Children's reading development:

learning about sounds, symbols and cross-modal mappings.

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Reading draws upon multiple cognitive and linguistic domains in complex ways. Research in the last half a century or so has begun to clarify how children learn about the script of a language. A comprehensive theoretical account about reading development however remains elusive and it is not immediately apparent how theories that have evolved in the context of one language or script can account for phenomena seen in other writing systems. A mature science of reading should explain how learning occurs across languages and across scripts. Moreover, because languages and scripts vary in multiple ways, it follows that models of reading need to factor in different developmental pathways into proficiency.

Ziegler and Goswami (2005) drew together cross-linguistic findings to explain reading development across languages, proposing three contributing factors. The first factor was the availability of different sound units prior to reading. The second factor was the degree of consistency seen in the associations between the sounds and the symbols of the language. The third factor was granularity which refers to the level of mappings between the sounds and symbols in the language, whether they were smaller or larger sized units. The authors also argued the nature of instruction is important for understanding reading development.

This framework, known as the Psycholinguistic Grain Size Theory considers reading development to depend upon the abstraction of optimal mappings between orthographic units and the sounds of the language.

The factors of availability, consistency and granularity are each seen to aid in the process of learning. Thus, if the sound units represented by the writing system are phonological structures that are already established in everyday speech, that availability should make learning to read easier. If the correspondences between sounds and symbols are consistent
and hence predictable, then learning the associations become easier. Granularity is perhaps the least specified factor in the proposal. Granularity refers to whether a writing system represents sounds at one particular sub-lexical level or if there are multiple mappings (as in English to large and small units simultaneously); the concept thus embodies the ‘grain size’ of the phonological units to which the symbols map (large versus small) and whether the mappings are fine or coarse-grained. Within this view, scripts that contain predominantly one size of unit (e.g., Finnish with phoneme level units) should be easier to learn than languages where mappings to symbol units are at more than one unit size. English is often given as an example of a language with such multi-sized mappings in which minimal sound units (e.g., the phoneme [ai]) may be represented by single letters (e.g., I) and also by letter strings (e.g., igh). Such multiple mappings are seen as presenting a challenge to learners. It is notable, however, that the Psycholinguistic Grain Size framework is silent about scripts outside the alphabetic writing systems, and while there is an implicit assumption that the formulation is language-general (e.g. Yang, McCandliss, Shu & Zevin, 2009), it is as yet unclear how universal are the constructs in the framework.

In this chapter we will begin by discussing some of the ways in which scripts differ and why it is important to attend to these differences in order to understand children’s reading development. We will then go on to examine one particular script, the alphasyllabary of Kannada, a language spoken in South India. The Kannada orthography (and more generally alphasyllabic writing systems) is understudied, and is a good test case for current theories of reading development. Taking the Psycholinguistic Grain Size model as a framework, we first specify the processes involved in learning about the sounds and symbols in the Kannada writing system and then examine the predictors of individual differences in reading attainment. We end this chapter by discussing the commonalities in reading development
using findings from the alphasyllabic, logographic and alphabetic scripts. Specifically, we consider the cognitive universals that underpin reading acquisition across writing systems.

The ground that this chapter covers is specific to the sound-symbol learning processes involved in learning to read. We acknowledge that the purpose of reading is for understanding and hence, knowledge of morphology and syntax is also important to reading development. Moreover, methods of instruction can change the developmental pathways into literacy. However, our focus will be on reading accuracy and reading fluency and the skills for learning the symbols of a writing system and the sounds they represent.

**Diversity in scripts**

Scripts differ in appearance, the visual form of its symbol set. They also differ in the ways in which the symbols map on to spoken speech. The alphasyllabic scripts of South Asian languages like Bengali, Hindi and Tamil code two levels of spoken speech. Symbol units, called *akshara*, represent sounds at the level of both a syllable and a phoneme (Salomon, 2000). In contrast, the alphabetic scripts of languages like English, Czech, and Italian represent sounds at the level of the phoneme. In the case of both alphasyllabic and alphabetic scripts, the symbol units are sub-lexical representations. These symbol units map on to spoken language at a level that is not meaning bearing in itself. In other scripts, such as Japanese Kanji, symbol units called characters, typically encode lexical information. Each character maps onto a morpheme, making the symbol units lexical or meaning-representations of spoken language. The difference between a meaning and a non-meaning bearing symbol system implies that scripts differ in their representational characteristics.

