

Association Between a Standardized Digit-Comparison Task and Reading Comprehension in Japanese Schoolchildren With Adequate Decoding

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Abstract

Background

Reading comprehension is generally considered to depend on decoding and language comprehension. However, some children experience reading comprehension difficulties despite adequate decoding. Whether performance on standardized digit-comparison tasks is associated with reading comprehension in such children remains unclear. The present study aimed to examine the association between performance on standardized Number Comparison tasks and reading comprehension in Japanese schoolchildren with learning difficulties but adequate decoding abilities.

Methods

This cross-sectional study included 410 elementary schoolchildren with learning difficulties who were referred to a hospital. Children meeting standardized criteria for decoding difficulties were excluded. Reading comprehension was assessed using Reading Sentences 3A and 3B from the Comprehensive Assessment of Reading Domains (CARD). Digit-comparison performance was assessed using Number Comparison I and II, standardized subtests of the Wide-range Assessment of Vision-related Essential Skills (WAVES). Hierarchical multiple regression analyses were performed after controlling for sex, full-scale intelligence quotient (FSIQ), and decoding-related measures.

Results

Number Comparison I ($\beta = .095, p = .048$) and Number Comparison II ($\beta = .112, p = .022$) were significantly associated with Reading Sentences 3B but not with Reading Sentences 3A. These associations remained significant after adjustment for decoding-related measures and FSIQ. The additional explained variance was modest ($\Delta R^2 = 0.8\text{--}1.1\%$).

Conclusions

Performance on standardized digit-comparison tasks was associated with one measure of reading comprehension in Japanese schoolchildren with adequate decoding ability, independent of decoding-related performance and general cognitive ability. Although the observed associations were modest, these findings suggest that standardized digit-comparison tasks may provide complementary information when evaluating reading comprehension difficulties in children without decoding impairments.

1 Background

Reading comprehension is fundamental to children's cognitive, linguistic, and academic development. Deficits in reading comprehension can substantially impede learning across school subjects and have long-term consequences for educational attainment, health, employment, and social outcomes [1, 2].

Originally proposed by Gough and Tunmer [3], the Simple View of Reading suggests that reading comprehension consists of two distinct components: decoding and language comprehension [1, 3, 4]. Decoding refers to the ability to efficiently translate written symbols into their corresponding spoken forms.

According to the Simple View of Reading, children with intact decoding but poor reading comprehension are generally considered to have deficits in language comprehension. However, different operational definitions of poor comprehenders have been used across studies. Some investigations have defined poor comprehenders as children with poor reading comprehension despite age-appropriate decoding skills, regardless of their language comprehension profile [1, 5, 6]. Furthermore, other studies have suggested that children with poor reading comprehension, despite having adequate decoding abilities, are commonly referred to as having specific reading comprehension deficits, and represent a clinically important subgroup of poor comprehenders [6–8]. From a clinical perspective, children with specific reading comprehension deficits are unlikely to be identified using common screening measures that emphasize decoding or phonological awareness, making early detection particularly difficult.

Although the Simple View of Reading emphasizes decoding and language comprehension, visual processing has also been proposed as a factor supporting successful reading. Visual perception contributes to accurate identification of letters and words and is associated with decoding performance in both typical readers and children with reading disorders [9–12]. Visual perception has generally been considered to contribute to reading comprehension indirectly through its influence on decoding. While visual perception has traditionally been discussed in relation to decoding, it has also been suggested that visual processing may contribute to reading comprehension through mechanisms beyond decoding. Reading comprehension is a complex process involving a variety of cognitive and linguistic skills. Beyond decoding, it is supported by multiple processes, including inference making, comprehension monitoring, working memory, and oral language [6]; therefore, deficits in these abilities may contribute to poor reading comprehension [13, 14]. However, little is known about the association between standardized visual processing measures and reading comprehension in children with adequate decoding abilities.

Number Comparison I and II are standardized visual processing subtests of the Wide-range Assessment of Vision-related Essential Skills (WAVES) [15]. These tasks require rapid comparison of adjacent digit strings under time constraints but do not require reading words aloud or converting written words into speech. Because Number Comparison tasks do not require word reading or phonological decoding, it remains unclear whether performance on these standardized tasks is associated with reading comprehension in children with adequate decoding abilities.

To our knowledge, no previous study has examined whether performance on standardized Number Comparison tasks is associated with reading comprehension in children with adequate decoding abilities. In this context, the present study focused on children with poor reading comprehension despite adequate decoding abilities. Therefore, the aim of the present study was to determine whether performance on the standardized Number Comparison subtests of the WAVES battery is associated with reading comprehension in Japanese schoolchildren with learning difficulties, but with adequate decoding abilities. Because Number Comparison was not designed to isolate a specific cognitive process, the present study did not attempt to determine the precise cognitive mechanisms underlying any observed association.

