Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The Emergence of Literacy in Sinhala: The Role of Manipulative Dexterity, Verbal Skills, and Executive Function

Piyadasa Kodituwakku

kodpw@unm.edu

University of New Mexico

Rumalie Gunawardena

Child, Adolescent and Family Services

Giselle Dass

Child, Adolescent and Family Services

Dinu Siriwardana

Child, Adolescent and Family Services

Anne Edward

Child, Adolescent and Family Services

Sukainah Wazeer

Child, Adolescent and Family Services

Jithangi Wanigasinghe

University of Colombo

Research Article

Keywords: Sinhala, rapid naming, literacy, orthography, executive function, dexterity

Posted Date: June 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10000864/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

The Emergence of Literacy in Sinhala: The Role of Manipulative Dexterity, Verbal Skills, and Executive Function

Introduction

Over the decades, researchers have gathered a vast body of empirical data on the typical and atypical development of reading, predominantly focusing on Western alphabetic orthographies. Influential theoretical models, such as the Dual-Route Cascaded (DRC) model (Coltheart et al., 2001) and the Psycholinguistic Grain Size Theory (Ziegler & Goswami, 2005), are largely rooted in data from the English language, an orthography recognized as particularly opaque. These models have inspired hundreds of investigations, yet they have historically paid little heed to reading acquisition in non-Anglo-European writing systems, including abjads (e.g., Arabic), abugidas (Brahmi-derived *akshara* scripts), and logographic systems (e.g., Chinese). Given English's status as an outlier even among European orthographies (Seymour et al., 2003), the generalizability of these findings has been increasingly questioned (Share, 2014, 2025). Specifically, a burgeoning body of research on Brahmi-derived *akshara* orthographies has recently demonstrated the limited applicability of English-based theories to reading development in these distinct writing systems (Nag, 2022; Nag & Snowling, 2012).

Brahmi-Derived Akshara Orthographies

Indic akshara orthographies, used by over 1.5 billion people in South Asia, are widely believed to descend from the Ashoka period in the 3rd century BCE. In these writing systems, the basic unit is the akshara (syllable), which functions as an alphasyllabary rather than a pure

alphabet. An akshara can represent a standalone vowel (V) when occurring at the beginning of a word, or a consonant-vowel combination (CV, CCV, etc.). In consonant-vowel combinations, the consonant inherently includes a short vowel (most often /a/ or /ə/); other vowels are indicated by adding a secondary, dependent marker called a mātrā (vowel diacritic). Therefore, learning to read akshara orthographies involves mastering akshara-phonology at a supra-segmental level (syllable-to-sound decoding).

Regarding the dimension of consistency, syllable-to-sound decoding in akshara orthographies falls on the transparent end of the spectrum. However, this does not imply that the cognitive processes required for acquiring akshara orthographies are less advanced, as some Western scholars have assumed in the past (Gelb, 1952). As Daniels and Share (2018) have enumerated, the depth of orthographies can vary along at least 10 dimensions, with akshara orthographies proving more complex than alphabetic systems on some of them. One such dimension is *inventory size*, the number of individual graphemes a learner has to acquire (Nag, 2007). Because vowel-consonant compounds are formed by embedding a vowel into a consonant or adding a diacritic mark, the visual inventory is vast. Given that some Indic orthographies possess a large number of vowels (e.g., 15 in Malayalam; 18 in Sinhala) and consonants (50 in Malayalam; 42 in Sinhala), learners are required to acquire over 600 different graphemes.

Beyond the sheer size of the graphemic inventory, akshara orthographies impose unique visuospatial and processing demands that are frequently overlooked by Anglocentric reading models. A defining feature of this challenge is non-linearity. Unlike the strict left-to-right linearity of the Latin alphabet, akshara scripts frequently require non-linear scanning; vowel diacritics may be spatially placed above, below, or even before the consonant they modify phonologically (Nag,

2017). Consequently, the resulting orthographic units vary substantially in visual complexity from simple Consonant-Vowel (CV) formation to dense consonant conjuncts incorporating multiple ligatures and diacritics (Bhide et al., 2021). Padakannaya et al. (2016) have graded the complexity of akshara on a scale with three levels, basic (vowel alone and consonant with an inherent vowel), intermediate (a consonant combined with a diacritic) and complex (conjunct consonants combined with a vowel). Crucially, eye-tracking data from this research demonstrates that the intricate spatial layout of the complex level demands significantly greater cognitive effort and visual attention to decode compared to the basic and intermediate forms.

Furthermore, these scripts are characterized by mixed granularity (Nag & Snowling, 2012), compelling the learner to simultaneously attend to phonemic details (individual letter sounds) and syllabic units (akshara). This dual demand suggests that the acquisition of literacy in these orthographies recruits a distinct configuration of cognitive resources. Initially, a novice reader may treat an akshara as a logographic whole, mapping its global shape directly to a syllabic sound (e.g., /ka/, /ki/ without necessarily decomposing its internal structure). For high-frequency, simple akshara, this syllabic mapping serves as an efficient retrieval mechanism, akin to unitized processing predicted by Share's (2025) combinatorial model. However, the introduction of complex akshara blocks disrupts this macro-level memorization strategy, as the combinatorial possibilities number in thousands. Consequently, the reader is forced to parse the internal visual features of the block- isolating the base consonant, vowel sign, and other diacritics. This decomposition process necessitates phonemic awareness, as it requires linking these constituent visual parts to their respective phonemes. Thus, as Nag and Snowling (2012) argue, fluency in these scripts is contingent upon acquiring the 'alphasyllabic principle', the ability to flexibly shift between whole-syllable recognition and sub-syllabic analysis. Applying Daniel and Share's

multidimensional framework (2018) to Malayalam, a south Indian Dravidian language, Haridas et al. (2024) identified additional dimensions that impede the acquisition of akshara orthographies (e.g., word length and spacing).

In light of the multidimensional complexities outlined above, the predictors of fluent reading in akshara orthographies have become the subject of several studies. Nag et al. (2014) examined both child-level and symbol-level determinants of literacy acquisition in Kannada, a related Dravidian language. Their analysis revealed that at symbol-level, akhara recognition is significantly predicted by visual complexity, phonological complexity, and orthographic frequency. Specifically, while elevated visual and phonological complexity were found to impede acquisition speed, higher frequency akshara were associated with significantly reduced learning effort. Complementing these symbol-level findings, the investigation into child-level characteristics revealed that Rapid Automatized Naming (RAN), vocabulary, phonemic awareness, age, and visual memory served as significant predictors of literacy outcomes. Extending this line of inquiry to Sinhala, Wijaythilake et al. (2019) examined the cognitive predictors of word reading in Grades 1 through 4. Their results identified akshara knowledge as the most potent unique predictor of reading accuracy across all grades, while a combination of akshara knowledge and RAN best predicted reading fluency. Notably, the study found that phonemic awareness did not make a unique contribution to word reading, suggesting that in the absence of explicit phonemic instruction, young readers rely heavily on the syllabic grain size of the akshara. Bajre and Khan (2018) also found that rapid naming, phonological knowledge, and dictation predicted reading fluency in Hindi learners.