Given the differing characteristics of writing systems, it is natural to expect that script-specific typological features will impact learning to read. For example, we know that the pace of learning depends on the size of the symbol set; the contained orthographies of Latin
derived scripts comprise between 20 and 40 letters and the names and sounds of these letters are typically learnt by the end of first year in school (Seymour, 2005). The more extensive symbol sets of the Indian alphasyllabaries with 200 to 500 symbols take longer, with less frequent symbols not yet fully mastered by children in Grades 3 and 4 (Nag, 2007; Tiwari, Nair & Krishnan, 2011; Sircar & Nag, in press). In Chinese, the number of characters runs into thousands and surveys show that learning of new character symbols continues into Grade 6 and beyond (Shu, Chen, Anderson, Wu & Xuan, 2003). Since learning to read depends upon establishing mappings between phonology and orthography, statistical learning principles underpin reading acquisition across languages (Seidenberg, 2007). The influence of statistical learning mechanisms in organising the reading system has been demonstrated in studies of symbol learning (Yang, McCandliss, Shu & Zevin, 2009) and reading (Zevin & Seidenberg, 2004). Notwithstanding this language-general learning mechanism, a comprehensive account of reading development needs to explain variations in component processes in different writing systems. Examples of components are symbol learning, phonology or sound processing, and cross-modal mappings between sounds and symbols. Such features of diversity in scripts have been examined from various points of view (see Box. 1).
Box 1: Three perspectives about writing systems

A typological perspective: This is essentially a non-historical approach that focuses on script characteristics rather than the context in which it has emerged and is used. A typology of writing systems that has been popular for several decades is the threefold classification of logographic, syllabic and alphabetic scripts. A problem with this narrow classification is that many of the world’s scripts do not neatly fit into these categories. There are scripts that have mixed characteristics such as the Indian akshara writing systems which have both alphabetic and syllabic features. In addition, the classification system undervalues the ways in which scripts, particularly those referred to as logographic, represent sub-lexical phonetic information.

A cultural enterprise perspective: In this perspective different types of writing systems are seen as particular solutions that emerged within different cultures for the common aim of coding spoken language. This perspective acknowledges all writing systems are a motivated solution (see for example, Seidenberg, in press) and essentially disagrees with the notion of alphabetic solutions being the best solution.

An evolutionary perspective: This is essentially a socio-politically driven approach which judges one script or set of scripts as higher in level than another. Thus the alphabetic scripts may be presented as more advanced than the logographic and syllabic scripts. Historically, the most strident manifestations of this perspective have been the mass scale destruction of non-alphabetic texts - the Mayan texts during the Spanish inquisition for example. In recent years the perspective is less visible, and often couched within arguments that the differing pace of learning in different scripts is problematic. A faster rate of learning is argued to make one script better than the other. For example, the shift from the Arabic script to the Latin script for the Turkish language comes to be seen as a ‘positive change’ because the Latin script is seen as being simple and allowing for a more transparent and easy to learn writing system (Davis, 2005, pg 10). The politics of placing one script over another has far reaching implications on policy and practice, and how theorising will account for differences.

**Script specific aspects of learning to read**

To begin our examination of the script-specific processes that are involved in learning to read, we turn to Kannada, an alphasyllabic writing system. Kannada belongs to the South Dravidian group of languages and is a language of South India. The Kannada symbol unit, called *akshara*, is derived from the ancient Indian script called the Brahmi script, and this
lineage makes Kannada closely related to the several other Brahmi-derived alphasyllabaries of South and South East Asia. Thus, like the Bengali, Hindi and Tamil scripts, the Kannada writing system comprises four types of symbol sets: primary vowels (/V/), consonants with the vowel /a/ (/Ca/), consonants with vowels other than /a/ (/CV/) and consonant clusters (/CCV/). The vowel /a/ in the orthographic syllable /Ca/ is unmarked, and this has led to the term ‘inherent’ vowel being used to describe these symbols. A second feature of the akshara system is the stacking together (arranging together) of two or more phonemic markers to form the /CV/ and /CCV/ symbols. The inherent vowels and stacked phonemic markers have together been considered as defining features of the akshara writing system (Salomon, 2000; Nag, 2011). Both of these typological features impact on children’s symbol learning, sound processing and the mapping of sounds to symbols in Kannada. Most of the current research in Kannada is on the impact of the stacked phonemes on learning to read, and even though the inherent feature of the vowel /a/ is one of the first aspects of the writing system that children encounter, we do not as yet understand how this null marker is learned, or what the influences of this feature may be on emergent understanding of mappings between sound and symbol (cf Sircar & Nag, in press).