2 Methods

2.1 Participants

This study was approved by the Ethics Committee of Osaka Medical and Pharmaceutical University Hospital (approval number: 2776-4). Informed consent was obtained from the parents of the participants. This work was supported by Japan Society for the Promotion of Science KAKENHI Grant Number JP18K13229.

The participants were elementary school students who presented with reading and writing difficulties and were referred to our hospital from August 2018 to September 2025. Normal intelligence was defined as a full-scale intelligence quotient (FSIQ) of ≥ 85 on the Wechsler Intelligence Scale for Children, fourth edition (WISC-IV). Participants with decoding difficulties were excluded based on the Practical Guidelines for the Diagnosis and Treatment of Specific Developmental Disorders.

In total, 410 children were included in the study. Of these, complete data for the main variables of interest, including reading comprehension (Reading Sentences 3A and 3B) and digit-comparison task performance (Number Comparison I and Number Comparison II), were available for 404 participants.

Among the remaining participants, three had data for Reading Sentences 3A, Reading Sentences 3B, and Number Comparison I only; one had data for Reading Sentences 3A and Number Comparison I only; one had data for Reading Sentences 3A and both Number Comparison I and II; and one had data for Reading Sentences 3B and both Number Comparison I and II. Analyses were conducted using available data, with sample sizes varying depending on the variables included in each analysis.

Participants had no history of sensory impairment or brain damage and were all native Japanese-speaking children. Children diagnosed with congenital disorders or chronic diseases that could affect cognition were excluded. Visual function was assessed by pediatricians and ophthalmologists, including refractive errors, visual acuity, color vision, anisometropia, amblyopia, and binocular vision. All participants had a binocular visual acuity of ≥ 0.8 . Children with ophthalmological conditions that could affect performance on visual comparison tasks, such as strabismus with diplopia or nystagmus, were excluded.

2.2 Measures

2.2.1 Wechsler Intelligence Scale for Children (Fourth edition)

The WISC-IV was originally developed in 2003 to test the intellectual abilities of children aged 6–16 years [16]. The Japanese version has been standardized and used in Japan [17]. The test provides a FSIQ score (mean = 100, SD = 15) based on the sum of scores from 10 core subtests (mean = 10, SD = 3) and four index scores: the verbal comprehension index, perceptual reasoning index, working memory index, and processing speed index [18]. The test provides a full-scale intelligence quotient (FSIQ; mean = 100, SD = 15) derived from 10 core subtests (scaled-score mean = 10, SD = 3), as well as four index scores: the Verbal Comprehension Index, Perceptual Reasoning Index, Working Memory Index, and Processing Speed Index [18].

2.2.2. Decoding

To evaluate decoding skills, four rapid reading subtests (single phoneme, real-word, nonword, and sentence reading) from the standardized Japanese reading assessment battery described in the *Practical Guidelines for the Diagnosis and Treatment of Specific Developmental Disorders* were administered [19]. Participants were classified as having decoding difficulty if their reading times were ≥ 2 standard deviations above the age-based normative values on at least two of the four rapid reading subtests. Children who met this criterion were excluded from this study. Thus, the analytic sample consisted of children who did not meet the standardized criterion for decoding difficulty.

Among these measures, the single phoneme and nonword rapid reading subtests are relatively less influenced by lexical knowledge and provide indices of phonological decoding efficiency. Although children with decoding difficulties were excluded, individual differences in decoding-related performance may still remain within the non-impaired range. Therefore, age-standardized z-scores of reading times for the single phoneme and nonword rapid reading subtests were included as covariates in subsequent analyses.

2.2.3 Comprehensive Assessment of Reading Domains

Reading comprehension was assessed using the CARD [20], a standardized Japanese reading assessment battery (Fig. 1). Two subtests were administered: Expository Text Comprehension (Reading Sentences 3A) and Narrative Text Comprehension (Reading Sentences 3B). Each subtest consists of 12 items. Because these subtests differ in text type and task characteristics, they were analyzed separately. Participants were instructed to answer as many items as possible within 3 minutes and then continue responding for up to 5 minutes. The number of correct responses at each time point was recorded as the raw score. Raw scores were converted to standardized scaled scores (range: 1–20, mean = 10) according to the normative scoring procedures provided in the test manual [20]. The 3-minute score reflects the balance between reading speed and comprehension, whereas the 5-minute score reflects comprehension under extended time conditions.