A consistent finding emerging from studies of Brahmi-based orthographies is that RAN and akshara knowledge are primary predictors of reading speed. However, the underlying factors that drive the development of these two components remain largely unaddressed. The current research seeks to fill this gap by examining reading fluency in Sinhala learners from a neuropsychological perspective, grounded in developmental theories of embodied and dynamic systems theories. Sinhala provides a unique window into these processes due to its rich, long-standing pedagogical traditions, which offer a structured environment for observing the emergence of literacy.

Sinhala language and orthography

Sinhala is the majority language of Sri Lanka, spoken by over 75% of the island's population- approximately 15.2 million people according to the 2024 Census. Sinhala has been uninterruptedly attested since the 3rd century BCE, allowing historical linguists and epigraphists to document its evolution (Coperahewa, 2022). Having evolved for over two millennia in isolation from its sister languages in the north and having had maintained close contact with Tamil and Malayalam during this period, Sinhala has developed into a unique language within South Asia.

The above distinct linguistic trajectory has culminated in a unique orthography, characterized by features generated through sustained Dravidian contact and independent creative evolution. While recognized internationally for its aesthetic and structural innovation, the Sinhala script is fundamentally a Brahmi-derived abugida (Nag, 2021; Wijaythilake & Parilla, 2014; Wijaythilake et al., 2019); cross-linguistic metrics highlight its exceptionally high graphic complexity, even among visually intricate scripts (Chang et al., 2018). Consistent with the Brahmi-based orthographies described above, vowels are represented as standalone characters in word-

initial positions or as diacritic markers, satellite to a consonant, when appearing medially or finally (See Table 1). The inherent vowel /a/ and its allophone [ə] are orthographically integrated into the consonant base, reflecting the high distributional frequency of these consonant-vowel combinations in Sinhala (as in other northern Indian and Dravidian lexicons).

Vowel Sound	Romanization	Vowel Marker (pili)	Combined Form (akshara)
a	pa	(Inherent)	ප
ā	pā	ා	පා
æ	pæ	ැ	පැ
ǣ	pǣ	ෑ	පෑ
i	pi	ි	පි
ī	pī	ී	පී
u	pu	ු	පු
ū	pū	ූ	පූ
e	pe	ෙ	පෙ
ē	pē	ේ	පේ
o	po	ො	පො
ō	pō	ෝ	පෝ
ai	pai	ෛ	පෛ
au	pau	ෞ	පෞ
(r̥)	pr̥	්ර	ප්‍ර

Table 1: Sinhala Vowel Markers and Consonant-Vowel Combinations for /p/

While spoken Sinhala comprises 40 phonemes (14 vowels and 26 consonants), the standard pedagogical alphabet consists of 60 characters (18 vowels and 42 consonants) (Dissanayake, 2012). This expanded *Misra* (mixed) set is maintained primarily to preserve the orthographic

integrity of loanwords, particularly those of Sanskrit and Pali origin. The symbol-sound mapping in Sinhala is highly consistent, making it a transparent orthography, though there are some exceptions. The main exception concerns the phoneme contrast of the inherent vowel /a/ as it is pronounced as /a/ or / ə/ dependent on the position in a word or the word itself. Vowel reduction usually occurs in medial or end positions of a word, except for the verb kərənəwa (do) and its derivatives, e.g. kərə (done), kərənə (verbal adjective) (Gair & Paolillo, 2013). This adds a dimension of complexity to orthography because an orthographically identical word can have different pronunciation and meaning. Example: kərə (done); karə (shoulder). Daniels and Share (2018) include this as a subtype of historical change.

Several other dimensions of complexity articulated by Daniels and Share (2018) apply to Sinhala orthography, most notably the dimension of linguistic distance. Sinhala exhibits a pronounced diglossia, where spoken and literary varieties differ significantly across lexical and syntactic levels. While contemporary sociolinguistic perspectives suggest a spectrum of diglossia (Mawelle, 2023), the distinction remains starkly relevant from a pedagogical standpoint. For primary-grade children, the acquisition of aspirated consonants, which is essential for literary Sinhala, poses a significant challenge, as their spoken environment utilizes only non-aspirated counterparts. Similarly, literary Sinhala enforces a distinction between dental and retroflex /n/ and /l/ phonemes that have largely collapsed in speech. This creates a critical orthographic-semantic hurdle; for instance, the meaning of the word *mala* shifts entirely based on whether the /l/ is dental (මල - flower) or retroflex (මළ - dead). Consequently, the learner must master visual distinctions that no longer correspond to auditory cues in their natural language consonant (see Table 1). Furthermore, the dimension of visual complexity is amplified by the frequent use of ligaturing in literary Sinhala. This practice results in complex glyphs that can be challenging for novice readers

to disassemble. For example, in glyphs like *kri* (කි) or krai (කෛ), the constituent consonant and vowel signs are fused or repositioned vertically and horizontally. This departs from a simple linear arrangement, forcing the learner to engage in sophisticated orthographic processing to identify the base consonant and its modified components. Such ligatures increase the 'grain size' of the visual unit, shifting the cognitive burden from simple sequential decoding to complex pattern recognition. Furthermore, Sinhala utilizes prenasalized consonants (saññaka), which represent a unique phonological category. In these characters, a nasal sound is blended into a subsequent stop consonant with a significantly shorter duration than a full-nasal cluster—for example, n + da transitions into ǹda (ඳ) and m + ba into mba (඼). This 'fused' phonetic quality requires the learner to treat the prenasalized unit as a single, distinct *akshara* rather than a sequence of two phonemes. Finally, much like Malayalam, literary Sinhala is characterized by an abundance of long compound nouns. A single orthographic string, such as *vishwavidyalaadhipathi* (**විශ්වවිද්‍යාලාධිපති** - Chancellor of a university), requires the reader to navigate a dense sequence of characters without the aid of internal spaces. This adds a formidable dimension of complexity to Sinhala orthography, as it demands high-level lexical integration and the ability to segment long, multi-syllabic strings into meaningful constituent parts.

Accordingly, the acquisition of literacy in Sinhala demands a broad range of skills, including phonological awareness, visual-spatial discrimination, fine motor control, and higher-order cognitive functions such as executive control. Given the high level of consistency in symbol-sound correspondence, ancient monastic education (Pirivena) in Sri Lanka relied heavily on oral-motor techniques, such as chanting and the rhythmic recitation of *suttas.* In accordance with traditional pedagogical methods, this training involves a systematic progression: starting with the

oral decoding of the alphabet and ligatures and culminating in the mastery of multi-syllabic compound words within texts such as the *Sakaskada*. This trajectory aligns with the nested hierarchy of sub-morphemic, morpho-lexical, and supra-lexical levels outlined in Share's (2025) combinatorial model. Notably, this pedagogical tradition emphasizes the attainment of fluency (rapid naming) through rhythmic sensory feedback and prosody training, illustrating that learning to read is fundamentally an embodied process (Thelen, 2000).