**Learning about symbols**

Children learning to read in Kannada have to master a set of about 400 akshara. For each akshara, they have to learn the association between the symbol and the constituent sounds, and the rules that govern making of symbol sequences in the system. Because information in much of the 400 plus symbol set is redundant, learning the combinatorial rules for stacking of

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1 The phonemic consonant /C/ is the fifth akshara type; derived from the /Ca/ akshara using markers to suppress the inherent vowel /a/.
phonemes to form CV and CCV akshara allows for a more economical route to mastery. In
addition, the frequency of encounters with the akshara shapes the learning process. In this
section we examine each of these aspects of learning the akshara symbols.

The influential Orthographic Depth framework categorises writing systems according to the
extent to which symbols reliably and consistently represent sounds. The more consistent
systems are called ‘shallow’ or transparent orthographies and the more unpredictable ones,
‘deep’ or opaque orthographies (Bentin & Frost, 1987). Within the orthographic depth
framework, Kannada would feature as a transparent orthography and research with other
consistent, but alphabetic, writing systems would suggest that this consistency aids the
process of learning to read (Seymour, 2005; Ziegler, Bertrand, Toth, et al., 2010).

There are no published studies that have investigated systematically the consistency effect in
Kannada. One study in the Hindi alphasyllabary however confirms that the consistency of
the akshara writing systems aids reading (Rao, Vaid, Srinivasan & Chen, 2011). Hindi-Urdu
words can be closely matched on morphological and semantic parameters because of the
socio-historical processes that have shaped these languages. It is therefore possible to
compile lists of words that differ only in the script used to write the items. In this way it is
possible to contrast the consistency in an akshara script (Hindi) with the more opaque Arabic-
language pair to study the impact of consistency on adult word recognition. They showed
that the orthographic depth of Urdu attracted greater processing costs during visual word
recognition than the more consistent Hindi. In Kannada too, similar advantages of
consistency can be expected during visual word recognition. But given the sheer number of
symbols that must be learned, the advantages of consistency are overshadowed by the extensiveness of the symbol set, at least in the initial phases of akshara learning (Nag, 2007).

Graphotactics can be defined as rules for the use of specific symbols, individually and in combination with other symbols (Coulmas, 1999). These rules define what is legal in a writing system. In linear writing systems such as French and English, graphotactic conventions define what sequences of letters are allowed in spelling. In the visually complex Chinese, spatial conventions define how the characters must be written out. In Kannada, the role of graphotactic conventions in symbol learning flows out of the availability of two symbol representations for all sounds. All consonants and vowels have two symbol representations - a full symbol called the primary form and a diacritic symbol referred to as the secondary form (see Figure 1 for examples). Each pair of primary and secondary forms maps onto the same sound on every occasion, and it is this regularity of mapping that makes Kannada a consistent orthography. Among consonants, the primary form is used to represent the consonant in the /Ca/ and /CV/ syllables and the diacritic form, to represent the second and third consonant in consonant clusters. Among vowels, the diacritic form is used when the vowel follows a consonant. For vowels in word initial positions or representing a separate morpheme, the primary form is used. These rules for choosing the appropriate symbols based on the phonological context of a sound adds a layer to symbol learning in Kannada (and indeed all akshara languages) that is not seen in many writing systems.
Figure 1: A selection of Primary and Secondary forms in two akshara systems

<table>
<thead>
<tr>
<th>Primary Symbol Form</th>
<th>Secondary Symbol Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kannada</td>
<td></td>
</tr>
<tr>
<td>/o/</td>
<td>ಡೆ</td>
</tr>
<tr>
<td>/m/</td>
<td>ಮೆ</td>
</tr>
<tr>
<td>/p/</td>
<td>ಪೆ</td>
</tr>
<tr>
<td>Bengali</td>
<td></td>
</tr>
<tr>
<td>/o/</td>
<td>ওঃ</td>
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<tr>
<td>/n/</td>
<td>নঃ</td>
</tr>
<tr>
<td>/b/</td>
<td>বঃ</td>
</tr>
</tbody>
</table>
A further detail about the akshara system is that some akshara in the middle of words are representations of sound units from two syllables. These medial akshara represent the coda of the preceding syllable and the onset or full syllable of the next. Thus the second akshara /nu/ in the word /ka-nnu/ (eye) comprises the coda in /kan/ and the final syllable /nu/.

