	.06*
	(1) Objects	.12**	.07*	.13**	.08*	.24**	.14**
	(2) Digits	.30**	.34**	.18**	.14**	.12**	.05*
	Total R^2	.42	.41	.31	.22	.36	.19
Korean							
	(1) Digits	.55**	.38**	.46**	.44**	.48**	.38**
	(2) Objects	.01	.00	.04**	.00	.02	.02
	(1) Objects	.32**	.19**	.31**	.19**	.23**	.19**
	(2) Digits	.24**	.19**	.20**	.26**	.27**	.21**
	Total R^2	.56	.38	.51	.45	.50	.40

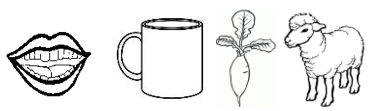
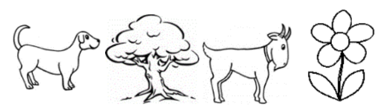
Note. WRF = Word reading fluency; TRF = Text reading fluency. Digit or Object naming was entered as a predictor at Step 1 or at Step 2, and vice versa, to examine its unique contribution (i.e., Step 2) after controlling for the effect of the predictor variable entered at Step 1.

[a] Grade 6 in Chinese and Grade 5 in Korean.

*$p < 0.05$, **$p < 0.0005$.

Appendix A

Lists of stimuli

Materials	Korean Hangul	Chinese
Number words	일, 삼, 사, 육	二, 三, 五, 六
Digits	1, 3, 4, 6	2, 3, 5, 6
Object words	입 (mouth), 컵 (cup), 무 (daikon), 양 (sheep)	狗 (dog), 树 (tree), 羊 (goat), 花 (flower)
Objects		
Word list 1	앞, 잎, 인, 암, 읍, 엔, 옥, 묘, 악, 문, 잠, 신, 색, 섬, 정, 턱, 댐, 상, 비, 키, 코, 게, 벼, 배, 서, 노, 티, 솔, 연, 혹, 북, 독, 숓, 용, 욕, 욮	安, 上, 宝, 冬, 见, 买, 土, 头, 田, 西, 又, 远, 南, 成, 用, 国, 她, 雨, 的, 走, 打, 木, 草, 笔, 鸟, 回,车, 爸, 几, 路, 个, 手, 本, 哭, 朋, 天
Word list 2	안, 차, 나, 혀, 소, 쥐, 음, 알, 울, 밥, 셈, 탓, 돌, 빵, 논, 덕, 벌, 삽, 해, 새, 개, 피, 파, 매, 재, 토, 패, 윷, 폼, 톱, 붓, 숯, 둑, 국, 약, 형	动, 春, 高, 门, 石, 工, 山, 早, 女, 好, 跑, 要, 水, 看, 坐, 年, 妈, 方, 心, 衣, 红, 地, 他, 不, 可,为, 云, 大, 过, 毛, 名, 刀, 飞, 白, 在, 比
Text	추운 겨울 밤 늦은 시간이었다. 민영이는 아직 잠들지 않고 아빠를 기다렸다. 그때 누군가 멋진 목소리로 노래를 부르며 지나갔다. 그건 틀림없는 아빠 목소리였기 때문에 달려 나갔다.	我们家有一只大花猫. 它喜欢在院子里玩. 昨天它爬上路边的大树. 它看着天空中的小鸟.