Current pedagogical practices in Sri Lankan primary schools continue to integrate sensory-motor and phonological training by requiring students to learn through the simultaneous acts of writing, speaking, and singing. The Sinhala script is categorized into middle, ascending, and descending characters based on their distinct perceptual features; learners practice these on specialized five-ruled paper designed to stabilize the spatial orientation of each *akshara*. Throughout Grades 1 and 2, students are introduced to the full inventory of sixty glyphs and their corresponding vowel diacritics (*pili*). By Grade 3, learners transition to writing on unruled pages, a shift that demands higher levels of internal orthographic representation and motor control. Much like the historical monastic tradition, this contemporary instructional schedule reinforces reading as an embodied process, where the physical constraints of writing and the rhythmic nature of recitation converge to facilitate literacy acquisition. Furthermore, these embodied processes encompass a significant emotional dimension; positive or negative feedback from teachers and peers, alongside the positive affect associated with singing and collective recitation, fundamentally shapes the learning trajectory.

Current Research

Since the bottleneck in learning alphasyllabary scripts is not accuracy but the rapid processing of a large, complex character set, the current research utilized the rapid automatized naming paradigm (Denckla & Rudel, 1976) to investigate the cognitive-motor variables underlying the acquisition of Sinhala orthography. Building on the paradigm established by (Nag et al., 2014), the current design systematically manipulated stimuli to test hypotheses regarding visual and phonological demands. Five types of stimuli were used: inherent vowel consonants (letters without *pili*), consonants with diacritics, isolated diacritics, degraded letters, and rotated letters.

Three planned contrasts were tested: inherent consonants vs. diacritic-attached consonants to assess the mapping cost of visual complexity; diacritic-attached consonants vs. isolated diacritics to assess the cost of phonological segmentation; and inherent consonants vs. degraded/rotated stimuli to test whether children process *akshara* as global perceptual units.

The association between child-related cognitive-motor skills and rapid naming was analyzed in two phases. In Phase 1, a general linear mixed model (GLMM) tested the influence of verbal fluency, verbal memory, visual construction, executive planning, and manipulative dexterity across all stimuli. We expected a significant repeated measures effect, specifically a "segmentation penalty" evidenced by significantly longer naming times for isolated diacritics. In Phase 2, we focused on identifying specific predictors of this segmentation ability, as it represents a critical phase transition toward fluent, analytical reading.

Methods

Participants

The sample included 47 girls and 46 boys (Total=93), ranging in age from 7-17 years (M=10.87, SD=2.77). Participants were categorized into three distinct developmental groups to capture distinct phases of orthographic mastery: Early Primary (7-8 years; N=21), representing the initial acquisition of akshara mapping (N=21); Upper Primary (9-11 years; N=34)), representing the transition toward automaticity; and Secondary (12-17 years; N=38), representing the stable, expert state of the literary system. Participants were recruited from suburban areas within the Colombo District of Sri Lanka. To ensure a representative socioeconomic sample, recruitment was conducted through community centers in two low-socioeconomic status neighborhoods, two small suburban schools, and a local church community. All participants were native Sinhala speakers, with Sinhala being the primary language spoken at home. Strict inclusion criteria were applied: all children were receiving education in regular classrooms and had no history of learning disorders, developmental delays, or significant neurological and psychiatric conditions. This ensured that the observed variations in naming speed and accuracy reflected typical developmental trajectories rather than clinical impairments. The sample represented a broad socioeconomic spectrum; maternal education levels were diverse, with 67.5% of mothers having completed at least an O/Level education and 18.2% holding qualifications above the A/Level. Similar trends were observed for paternal education, ensuring the findings reflect a representative range of home literacy environments.

Materials and Procedures

Experimental Task: Rapid Naming of Sinhala Orthography

Stimuli were presented in five distinct experimental conditions designed to systematically vary the visual and phonological complexity of the orthographic units. Each condition consisted

of 40 items arranged in a 10 X 4 array, as in RAN/RAS (Wolf & Denckla, 2005). These experimental conditions are illustrated in Table 2.

Condition	Description	Example Stimuli
1. Inherent Vowel	Consonants carrying the inherent /a/ vowel sound.	ව ම ච න ක
2. Consonants with Diacritics	Consonants modified by various vocalic diacritics (pili).	සෝ යා නි වැ චෙ
3. Isolated Diacritics	Vocalic diacritics presented without a consonant base, using a circular placeholder.	◌ෙෝ ◌ා ◌ී ◌ැ ◌ේ
4. Degraded Consonants	Visual fragmentation applied to the base consonants to test perceptual resilience.	
5. Rotated Consonants	Base consonants rotated 180 degrees to assess global processing.	

Table 2: Experimental stimulus conditions and examples

Children were instructed to name the items as quickly and accurately as possible, moving from left to right, starting from the top row. The experimental session was recorded, and two primary metrics were obtained for each condition: Naming Latency: The total time taken (in seconds) to complete the 40-item array; and Error Rate: Total number of incorrect naming responses.

Predictor Measures

Progressive Planning Test (Kodituwakku et al., 1995) This look-ahead puzzle was used to measure cognitive planning through 10 problems of increasing difficulty. The apparatus consists of three pegs mounted on a wooden base with 3–5 beads arranged in a specific starting configuration on the first peg. Participants are required to move the beads to a target goal position (the third peg) while adhering to two specific constraints: Only one bead may be moved at a time; and a bead, once removed cannot be returned to the initial position. These rules create a constrained problem

space that requires the participant to generate and hold a sequence of moves in mind before execution, thereby assessing forethought and inhibitory control.

Block Design (Wechsler, 2011). This subtest from the Wechsler Scales of Intelligence was used as a measure of visual construction. It was expected that the ability to decompose and recompose visual patterns would be related to learning visually complex Sinhala glyphs.

Children's Verbal Learning Test–Sinhala. This task assessed the capacity for serial verbal learning and phonological storage. Children were required to learn a list of 16 unrelated items (List A) across five consecutive learning trials. To assess the stability of these memories against distraction, an interference list (List B) was administered, followed by an immediate recall trial of List A. After a 30-minute delay, long-term retention was assessed via free recall and recognition trials. For the purposes of the current research, the total number of items correctly recalled over the five learning trials was used as the primary measure of verbal memory, representing the efficiency of phonological acquisition.

Sinhala Letter Fluency and Category Fluency. Assessing letter fluency in *akshara* orthographies requires addressing the unique mapping of consonant-vowel combinations. In the Letter Fluency condition, children were tasked with generating as many words as possible within one minute for a target consonant. Crucially, two consonants were tested (/k/ and /p/) under two distinct conditions: Words beginning with the consonant and its inherent vowel (e.g., *ka*) and words beginning with the consonant modified by any vocalic diacritic (*pili*; e.g., *ki, ko, kæ*). Proper nouns and word variants were excluded. The average number of words across these four conditions served as the measure of phonemic retrieval.