Although not much is known about how akshara that straddle two syllables are learnt in Kannada, there is evidence from Bengali that these sorts of akshara-syllable relationships are particularly difficult for children to learn (Sircar & Nag, in press).

Individual differences in learning the details of the symbol set can be seen early in development. In a longitudinal study, differences in akshara knowledge were seen right through primary school (Nag, 2007). When these children were in middle school, we investigated the profile of the poor readers in the group. Children who fell in the bottom 15% of reading attainments had difficulties in multiple domains: phonological processing, speed of processing, vocabulary and knowledge of inflections, and visual processing.

Importantly, poor readers almost always showed very poor knowledge of the akshara (Nag & Snowling, 2011). Their knowledge of consonant clusters and less often encountered akshara was particularly low. One reason for consonant clusters (CCV, CCCV) being difficult could be because these clusters represent a larger set of phonemes and thus require recall of more visual features to construct the akshara. On the other hand, limited encounters with certain /Ca/ and /CV/ akshara in day to day reading and writing tasks probably accounts for the time taken to become fluent. While all children take longer to learn these infrequently encountered akshara, acquisition is particularly slow for poor readers.

**Learning about sounds**

Children’s phonological awareness is influenced by the characteristics of their ambient language. In a comparison of Czech and German, which share several cognates, ambient
language shaped the extent of explicit awareness that children had about word onsets (Caravolas & Landerl, 2010). Czech, unlike German, has a high frequency of consonant clusters in the word initial position, and phonemic awareness for word initial sounds had developed to a greater extent among the Czech children when compared to the German children in the study. These were children who had not yet received any reading instruction, making the finding particularly important because the main debate in research with alphabetic scripts has been the nature of the relationship between growth of phonemic awareness and reading instruction.

In Kannada, as in the few other akshara languages that have been documented, children show high levels of syllable awareness but growth of phonemic skills is relatively slow. In this section we examine the factors that influence the growth of syllable and phoneme level processing based on a study of 95 Grade 4-5 children studying Kannada as their first school language. We first developed a set of 73 nonsense words by taking a list of common, bi-syllabic words and interchanging one syllable between word pairs. We did this iteratively until all the obtained items were meaningless in the language. We chose to study how children would perform at the syllable and phoneme level on tasks that were matched for task demands – a substitution task in which a target had to be replaced with another supplied syllable/phoneme, and a deletion task where the target had to be dropped. We were also interested to see how the position of a phonological unit would influence performance.

Overall children found tasks requiring syllable processing easier than those requiring processing of phonemes. Figure 2 shows the means for performance in two positions (initial, final) for two types of tasks (substitution, deletion). The left panel is the results for syllable manipulations and the right panel for phoneme manipulations. Children’s performance was significantly better when the target sound was in the initial position. Moreover, manipulations requiring initial syllable deletions were easier than initial syllable
substitutions. It is also clear from Figure 2 that the children had significant difficulty in all conditions requiring the manipulation of phonemes (right panel). Seventy four of the 95 children performed above chance level on both tasks in both positions, the rest unable to be accurate even on one trial (floor effect). Among these 74 children, the mean proportion score for phoneme deletion was .21 (SD = .29) on initial and .23 (SD = .25) on final phonemes, and for phoneme substitution, .16 (SD = .21) for initial and .24 (SD = .30) for final phonemes. When compared to syllable manipulations, the trends were reversed for phonemes where the final position was easier than the initial position on the phoneme substitution task.

We also examined the role of syllable complexity on performance. Figure 3 shows the mean success rate on the four conditions of syllable substitution and syllable deletion for simple and complex syllables in the word final position. The performance on the complex syllables was significantly more difficult than on the simple syllables. Similarly, the performance was significantly different on the two types of syllables. We also found a task by complexity interaction. Complexity affected performance in deletion more than in substitution and the effect of task was significant on CCV but not CV structures. The analysis did not include the comparable phoneme tasks since too few children had shown a degree of skill on these tasks.