2.2.4 Number Comparison

Performance on digit-comparison tasks was assessed using Number Comparison I and II, subtests of WAVES [15], a battery developed and standardized for Japanese children to evaluate vision-related essential skills. WAVES was designed to evaluate visual-perceptual and visual–motor integration skills based on normative data from Japanese populations [15].

In both Number Comparison tasks, participants were presented with pairs of horizontally arranged digit strings and were required to judge whether the two strings were identical or different; when different, the strings differed by one or two digits. Responses were recorded by marking the appropriate option. The number of correct responses within 2 minutes was used as the task score, and age-standardized scale scores derived from normative data were used for statistical analyses [15]. Number Comparison I involved digit strings arranged at regular and closely spaced intervals with visual segmentation, whereas Number Comparison II involved digit strings presented at irregular and wider intervals without segmentation, which may increase demands on visual scanning and attentional control [15] (Fig. 2).

2.3. Procedures

All participants were assessed for sex, age, FSIQ, reading comprehension (Reading Sentences 3A and 3B scale scores), decoding-related reading performance (rapid reading subtests for single phoneme, real-word, nonword, and sentence reading), and digit-comparison task performance (Number Comparison I and II).

The relationships between Number Comparison performance and reading comprehension, as well as decoding-related measures, were subsequently examined. All assessments were conducted according to standardized procedures. Examiners were trained in the administration of the tests and were not involved in the data analysis.

2.4 Data Analysis

Descriptive statistics were calculated for all study variables. To examine the relationships between study variables, Pearson's correlation coefficients were calculated to assess bivariate associations among reading comprehension (Reading Sentences 3A and 3B), digit-comparison task performance (Number Comparison I and II), FSIQ, and decoding-related measures.

To further investigate whether digit-comparison task performance was associated with reading comprehension after controlling for decoding-related measures and general cognitive ability, hierarchical multiple regression analyses were conducted. Reading comprehension (Reading Sentences 3A and 3B scale scores) was entered as the dependent variable in separate models.

In the first step, sex, FSIQ, and age-standardized z-scores of single phoneme and nonword rapid reading time were entered as covariates. In the second step, either the Number Comparison I or Number Comparison II scale scores were entered. The change in the coefficient of determination (ΔR^2) was used to evaluate the additional contribution of Number Comparison performance beyond the covariates.

The assumptions of linear regression were assessed by examining standardized residual plots for linearity and homoscedasticity, normal probability (P–P) plots for normality of residuals, Cook's distance for influential observations, and multicollinearity statistics (tolerance and variance inflation factor [VIF]). All analyses were conducted using IBM SPSS Statistics version 23 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < .05$.

3 Results

The descriptive statistics for all study variables are presented in Table 1. Pearson's correlation analyses showed that Number Comparison performance was associated with reading comprehension scores, particularly for Number Comparison II (see Table 2).

Table 1
Descriptive statistics of study variables

Variable	Mean	SD	N
Scale score of Reading Sentences 3A	8.64	2.81	409
Scale score of Reading Sentences 3B	8.83	2.76	408
Scale score of Number Comparison I	7.94	2.78	410
Scale score of Number Comparison II	7.68	2.60	406
FSIQ	99.2	10.9	410
z-score of single phoneme reading time	.658	1.11	410
z-score of nonword reading time	.893	1.05	410

Table 2

Pearson correlation coefficients among study variables FSIQ; full-scale Intelligence Quotient, *: $p < .05$, ** $p < .01$

Reading Sentences 3A	Reading Sentences 3A	Reading Sentences 3B	Number Comparison I	Number Comparison II	z-score of single phoneme reading time	z-score of nonword reading time	FSIQ
	-						
Reading Sentences 3B	.474**						
Number Comparison I	.102*	.191**					
Number Comparison II	.177**	.244**	.718**				
z-score of single phoneme reading time	-.130**	-.079	-.109*	-.133**			
z-score of nonword reading time	-.115**	-.114*	-.290**	-.261**	.372**		
FSIQ	.372**	.400**	.234**	.316**	-.149**	-.149**	

FSIQ; full scale intelligence quotient; SD, standard deviation.

[insert Table 2 here]

Hierarchical multiple regression analyses were conducted to examine whether these associations remained after controlling for sex, FSIQ, and decoding-related measures (single phoneme and nonword reading time z-scores), to control for potential confounding effects.