In the Category Fluency condition, participants generated exemplars for four semantic categories (fruits/vegetables, animals, Sri Lankan cities and towns, and trees/vines) for one minute each. The average score across these categories provided a measure of semantic retrieval and organized lexical search.

Grooved Pegboard (Kløve, 1963). This task assessed manual dexterity and fine-motor coordination. Participants were required to insert 25 small metal pegs, each featuring a longitudinal groove, into matching slots on a board. The slots are angled in varying directions, requiring the participant to manipulate and rotate each peg to achieve a correct fit. The time taken to complete the board was recorded for the dominant hand followed by the non-dominant hand.

Procedure

All measures were administered individually in quiet rooms provided by two community centers and a child and family clinic in a suburban area of Colombo. To ensure optimal performance and minimize fatigue, the battery was completed in a single session with brief rest periods provided between tasks as needed.

Ethics

The protocols and procedures of this research were approved by the Ethics Review Committee of the Faculty of Medicine, University of Colombo (Protocol No. EC-20-091). Prior to testing, written informed consent was obtained from all parents/guardians, alongside written assent from participants aged 12 years and older.

Results

Preliminary exploratory analyses were conducted to examine the distributional characteristics of naming latencies across the five stimulus conditions. Assessment of skewness revealed that the response times for all conditions were significantly positively skewed: Inherent Vowel ($z = 7.43$, $p < .001$), Consonants with Diacritics ($z = 4.31$, $p < .001$), Isolated Diacritics ($z = 2.54$, $p < .001$), Degraded Consonants ($z = 7.04$, $p < .001$), and Rotated Consonants $z = 3.69$, $p < .001$).

Given this non-normal distribution, a Generalized Linear Mixed Model (GLMM) procedure (IBM-SPSS version 29) was employed. This approach allowed for the modeling of skewed repeated measures using a Gamma distribution with a log link function, which is better suited for response time data than traditional transformation methods. The analysis proceeded in two stages: first, identifying the cognitive and developmental predictors across all naming tasks collectively, and second, evaluating the specific effects of orthographic complexity through planned contrasts of the repeated measures factor.

Predictors of rapid naming performance across tasks

A GLMM model including a combination of cognitive, motor, and demographic predictors revealed a significant overall fit, F (13, 355) = 62.73, $p < .001$), with several specific variables emerging as robust predictors of naming latency.

Variable	F	df	Beta (β)	Sig. (p)
Letter Fluency	6.096	1, 355	-0.032	.014

Variable	F	df	Beta (β)	Sig. (p)
Verbal Memory	4.701	1, 355	-0.005	.031
Manipulative Dexterity	4.920	1, 355	0.002	.027
Age Group 1 (vs 3)	—	—	0.400	<.001
Age Group 2 (vs 3)	—	—	0.044	.398
Gender (Male vs Female)	5.616	1, 355	0.097	.018
Executive Planning	0.853	1, 355	-0.005	.356
Block Design	0.100	1, 355	0.001	.752
Category Fluency	0.171	1, 355	-0.003	.679

Table 3: Generalized linear mixed model of predictors for rapid naming latency

---

Linguistic and motoric predictors

As Table 3 shows, naming speed in Sinhala is primarily driven by linguistic retrieval efficiency and motoric precision. Letter Fluency was a significant predictor; the negative coefficient (β = -0.032) indicates that higher fluency scores were associated with faster (lower) naming times. Verbal Memory also significantly contributed to the model, suggesting that phonological storage capacity is a key driver of rapid orthographic mapping.

Notably, Manipulative Dexterity emerged as a significant predictor. The positive coefficient for the Grooved Pegboard (β = 0.002) reflects the fact that children with slower manual

completion times exhibited increased naming latencies. In contrast, measures with heavy visual-spatial or executive demands did not reach significance. Neither Executive Planning, ($p = .35$) nor Block Design, ($p = .752$) was associated with naming speed. These findings suggest that while the Sinhala script is visually complex, the developmental bottleneck for rapid naming lies in the efficiency of the phonological retrieval system and motor coordination rather than general visual construction or higher-order planning.

Developmental and Demographic Predictors

Age group was a powerful predictor, primarily driven by the youngest children (Group 1) exhibiting significantly higher latencies compared to the oldest adolescents (Group 3; ($\beta = 0.40$). A significant effect of gender was also observed, with males exhibiting slightly slower naming latencies (beta = 0.097) than females.

After controlling for the aforementioned predictors, the repeated measures factor—naming condition—emerged as the most robust effect (F (4, 363) = 152.86, $p < .001$), indicating that naming latency varied significantly by stimulus type. To further explore these differences across development, a Generalized Estimating Equation (GEE) was employed. This analysis revealed significant main effects for both age group, $\chi^2(2) = 75.15$, $p < .001$, and naming condition, $\chi^2(4) = 379.25$, $p < .001$). However, the age x condition interaction did not reach significance, χ^2 (8) = 9.55, $p = .298$). As illustrated in Figure 1, the lack of interaction indicates that while naming speed significantly improves with age, the analytic cost (orthographic/phoneme segmentation) associated with isolated diacritics (Condition 3) remains a consistent cognitive burden across the

developmental span. Given the absence of significant interaction, naming latencies were collapsed across age groups for the subsequent planned contrasts.