Appendix B

List of Chinese stimuli properties

Measure	Number words				Object words				Word list 1				Word list 2				Text			
	M	*SD*	min	max	*M*	*SD*	min	max	*M*	*SD*	min	max	*M*	*SD*	min	max	*M*	*SD*	min	max
Number of strokes	3.3	1.0	2	4	7.5	1.3	6	9	5.9	2.4	2	13	5.3	2.2	2	11	6.3	2.9	1	13
Number of phonemes	2.5	1.3	1	4	2.8	0.5	2	3	2.7	0.7	1	4	2.7	0.6	1	4	2.6	0.9	1	4
Number of syllables	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
Syllable frequency	4448	3035	1812	7123	3379	1503	1192	4505	5462	7862	152	45283	6213	7735	414	36602	9052	10779	152	45283
Number of consonants	1.0	0.8	0	2	1.3	0.5	1	2	1.2	0.5	0	2	1.3	0.6	0	2	1.2	0.6	0	2
Number of vowels	1.5	1.0	1	3	1.5	0.6	1	2	1.5	0.6	1	3	1.5	0.6	1	3	1.4	0.7	0	3
Number of V syllables	0.3	0.5	0	1	0	0	0	0	0	0.2	0	1	0	0.2	0	1	0	0.2	0	1
Number of CV syllables	0	0	0	0	0.3	0.5	0	1	0.4	0.5	0	1	0.3	0.4	0	1	0.4	0.5	0	1
Number of CCV syllables	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of CVC syllables	0.3	0.5	0	1	0	0	0	0	0.2	0.4	0	1	0.3	0.5	0	1	0.2	0.4	0	1
Number of CCVC syllables	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Printed frequency (children)	1959	1182	664	3007	961	804	220	1763	2674	6368	210	37787	2195	1920	200	7749	6064	10027	203	37787
Printed frequency (adult)	1153	574	488	1716	323	284	98	689	2616	8071	113	48867	2333	2540	109	10707	5482	11120	59	48867

Note. Syllable frequencies are calculated based on the first 3500 characters of the Modern Chinese character frequency list, in occurrences per million tokens (Da, 2004); children frequencies are based on textbooks for Grades 1–6, in occurrences per million tokens (Zeng, 2000); adult frequencies from the CNCORPUS, in occurrences per million tokens (Xiao, 2012).

Appendix C

List of Korean stimuli properties

	Number words				Object words				Word list 1				Word list 2				Text			
Measure	M	SD	min	max	M	SD	min	max	M	SD	min	max	M	SD	min	max	M	SD	min	Max
Number of letters	2.8	0.5	2	3	2.8	0.5	2	3	2.7	0.5	2	3	2.6	0.5	2	3	2.5	0.6	2	4
Number of phonemes	2.3	0.5	2	3	2.3	0.5	2	3	2.4	0.5	2	3	2.4	0.5	2	3	2.3	0.6	1	3
Number of syllables	1.0	0	1	1	1.0	0	1	1	1.0	0	1	1	1.0	0	1	1	1.0	0	1	1
Syllable frequency	3954	4286	544	9497	1574	1318	32	3231	1626	2609	6	11625	1240	1995	1	9781	8210	9813	66	35495
Number of consonants	1.3	0.5	1	2	1.3	0.5	1	2	1.4	0.5	1	2	1.4	0.5	1	2	1.3	0.6	0	2
Number of vowels	1.0	0	1	1	1.0	0	1	1	1.0	0	1	1	1.0	0	1	1	1.0	0	1	1
Number of V syllables	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3	0	1
Number of VC syllables	0.5	0.6	0	1	0.5	0.6	0	1	0.3	0.5	0	1	0.1	0.4	0	1	0.1	0.3	0	1
Number of CV syllables	0.3	0.5	0	1	0.3	0.5	0	1	0.3	0.5	0	1	0.4	0.5	0	1	0.5	0.5	0	1
Number of CCV syllables	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of CVC syllables	0.3	0.5	0	1	0.3	0.5	0	1	0.4	0.5	0	1	0.5	0.5	0	1	0.4	0.5	0	1
Number of CCVC syllables	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Printed frequency (children)	NA																			
Printed frequency (adult)	153	89	56	245	122	188	17	403	122	209	8	1165	393	1212	1	6954	835	1292	0	5968

Note. Syllable frequencies and adult frequencies are based on the Korean Corpus (National Institute of the Korean Language, 2005), in occurrences per million tokens; children's frequencies are not available.