For Reading Sentences 3A, neither Number Comparison I ($\beta = .001, p = .988, \Delta R^2 = .000$) nor Number Comparison II ($\beta = .047, p = .347, \Delta R^2 = .002$) was significantly associated with reading comprehension. The inclusion of Number Comparison II resulted in an additional explained variance of only 0.2% (see Table 3).

Table 3
Hierarchical multiple regression analyses predicting reading comprehension

Dependent Variable	Predictor	N	β	p	ΔR^2	1st step R^2	2nd step R^2
Reading Sentences 3A	Number Comparison I	409	.001	.988	.000	.146	.146
	Number Comparison II	405	.047	.347	.002	.149	.151
Reading Sentences 3B	Number Comparison I	408	.095	.048	.008	.177	.185
	Number Comparison II	405	.112	.022	.011	.180	.191
ΔR^2 indicates the change in explained variance after adding Number Comparison variables.							

For Reading Sentences 3B, both Number Comparison I ($\beta = .095, p = .048, \Delta R^2 = .008$) and Number Comparison II ($\beta = .112, p = .022, \Delta R^2 = .011$) were significantly associated with reading comprehension. The inclusion of Number Comparison I resulted in an additional explained variance of 0.8%, whereas the inclusion of Number Comparison II resulted in an additional explained variance of 1.1% (see Table 3).

These results indicate that Number Comparison task performance was associated with Reading Sentences 3B, but not Reading Sentences 3A, after controlling for decoding-related measures and general cognitive ability.

[insert Table 3 here]

4 Discussion

This study examined whether performance on digit-comparison tasks was associated with reading comprehension in Japanese schoolchildren with learning difficulties, but with adequate decoding abilities. The main finding was that Number Comparison I and Number Comparison II were significantly associated with Reading Sentences 3B, even after controlling for sex, FSIQ, and decoding-related measures. In contrast, these tasks were not significantly associated with Reading Sentences 3A. The present findings indicate that performance on Number Comparison tasks was associated with Reading Sentences 3B after controlling for decoding-related measures. Although the observed associations were statistically significant, the additional explained variance was modest ($\Delta R^2 = 0.8\text{--}1.1\%$), suggesting that digit-comparison task performance

accounts for only a small proportion of variability in reading comprehension. These findings should therefore be interpreted as indicating a limited but measurable association that warrants further investigation, rather than a major determinant of reading comprehension performance.

Previous studies of poor comprehenders with adequate decoding ability have suggested that oral language alone does not fully account for individual differences in reading comprehension [6, 8] and have explored additional cognitive processes, such as inference making, comprehension monitoring, and working memory [6]. The present findings add to this research by showing that performance on a standardized visual processing task was associated with reading comprehension in children with adequate decoding ability. However, because Number Comparison tasks were not designed to isolate a single cognitive process, we cannot determine whether this association reflects visual attention, visual comparison, processing speed, or another integrative cognitive mechanism. Therefore, the present findings should be interpreted as demonstrating an association between standardized visual processing task performance and reading comprehension, rather than identifying the specific cognitive process underlying this relationship.

Importantly, the association between Number Comparison performance and reading comprehension was not observed across all reading measures. Neither Number Comparison I nor II was associated with Reading Sentences 3A, whereas both tasks were associated with Reading Sentences 3B. This pattern suggests that digit-comparison task performance may be related to specific aspects of reading comprehension rather than to reading comprehension in general. The differential pattern observed between Reading Sentences 3A and 3B is noteworthy. Because Number Comparison tasks requires rapid comparison of adjacent digit strings [15], these tasks do not require phonological decoding of written words. Nevertheless, performance on these tasks showed a modest association with Reading Sentences 3B even among children without decoding difficulties. This finding suggests that individual differences in reading comprehension may be associated with cognitive processes involved in successful performance on digit-comparison tasks, although the specific underlying mechanisms cannot be determined from the present study.

Additionally, the distinction between Number Comparison I and Number Comparison II may provide further insights. Although both tasks share a similar format, Number Comparison II may impose greater processing demands because of its irregular stimulus arrangement and the lack of visual segmentation. The finding that both tasks were associated with Reading Sentences 3B but not with Reading Sentences 3A suggests that task-related processes involved in digit comparison may be relevant to performance on more demanding reading comprehension tasks. However, this interpretation remains speculative.

According to the Simple View of Reading [3], reading comprehension is primarily determined by decoding and language comprehension. The present findings do not challenge this framework. In the present study, participants with decoding difficulties were excluded, and decoding-related performance was controlled for. Nevertheless, digit-comparison task performance was associated with Reading Sentences 3B. This finding suggests that, among children without decoding impairments, digit-comparison task performance may be related to reading comprehension, even after accounting for decoding-related measures.