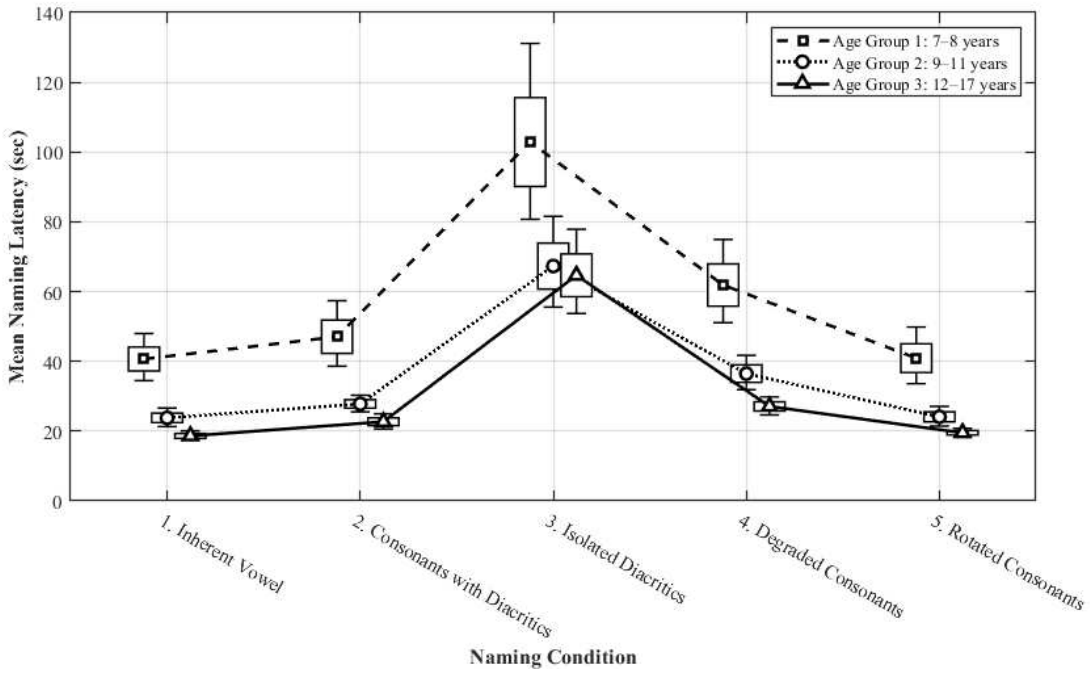

Figure 1: Mean naming latency by naming condition for the three age groups

Planned Contrasts: The cognitive cost of orthographic manipulation

To further delineate the significant main effect of naming condition, a series of pairwise contrasts were conducted using Sequential Sidak adjustments to control for multiple comparisons. These contrasts were designed to isolate the specific cognitive demands of Sinhala orthography.

Comparison	Contrast Estimate	Std. Error	t	p (Sidak)
Modification Cost (1 vs. 2)	-4.659	1.817	-2.564	.032
Degradation Cost (1 vs. 4)	-13.001	3.830	-3.395	.004
Orientation Cost (1 vs. 5)	-0.627	1.549	-0.405	.686
Analytical Cost (2 vs. 3)	-48.429	12.771	-3.792	.002

Table 4: Pairwise contrasts of naming latencies across conditions

The analytic cost of segmentation: As Figure 1 depicts, the most substantial increase in naming latency occurred when diacritics were presented in isolation compared to when they were integrated into a holistic *akshara* unit, with a significant delay of 48.43 seconds (see Table 4). This supports the hypothesis that stripping a diacritic of its consonant base forces the reader out of a rapid, holistic recognition mode and into a taxing, analytical mode of processing.

The cost of vocalic modification: The addition of a vocalic diacritic (*pili*) to an inherent-vowel consonant also imposed a measurable cost, though it was significantly less than the cost of segmentation. As shown in Table 4, naming integrated consonants with diacritics (Condition 2) was slower than naming inherent-vowel consonants (Condition 1), with a mean difference of 4.66 seconds.

The cost of perceptual degradation: The third contrast examined the impact of removing nonessential global features from the glyphs (Condition 4) compared to the baseline inherent vowels (Condition 1). This perceptual degradation imposed a significant cognitive load, resulting in a 13.00-second increase in naming latency.

Perceptual resilience to rotation: Remarkably, the system showed high resilience to global spatial disruption. There was no significant difference between naming inherent-vowel consonants in their canonical orientation (Condition 1) and those rotated by 180 degrees (Condition 5; $p = .686$). This

suggests that once a consonant's orthographic template is established, it can be accessed rapidly regardless of orientation, a stark contrast to the heavy temporal cost of diacritic segmentation seen in Condition 3.

Predictors of segmentation

Given that the analytical cost of segmentation emerged as the most pronounced effect, a subsequent analysis was conducted to identify the specific cognitive predictors of orthographic/phonemic segmentation (Condition 3). A Quantile Regression (q=0.5) was utilized for this purpose (n=58).

In contrast to the overall naming models, Executive Planning emerged as a robust predictor of segmentation efficiency ($\beta = -3.52$, $t(58) = -2.84$, $p = .006$), indicating that higher planning capacity is associated with significantly lower naming latencies in the isolated diacritic condition. Manipulative Dexterity also remained a significant contributor to the model ($\beta = 0.75$, $t(58) = 2.03$, $p = .047$). Notably, linguistic measures such as Letter Fluency and Category Fluency did not significantly predict segmentation performance ($p > .50$). This divergence suggests that while general *akshara* naming is primarily a linguistic-motor task, the analytical segmentation of diacritics from their consonant base recruits additional higher-order executive resources.

Errors in rapid naming

Any incorrect naming, including substitutions and omissions, that was not immediately self-corrected was counted as an error. As shown in Table 5, error rates remained remarkably low across all age groups and conditions, with mean errors consistently falling below 2.5 out of a possible 40 (an accuracy rate of >93%). This high level of precision, even in the youngest cohort

(Age 7–8), indicates that the foundational mapping between Sinhala orthography and phonology is established early in the developmental trajectory.

Naming Condition	Age 7–8 yrs (Mean, SD)	Age 9–11 yrs (Mean, SD)	Age 12–17 yrs (Mean, SD)
Inherent Vowel	0.27 (0.80)	0.13 (0.43)	0.11 (0.39)
With Diacritics	0.73 (1.10)	0.59 (1.93)	0.16 (0.50)
Isolated Diacritics	1.20 (1.74)	2.03 (3.08)	2.22 (2.80)
Degraded	0.73 (0.88)	0.53 (0.94)	0.51 (1.04)
Rotated	0.07 (0.26)	0.13 (0.43)	0.05 (0.23)

Table 5: Mean errors and (standard deviations) for naming conditions by age group

However, a paradoxical trend emerged in the Isolated Diacritics condition: while children's timing improved with age, their error rates did not follow a typical developmental decline. In fact, the oldest adolescents (Age 12–17) exhibited a higher mean error rate (M = 2.22) compared to the youngest group (M = 1.20). The Kruskal-Wallis nonparametric 3-group comparison revealed significant age-related improvements in accuracy for consonants with diacritics (χ^2 (2) =9.83, p = .007) and degraded consonants (χ^2 (2) = 6.62, p = .036), indicating that as children mature, they become more precise in identifying holistic and visually challenged aksharas. However, error rates for isolated diacritics did not significantly differ by age (χ^2 (2) = 0.99, p = .610).

Discussion

The present study sought to delineate the child-level and akshara-level factors governing the emergence of processing efficiency in Sinhala. While children achieve high levels of reading

accuracy early in development, their speed in processing visually complex glyphs continues to refine well into adolescence

Initial analyses explored the association between global naming latency and a combination of child-level variables. Among these, letter fluency, verbal memory, and manipulative dexterity emerged as significant predictors of rapid naming. Specifically, children with higher phonological retrieval (letter fluency) and stronger verbal memory demonstrated faster naming latencies. Furthermore, slower manipulative dexterity was associated with slower akshara naming, suggesting a motoric component in the naming process. Notably, variables requiring visual construction and executive planning with a significant visual component did not predict naming speed. Crucially, despite the significance of letter fluency, category fluency was not a significant predictor. This dissociation suggests that the executive control required for effortful phonological retrieval, rather than general semantic access, is a primary driver of naming efficiency. Demographic factors also played a role: girls generally performed faster than boys, and the 9–11-year-old group demonstrated greater efficiency than the 6–8-year-old group.