In summary, in a sample of Kannada readers, performance on syllable processing tasks was better than on phoneme processing tasks, and performance was modulated by the position of the phonological unit and its complexity. This detailed examination gives us insights into the factors that account for the pattern of phonological development among native speakers of Kannada.
Figure 2

Means (and 95% within-subject confidence intervals) for the Proportion of Correct Responses on Substitution and Deletion tasks in the Initial and Final positions for Syllable level (left panel) and Phoneme level (right panel) Manipulations (expressed as z scores).

There was a significant main effect of Position (initial, final), $F(1, 94) = 317.26, p < .001, \eta^2 = .5$ but not Task (substitution, deletion), and there was an interaction between Task and Position, $F(1, 94) = 21.77, 20.63, p < .001, \eta^2 = .04$. 
Figure 3

Means (and 95% within-subject confidence intervals) for the Proportion of Correct Responses on Syllable Manipulation in the Final Position according to Complexity of the Manipulated Unit.

There was a significant main effect of Complexity (simple syllable, complex syllable), $F(1, 94) = 304.46, p < .001, \eta^2 = .6$ but not Task (substitution in final position, deletion in final position) and a significant Complexity X Task interaction, $F(1, 94) = 25.08, p < .001, \eta^2 = .03$. 
Learning about cross-modal mappings

We next turn to the connections or mappings that emerge between the symbols of the writing system and the sounds of the language. The associative learning of symbols-to-sounds and sounds-to-symbols occurs across sensory modalities and is therefore a cross-modal process. Efficient mapping requires a fine-grained representation of the phonological details as well as the symbol system of the language. In the visually complex symbols of the Chinese writing system, linear and non-linear arrangements of individual strokes combine to make functional symbol units called radicals. These units may be further organised into characters that, in part, indicate the sound(s) they represent. Since individual strokes and radicals may not always carry phonetic information, this introduces a level of surface ambiguity to sound representation, particularly if the Latin-centric logic, of a linear mapping of sound strings onto symbol strings, is applied. Despite the seemingly arbitrary nature of sound-symbol associations, and debates about the architecture of the orthography-phonology connections in the language (Perfetti, Liu & Tan, 2005; Yang et al, 2009), there is evidence that fine-grained cross-modal mappings are an important learning requirement for Chinese literacy (Tong & McBride-Chang, 2010; Tong et al, 2011).

An indication of the possible cross-modal associations occurring in the Kannada alphasyllabary was first reported by Nag (2007). In a three year longitudinal survey that began when children were first in Grades 1-3, the associations between type of akshara knowledge and level of phonological awareness was seen across grades. In Grade 1, knowledge about the akshara was limited to the /Ca/ symbols (i.e. akshara without phoneme markers), performance on phoneme tasks was at floor and among the areas assessed, association of symbol-sound knowledge was circumscribed to the syllable. In Grade 4, knowledge of the akshara with phoneme markers (CV, CCV) had developed, performance on
phoneme tasks, while still low, had emerged for many children, and association of
phonological awareness and symbol-sound knowledge was strongest at the level of the
phoneme. Further, children’s knowledge of the akshara with phonemic markers was a
predictor of phoneme processing skills fifteen months later. It would appear that those
children who have better knowledge of cross-modal mappings between sound and symbol are
more advanced in reading, and reciprocally, better reading helps to further improve cross-
modal mappings.

We tested this proposal in a cross-sectional analysis of the same 95 middle school children
reported in the earlier section. We divided the children into three levels of reading fluency
based on their speed and accuracy. Figure 4 summarises the level of akshara knowledge,
syllable and phoneme processing of the three reading fluency groups. Better readers had
better akshara knowledge and better syllable and phoneme processing. But more importantly,
there were differences in the inter-correlations between the measures. Among Level 1
readers, the association between akshara knowledge and syllable processing was significant
\((r = .51)\) but this was not the case among children in the more advanced reading fluency
groups (Level 2, \(r = .35\); Level 3, \(r = .27\)). At the level of the phoneme, a step wise pattern
was seen; Level 3 readers showed the strongest associations between akshara knowledge and
phoneme processing \((r = .68)\); followed by Level 2 \((r = .48)\) and Level 1 \((r = .33)\).
Figure 4

*Percentage of Correct Responses among Children in 3 Reading Levels on Measures of Akshara Knowledge, Syllable Processing and Phoneme Processing.*

![Bar Chart](image)

*Note.* Error bars are at 95% Confidence Interval.