Alternatively, performance on the Number Comparison tasks may reflect broader task-related processes beyond phonological decoding. However, the present study was not designed to determine which specific

processes account for the observed association. The present findings suggest only that performance on these standardized digit-comparison tasks was associated with Reading Sentences 3B, even among children without decoding difficulties. In addition, the Number Comparison tasks involved horizontally arranged digit strings, whereas the reading comprehension tasks were presented vertically. The observed association with Reading Sentences 3B, despite this difference in stimulus orientation, suggests that the relationship is unlikely to be explained solely by direction-specific visual scanning characteristics. However, the mechanisms underlying this association remain unclear and should be examined in future studies using tasks that separately assess visual comparison, visual attention, eye movements, processing speed, and language comprehension.

Some limitations to this study should be noted. First, the cross-sectional design precludes any causal inferences. Therefore, the present findings should be interpreted as associations rather than evidence that digit-comparison task performance directly affects reading comprehension. Second, listening comprehension was not directly assessed. However, because children with decoding difficulties were excluded and decoding-related measures were statistically controlled, the influence of decoding difficulty on reading comprehension was minimized. Thus, the present findings indicate an association between digit-comparison task performance and reading comprehension after accounting for decoding-related measures, although the contribution of broader language comprehension remains to be clarified. Third, because Number Comparison tasks involve multiple cognitive components, the present study cannot determine which specific component was responsible for the association with Reading Sentences 3B. Fourth, the participants were clinically referred children with learning difficulties, which may limit the generalizability of the findings. Nevertheless, this sample is clinically meaningful because it allowed us to examine children who experience learning difficulties despite not meeting the criteria for decoding impairment, a group for whom support needs may be difficult to identify based on decoding measures alone.

Conclusions

Digit-comparison task performance was associated with Reading Sentences 3B in Japanese schoolchildren with learning difficulties, but with adequate decoding abilities, even after controlling for FSIQ and decoding-related measures. These findings suggest that digit-comparison task performance may provide clinically relevant information when evaluating reading comprehension difficulties in children with adequate decoding abilities.

Abbreviations

FSIQ

full-scale intelligence quotient

VIF

variance inflation factor

WAVES

Wide-range Assessment of Vision-related Essential Skills

WISC-IV

Wechsler Intelligence Scale for Children
fourth edition.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Osaka Medical and Pharmaceutical University Hospital (approval number: 2776-4). Informed consent was obtained from the parents of the participants.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

YKI, MF, HTK, and SS substantially contributed to the study conceptualization. YKI, MF, SS, and TO significantly contributed to data analysis and interpretation. AA substantially contributed to the manuscript drafting. All authors critically reviewed and revised the manuscript draft and approved the final version for submission.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available because they contain potentially identifiable clinical data from children, but are available from the corresponding author on reasonable request and with appropriate ethical approval.

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Figures

Figure 1

Reading Sentences 3A

Japanese

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English

Hanako, Taichi, and Yuko are standing in a line. Akiko is not in the line—she is watching to see if the other three are lined up properly. Yuko is standing in front of Hanako. Taichi is standing in front of Yuko.

Question: Which position is Taichi from the back?

① first ② second ③ third

Reading Sentences 3B

Japanese

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English

Hanako put an apple in a basket. Akiko put a mandarin orange in a box. While Hanako and Akiko were away, Taichi moved the apple into the refrigerator. Later, Hanako came back.

Question: Where will Hanako look first to find the apple?

① Basket ② Box ③ Refrigerator

Figure 1

Representative examples of Reading Sentences 3A and 3B. Japanese uses kanji and kana; kanji are ideographic characters, whereas kana are phonographic. In these examples, kana printed beside the kanji indicate their pronunciations, so participants were not required to infer the readings of unfamiliar kanji. English translations are provided below the original Japanese items.

Figure 2

Number Comparison I									
3 1 8 9 2					3 1 8 9 2				
4 1 3 6 2					4 1 8 6 2				
2 5 7 8 9					2 5 7 8 9				

3 1 8 9 2					3 1 8 9 2				
4 1 3 6 2					4 1 8 6 2				
2 5 7 8 9					2 5 7 8 9				

same	one different	two different
same	one different	two different
same	one different	two different

same	one different	two different
same	one different	two different
same	one different	two different

Figure 2

Representative examples of Number Comparison I and II from the Wide-range Assessment of Vision-related Essential Skills (WAVES). Participants were required to compare pairs of horizontally arranged digit strings and determine whether the strings were identical, differed by one digit, or differed by two digits.