The most pronounced effects were observed at the akshara-level, revealing uneven naming latencies across the five experimental conditions. The most dramatic increase in latency occurred in the isolated diacritic condition, reflecting a significant cognitive cost associated with analytical segmentation. Interestingly, the results also revealed a ‘speed-accuracy paradox’: while the 9–11-year-old group demonstrated significantly faster processing speeds, they also exhibited more naming errors compared to the 6–8-year-old group. Interestingly, executive planning and manipulative dexterity emerged as specific predictors for the development of orthographic/phonemic segmentation skills.

Planned contrasts revealed a clear modification cost, as children took significantly longer to name aksharas with modifying diacritics compared to base characters. A degradation cost was also evident; children were slower to process aksharas with missing global features compared to intact ones. Interestingly, alteration of orientation did not impact naming latency. This indicates that children can rapidly process globally intact aksharas regardless of spatial orientation, suggesting that the "bottleneck" in processing is related to internal structural complexity rather than external positioning.

Accordingly, the present results show that predictors of naming latencies vary depending on the task demands. The global naming latency, which reflects the processing of both early and later acquired aksharas, was uniquely associated with a ‘verbal factor’ comprised of verbal memory and letter fluency. The types of list learning tasks employed here, such as the Children’s Verbal Learning Test, involve a complex interplay of memory, executive function, and processing speed (Almkvist et al., 2025; Dorr et al., 2023). Similarly, the Letter Fluency task is heavily dependent on executive control and rapid retrieval of phonological codes. In contrast with Category Fluency, which relies on the integrity of semantic memory networks (Dorchies et al., 2024). Georgiou and Parrila (2020) identified access to phonological representations as key mechanisms accounting for the association between rapid naming and reading. Both verbal memory and letter fluency tasks require access to phonological representations alongside executive monitoring to sequence responses. The lack of association between Category (semantic) fluency and naming latency suggests that rapid akshara naming is a ‘semantically thin’ process. In the absence of lexical meaning, the naming circuit primarily relies on the efficiency of the visual-phonological loop rather than deeper semantic retrieval.

Consistent with Bhide's (2018) finding that the motor act of copying helps novice readers acquire orthographic knowledge, the current research reveals a robust association between manipulative dexterity and naming latency. Dexterity emerged as a significant predictor for both global naming and orthographic segmentation, even after accounting for linguistic and executive variables. This suggests that language and motor skills are not independent modules but are developmentally co-emerging systems (Kent, 1984) that share common neuroanatomical substrates. This is consistent with Ojemann's (1984) classic finding that the ventrolateral thalamic nucleus, a key node in the motor system, is actively involved in language functions. Furthermore, stimulation mapping in the lateral perisylvian cortex has been shown to simultaneously alter both language and motor performance. Recent neuroimaging has reinforced these ties, highlighting common neural networks (Zheng et al., 2025) and the critical involvement of the cerebellum in linguistic processing (Jobson et al., 2024). From an 'enactive mind' perspective (Varela et al., 2016), these findings suggest that literacy is an embodied process. Sensory-motor pedagogical activities, such as the rhythmic writing of Sinhala glyphs, likely encode *aksharas* at both motor and phonological levels. Consequently, the efficiency of the naming circuit may depend on the integrity of this 'embodied' representation, where manual precision and orthographic recognition are deeply intertwined.

A particularly noteworthy finding is that gender remained a significant predictor of global naming latency even after accounting for the robust contributions of manipulative dexterity and verbal measures such as verbal fluency and verbal memory. This indicates that female advantage in processing Sinhala glyphs is not merely a byproduct of superior fine motor precision or verbal fluency. Instead, this unique variance suggests a gender-specific efficiency in the core naming circuitry, specifically the rapid mapping of orthographic templates to phonological representations.

As meta-analytic studies of Hirnstein et al.(2023) and Voyer et al. (2021) have revealed, females often exhibit superior ‘access speed’ to the mental lexicon.

Turning to akshara-level variance, the current data reveal the mapping cost of diacritics in rapid naming, a finding attested in other Indic orthographies (Nag, 2007; Nag & Snowling, 2012; Padakannaya et al., 2016; Share & Daniels, 2015). Although both inherent-vowel consonants and those with diacritics are processed as holistic units, the addition of a vocalic diacritic (pili) introduces an 'orthographic hurdle' that significantly increases naming latency. As Table 2 illustrates, modifying vowel markers can occur above, below, front or after a base consonant and such added visual complexity increases scanning time as shown by eye tracking investigations (Padakannaya et al., 2016). Because Sinhala novice readers are not explicitly taught to segment constituent phonemes of these akshara blocks until grade 5 (Marasinghe et al., 2019), they must learn each modified form as a distinct visual-phonological entity, placing an immense burden on verbal memory. The clinical significance of this burden is highlighted by Sumanasena et al. (2025), who found that 13.2% grade 1 and grade 2 students failed to read aksharas with diacritics entirely. These investigators identified increased visual complexity as a primary factor contributing to this difficulty, reinforcing our conclusion that the transition from inherent-vowel consonants to diacritic-modified forms represents a critical bottleneck in the emergence of Sinhala literacy.

The rotation and degradation contrasts were designed to assess the impact of manipulating the global integrity of *akshara* units. Notably, rotating intact consonants by 180° did not significantly impact naming speed compared to the baseline. This resilience to inversion suggests

that the orthographic representation of Sinhala consonants is orientation-independent once the internal structural relationships are preserved.

In contrast, degrading the consonants by removing non-essential global features significantly increased naming latency. This cost demonstrates that Sinhala readers do not rely solely on 'minimalist' key features; rather, they process *aksharas* as intact perceptual gestalts. In the degraded condition, the disruption of the global 'envelope' of the *akshara* forces the reader to engage in a more taxing, bottom-up integration of the remaining local features. The fact that naming speed suffered even when defining features remained intact confirms that the *akshara* is recognized through its global configuration, rather than a piecemeal assembly of strokes.

The most dramatic cost to naming latency was observed in the segmentation condition, where children named vowel sounds associated with diacritics in the absence of base consonants. While accuracy remained high (>92%), the massive latency suggests a profound bottleneck in processing efficiency. Our regression analysis reveals a critical shift: while holistic naming is predicted by linguistic factors, segmentation is uniquely predicted by executive planning and manipulative dexterity. The significance of these predictors points toward a structural neurocognitive requirement. It is well-established that performance on the planning task used here is sensitive to disorders with reduced white matter integrity (Kodituwakku et al., 1995), and the Grooved Pegboard has similarly been identified as a marker of white matter health (Bezdicek et al., 2014) and executive control (Tolle et al., 2020).