Together, these findings suggest there is a reciprocal relationship between learning about symbols and cross-modal mappings, phonological processing, and reading development. We suggest that the better knowledge of the akshara seen among fluent readers was accompanied by an awareness of the intra-symbol visual features that constitute the phonemes in the akshara. We propose that increasing knowledge about mappings of specific markers-to-phonemic units provides a boost to phonemic processing. This then is an important script-specific phenomenon, tied down entirely to the type of sub-lexical representations embodied in the akshara writing system. The akshara has an alphasyllabic system of symbolic representation both at the level of syllables as well as phonemes. Children who infer this alphasyllabic principle are better readers.

The concurrent predictors of individual differences in this sample of readers, further confirm the role of symbol and sound learning (akshara knowledge, phonological processing) and
cross-modal mappings (which, we argue is captured by the Rapid Automatized Naming (RAN) task) in Kannada reading (Nag & Snowling, in press). As might be predicted from our foregoing discussion, Kannada reading accuracy was strongly predicted by akshara knowledge, syllable awareness and phoneme awareness. However, Kannada reading fluency was predicted by akshara knowledge, phoneme awareness and RAN. Thus, similar to other writing systems, symbol knowledge was an important predictor for reading (Muter, Hulme, Snowling & Stevenson, 2004; Pualakanaho, Ahonen, Aro et al, 2008 ; Lin, McBridge-Chang, Shu, Zang, Li et al, 2010). But akshara-specific factors also emerged as important. Recall that akshara knowledge is quite different from letter knowledge and character knowledge because of the way in which phonemic markers within a syllable are either parsed or stacked in non-linear arrangements. At the level of sounds, we found that syllable and phoneme awareness were independent predictors of alphasyllabic reading. Whereas most studies with other writing systems have found one particular unit as being the best predictor of reading accuracy, this study with the alphasyllabic writing system suggests a dual representation at the level of the syllable and the phoneme. Thus, for logographic Chinese, syllables are important (Tong et al, 2011) and for alphabetic languages, phonemes (Zeigler et al, 2010); against this backdrop, our finding of a dual syllable-phoneme pattern of predictors makes this another script-specific finding.

There is one other aspect of script-specific processing that needs highlighting. Even though English and Kannada can be characterised as representing phonological details at both small and large grain sizes, there is a fundamental difference in the consistency of the sound-symbol mappings in the two writing systems. In English, the multiple types of sound-symbol mappings cause ambiguity (thus the mappings in [ai] - igh, I, eye, ai). In contrast, mappings in Kannada are regular and consistent; the small grain size representations of
phonemic markers are not confusable with the large grain size representation of an orthographic syllable.

**The Psycholinguistic Gran Size framework revisited**

We next consider the implications of our findings from an alphasyllabic writing system for Psycholinguistic Grain Size theory (Ziegler & Goswami, 2005). We will review three main predictions emerging from the theory: first, that the ease of learning to read is determined by the availability of the phonological units in the spoken language; second, that the consistency of the mappings between phonological and orthographic units should ease learning to read; third, that the granularity of the mappings when fixed to one grain size should better support learning to read.

As we have seen, the Kannada alphasyllabary is an example of a writing system that is high in availability (of the sounds) and consistency (of the mappings). The akshara represents syllables, a phonological unit prominently available in ambient speech. Learning these large size representations enables reading to begin, leaving the task of learning the more ambiguous (less available) phoneme level units for later. Our findings confirmed that children were better at syllable than phoneme awareness, and in line with this, better readers had better developed awareness of phonemes. Next, the Framework’s definition of consistency has to be refined from one-to-one correspondences, a construct that has grown out of alphabetic systems, to a description that includes mappings of one phoneme-to-two symbols. Within this broadened definition of consistency, the number of symbols increases, and the straightforward prediction that consistency implies ease of reading acquisition needs modification. Though Kannada is a consistent akshara language, both reading and spelling of words with low frequency symbols remains hard well into middle school (Nag, 2007; Nag, Treiman & Snowling, 2010).
However, it is in the third construct of granularity, the size of symbol units that can reliably map phonology in a language, that the framework is most clearly limited by conceptions that are based on linearised alphabetic writing systems. In alphabetic scripts, grain size refers to single letters (small grain size) or letter strings (chunks of large grain size). In this formulation, a writing system supports efficient reading more easily when the mappings are representations of a single grain size than when mappings are to both small as well as large grain size units. Kannada with its consistent but dual representation at large and small unit sizes (syllable and phoneme) challenges this conception of granularity. Our findings suggest that akshara knowledge among the skilled readers of Kannada is characterised by knowledge of both the small and large unit sizes embedded in each symbol. Thus our findings run contrary to the predictions made by the \textit{Psycholinguistic Grain Size Theory} because this mixed representation did not appear to have an adverse effect on the rate of reading acquisition. Rather than multiple grain sizes increasing processing costs, better akshara knowledge predicted greater reading fluency. Put differently, alphasyllabic strategies that draw upon mappings to phonemes and syllables (small and large grain-sized units), reduce rather than increase processing demands.