Given that the development of white matter tracts is a primary correlate of literacy acquisition (Roy et al., 2024), these results suggest that orthographic segmentation acts as a 'stress test' for the reading brain. While integrated *aksharas* are processed through automated,

encapsulated linguistic circuits, isolated diacritics demand the recruitment of long-range neural networks associated with fluid intelligence and executive monitoring. Consequently, children with greater white matter maturity—and the resultant higher executive control—are better equipped to handle the high 'analytical cost' of deconstructing the *akshara* unit.

Theoretical Implications

The observation that naming latency is governed by a dynamic interaction between orthographic demand and child-level cognitive- motor competencies aligns with Wolf's (1991; Wolf & Bowers, 2000) foundational model. Wolf (1991) argued that while reading and naming share common underlying sub-processes, these components are differentially recruited based on the specific demands of the task and the learner's level of mastery. This interplay of variables, ranging from sensory-motor to higher cognitive functions, can be conceptualized within the framework of Complex Dynamic Systems (Thelen, 2000; Thelen & Smith, 1995). A central proposition of Thelen's developmental framework is that cognition is fundamentally embodied; In contrast to traditional stage theories, sensory-motor processes are not discarded as higher level competencies emerge but remain integral to the functional system. In the current research, the fact that manipulative dexterity accounted for unique variance in both global and diacritic naming suggests that akshara learning is an enduringly embodied process. This aligns with Share's Combinatorial Model, which posits that later developmental milestones in akshara acquisition supplement, rather than replace, foundational ones.

Furthermore, the finding that executive planning and manipulative dexterity, both correlates of fluid intelligence, predicted the variance of phoneme segmentation is of significant theoretical interest. It implies that children with higher cognitive resources possess self-learning

skills necessary to master the sounds of isolated diacritics through inductive reasoning. By leveraging these executive resources, these children achieve ‘infinite ends from finite means’, effectively deciphering the combinatorial logic of the Sinhala script through an internal, generative process.

Limitations and Future Directions

The primary limitation of this research is the small, non-probability sample, which constrains the statistical power of the analysis. However, the substantial effect sizes observed for key findings suggest these patterns may be generalizable to the broader population. Despite its preliminary nature, these data facilitate a novel framework grounded in developmental theory and cognitive neuroscience, specifically utilizing Thelen’s Dynamic Systems approach. This perspective allows for the modeling of reading acquisition not as a linear progression, but as a self-organizing system capable of handling the dynamic interactions of processes with varying complexity. Consequently, future research should employ longitudinal methodologies with larger cohorts. Such a design is essential to capture the non-linear trajectories and changing relationships between cognitive-motor variables over time. Furthermore, a longitudinal approach would clarify how the evolution of self-learning is driven by the deployment of executive functions, as proposed by Share’s combinatorial model. This would provide a more granular view of how independent literacy emerges within the unique orthographic constraints of akshara systems like Sinhala.

References

Almkvist, O., Rennie, A., Westman, E., Wallert, J., & Ekman, U. (2025). Methods for assessment of Rey Auditory Verbal Learning Test performance in memory clinic patients and healthy

adults - at the cross-roads of learning theory and clinical utility. *Clinical Neuropsycholist*, *39*(2), 424–438. https://doi.org/10.1080/13854046.2024.2384616

Bajre, P., & Khan, A. (2018). Reading Alphasyllabic Hindi: Contributions from phonological and orthographic domains. *Psychology and Language and Communication*, *22*(1), 492–515.

Bezdicek, O., Nikolai, T., Hoskovcova, M., Stochl, J., Brozova, H., Dusek, P., Zarubova, K., Jech, R., & Ruzicka, E. (2014). Grooved pegboard predicates more of cognitive than motor involvement in Parkinson's disease. *Assessment*, *21*(6), 723–730. https://doi.org/10.1177/1073191114524271

Bhide, A. (2018). Copying helps novice learners build orthographic knowledge: methods for teaching Devanagari akshara. *Reading and Writing*, *31*(1), 1–33. https://doi.org/10.1007/s11145-017-9767-8

Bhide, A., Perfetti, C., Luo, W., Viyay, N., Wang, J., Maries, A., & Nag, S. (2021). Spelling challenges in Hindi. *Psychological Studies*, *66*, 390–407.

Chang, L. Y., Chen, Y. C., & Perfetti, C. A. (2018). GraphCom: A multidimensional measure of graphic complexity applied to 131 written languages. *Behavior Research Methods*, *50*(1), 427–449. https://doi.org/10.3758/s13428-017-0881-y

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*(1), 204–256. https://doi.org/10.1037/0033-295x.108.1.204

Coperahewa, S. (2022). The lexicography of Sinhala. In P. Hanks & G.-M. d. Schryver (Eds.), *International handbook of lexis and lexicography*. Springer https://doi.org/https://doi.org/10.1007/978-3-642-45369-4_108-1

Daniels, P., & Share, D. (2018). Writing System Variation and Its Consequences for Reading and Dyslexia. *Scientific Studies of Reading*, *22*(1), 101–116. https://doi.org/10.1080/10888438.2017.1379082

Denckla, M. B., & Rudel, R. G. (1976). Rapid "automatized" naming (R.A.N): dyslexia differentiated from other learning disabilities. *Neuropsychologia*, *14*(4), 471–479. https://doi.org/10.1016/0028-3932(76)90075-0

Dissanayake, J. B. (2012). *Encyclopedia of Sinhala language and culture*. Sumitha Publishers.

Dorchies, F., Muchembled, C., Adamkiewicz, C., Godefroy, O., & Roussel, M. (2024). Investigating the cognitive architecture of verbal fluency: evidence from an interference design on 487 controls. *Frontiers in Psychology*, *15*, 1441023. https://doi.org/10.3389/fpsyg.2024.1441023

Dorr, F., Schafer, S., Ohman, F., Linz, N., Bodin, T. H., Skoog, J., Zettergren, A., Kern, S., Skoog, I., & Troger, J. (2023). Dissociating memory and executive function impairment through temporal features in a word list verbal learning task. *Neuropsychologia*, *189*, 108679. https://doi.org/10.1016/j.neuropsychologia.2023.108679

Gair, J. W., & Paolillo, J. (2013). *Sinhala*. LINCOM GmbH.

Gelb, I. J. (1952). *A study of writing* The University of Chicago Press.

Georgiou, G. K., & Parrila, R. (2020). What mechanism underlies the rapid automatized naming-reading relation? *Journal of Experimental Child Psychology*, *194*, 104840. https://doi.org/10.1016/j.jecp.2020.104840

Haridas, M., Vasudevan, N., Raman, R., Share, D. L., & Nedungadi, P. (2024). Developing a multi-dimensional phonological and morphological frameword for understanding reading

and spelling acquisition: A study in Malayalam literacy learning. *Reading and Writing*, *37*(10), 2927–2928.

Hirnstein, M., Stuebs, J., Moe, A., & Hausmann, M. (2023). Sex/Gender Differences in Verbal Fluency and Verbal-Episodic Memory: A Meta-Analysis. *Perspectives in Psychological Science*, *18*(1), 67–90. https://doi.org/10.1177/17456916221082116

Jobson, K. R., Hoffman, L. J., Metoki, A., Popal, H., Dick, A. S., Reilly, J., & Olson, I. R. (2024). Language and the Cerebellum: Structural Connectivity to the Eloquent Brain. *Neurobiology of Language 5*(3), 652–675. https://doi.org/10.1162/nol_a_00085

Kent, R. D. (1984). Psychobiology of speech development: coemergence of language and a movement system. *American Journal of Physiology*, *246*(6 Pt 2), R888–894. https://doi.org/10.1152/ajpregu.1984.246.6.R888

Kløve, H. (1963). Clinical neuropsychology. *The Medical Clinics of North America*, *47*, 1647–1658.

Kodituwakku, P. W., Handmaker, N. S., Cutler, S. K., Weathersby, E. K., & Handmaker, S. D. (1995). Specific impairments in self-regulation in children exposed to alcohol prenatally. *Alcoholism: Clinical and Experimental Research*, *19*(6), 1558–1564. https://doi.org/10.1111/j.1530-0277.1995.tb01024.x

Marasinghe, A., Wijaythilake, M., & Parilla, R. K. (2019). Reading and writing Sinhala. In R. M. Joshi & C. McBride (Eds.), *Handbook of literacy in Akshara orthography* (pp. 195–216). Springer.

Mawelle, I. (2023). A spectrum? Diglossia as seen in contemporary Sinhala novels. *Journal of Social Sciences and Humanities Review*, *8*(3), 91–108. https://doi.org/DOI: 10.4038/jsshr.v8i3.120

Nag, S. (2007). Early reading Kannada: The pace of acquisition of orthographic knowledge and phonemic awareness. *Journal of Research in Reading*, *30*, 7–22.

Nag, S. (2017). Learning to read in alphasyllabaries. In K. Cain, D. L. Compton, & R. K. Parilla (Eds.), *Theories of Reading Development* (pp. 75–98). John Benjamin.

Nag, S. (2021). How children learn to use a writing system Mapping evidence from an Indic orthography to written language in children's books. *Written Language and Literacy*, *24*(2), 284–302. https://doi.org/10.1075/wll.00056.nag

Nag, S. (2022). Reading the Akshara writing system. In M. Snowling, C. Hulme, & K. Nation (Eds.), *Science of Reading* (Second ed., pp. 372–390). Wiley Blackwell.

Nag, S., & Snowling, M. G. (2012). Reading in an alphasyllabary: Implications for a language universal theory of learning to read. *Scientific Studies of Reading*, *16*(5), 404–423.

Nag, S., Snowling, M. G., Quinlan, P., & Hulme, C. (2014). Child and symbol factors in learning to read visually complex writing systems. *Scientific Studies of Reading*, *18*, 309–324.

Ojemann, G. A. (1984). Common cortical and thalamic mechanisms for language and motor functions. *American Journal of Physiology*, *246*(6 Pt 2), R901–903. https://doi.org/10.1152/ajpregu.1984.246.6.R901

Padakannaya, P., Pandey, A., Saligram, D., & Rao, S. R. (2016). visual-orthographic complexity of akshara and eye movements in reading: A study in Kannada alphasyllabary. *Writing Systems Research*, *8*(1), 32–43.

Seymour, P. H., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, *94*(Pt 2), 143–174. https://doi.org/10.1348/000712603321661859

Share, D. L. (2014). Alphabetism in reading science. *Frontiers in Psychology*, *5*, 752. https://doi.org/10.3389/fpsyg.2014.00752

Share, D. L. (2025). Blueprint for a universal theory of learning to read: The combinatorial model. *Reading Research Quarterly*, *60*(2). https://doi.org/https://doi.org/10.1002/rrq.603Digital Object Identifier (DOI)

Share, D. L., & Daniels, P. T. (2015). Aksharas, alphasyllabaries, abugidas, alphabets and orthographic depth: Reflections on Rimzim, Katz and Fowler (2014). *Writing Systems Research*. https://doi.org/https://doi.org/10.1080/17586801.2015.1016395

Sumanasena, S. P., Lokubalasuriya, L., Rajmohan, R., Iranthika, W. K. H., Sooriyaarachchi, D. C. C., Widanapathirane, W. P., Wijesiri, J. S. U., Arulananthan, S., Handy, T. G., & Kumarendran, B. (2025). Early akshara knowledge in beginner readers in Sinhala: a cross-sectional study. *Annals of Dyslexia*, *75*(1), 110–148. https://doi.org/10.1007/s11881-024-00318-7

Thelen, E. (2000). Grounded in the World: Developmental Origins of the Embodied Mind. *Infancy*, *1*(1), 3–28. https://doi.org/10.1207/S15327078IN0101_02

Thelen, E., & Smith, L. B. (1995). *A dynamic systems approch to the development of cognition and action*. The MIT Press.

Tolle, K. A., Rahman-Filipiak, A. M., Hale, A. C., Kitchen Andren, K. A., & Spencer, R. J. (2020). Grooved Pegboard Test as a measure of executive functioning. *Applied Neuropsychology: Adult*, *27*(5), 414–420. https://doi.org/10.1080/23279095.2018.1559165

Varela, F. J., Thomson, E., & Rosch, E. (2016). *Embodied mind*. MIT Press.

Voyer, D., Saint Aubin, J., Altman, K., & Gallant, G. (2021). Sex differences in verbal working memory: A systematic review and meta-analysis. *Psychol Bull*, *147*(4), 352–398. https://doi.org/10.1037/bul0000320

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence-Second Edition*. NCS Pearson.

Wijaythilake, M., & Parilla, R. K. (2014). Predictors of word reading skills in good and struggling readers in Sinhala. *Writing Systems Research*, *6*(1), 120–131.

Wijaythilake, M., Parrila, R., Inoue, T., & Nag, S. (2019). Cognitive predictors of word reading in Sinhala. *Reading and Writing*, *32*(7), 1881–1907. https://doi.org/10.1007/s11145-018-9927-5

Wolf, M. (1991). Naming speed and reading: The contribution of the cognitive neurosciences. *Reading Research Quarterly*, *26*(2), 123–141.

Wolf, M., & Bowers, P. G. (2000). Naming-speed processes and developmental reading disabilities: an introduction to the special issue on the double-deficit hypothesis. *Journal of Learning Disabilities*, *33*(4), 322–324. https://doi.org/10.1177/002221940003300404

Wolf, M., & Denckla, M. B. (2005). *Rapid Automatized Naming and Rapid Alternating Stimulus Tests*. Pro-Ed.

Zheng, Y., Zhang, J., & Yang, Y. e. a. (2025). Neural representation of sensorymotor features in language-motor areas during auditory and visual perception. *Communications Biology*, *8*, 41. https://doi.org/https://doi.org/10.1038/s42003-025-07466-5

Ziegler, J., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*(1), 3–29. https://doi.org/10.1037/0033-2909.131.1.3