**Script independent aspects about learning to read**

A remaining question is whether there are some aspects of reading development that are universal. A quick task analysis of the skills involved in learning about symbols, sounds and the mappings between the two offers insights into script-independent processes. There is strong evidence that children focus on visual features when learning to read. They are sensitive to feature position and their internal details (e.g. Nag, Trieman & Snowling, 2010; Tong et al, 2011); and the distributed information associated with neighbouring visual
features (Yang et al, 2009). This is irrespective of whether the features are embedded within Chinese characters, Kannada akshara or Latin letters. Moreover, there appears to be a developmental progression in symbol processing for visually complex scripts, beginning with the processing of symbols as wholes and proceeding to attention to their internal details. In Chinese, for example, this would entail knowledge at the sub-character level about semantic and phonetic information-bearing radicals (Tong & McBride-Chang, 2010); in the akshara languages, knowledge that phonemic markers reveal sound sequences (Nag, 2011). The level of task complexity involved is however much reduced in Latin based scripts because of the simplicity of the visual arrangements in the writing system (Seidenberg, in press). It seems therefore that such analytic processing of the underlying design of a script may be a universal process at the foundation of reading development.

Moving to knowledge about sounds for learning to read, Perfetti and Tan (1998) proposed the universal phonological hypothesis whereby, irrespective of the writing system, recognition of written words entails activation of the phonological domain. Strong evidence for this cognitive universal comes from the European orthographies (Zeigler et al, 2010), Chinese (Tong et al, 2010; Lin et al, 2010) and our own study with the Kannada alphasyllabary (Nag & Snowling, in press). The strength of association of phonological awareness across the different component skills of reading differs and is moderated by the nature of the script. Among alphabetic scripts, phoneme awareness is a significant predictor for fluency in transparent orthographies but also of accuracy in opaque orthographies (Ziegler et al., 2010). Similarly, while the unit of significance may be different in different scripts – syllable for Chinese, phoneme for English, syllable-phoneme for Kannada – the processing skills for phonological units are unequivocally involved in learning to read.

Another general aspect of learning to read has to do with making efficient linkages between the sounds and symbols in a language. A pre-requisite for establishing efficient mappings
between sounds and symbols is fine-tuned knowledge about these two layers of representation; and we propose that precision mappings are important for skilled reading in all languages. Indirect evidence of the role of precision mappings comes from the robust finding that rapid naming is a predictor for reading across languages (Nag & Snowling, in press; Zeigler et al, 2010; Puolakanaho, Ahonen, Aro, et al, 2008; Ding, Richman, Yang & Guo, 2010). Rapid naming undeniably captures multiple parallel processes including speed of processing, visual processing and phonological processing. But the consistent finding that performance on the task predicts individual differences in reading skill across writing systems suggests that the associations are with the component in RAN associated with cross-modal mappings - a language-general phenomenon. Moreover, there is growing evidence that individuals who have difficulties in rapid naming are at high risk of reading failure (Puolakanaho et al, 2008).

Conclusions

In this chapter we examined many of the processes that are critical in order to ‘crack the code’ of a writing system. We have argued that there are both language-specific and language-universal cognitive demands of learning to read, and that different scripts pose differing challenges to the learner. Two key issues which remain under-studied are, how do children acquire knowledge of the symbols of the language and what places constraints on this process? More generally, models of reading and its development need to take account of the diversity across writing systems if they are to inform not only theory but also practice in the field of reading and its disorders.
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References


Grade Reading Outcomes: Strong to Accuracy but Only Minor to Fluency. *Journal of Learning Disability*, 41-353


