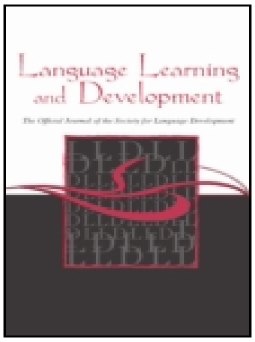

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Universal Reading Processes Are Modulated by Language and Writing System

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The connections among language, writing system, and reading are part of what confronts a child in learning to read. We examine these connections in addressing how reading processes adapt to the variety of written language and how writing adapts to language. The first adaptation (reading to writing), as evidenced in behavioral and neuroscience data, is achieved through a universal constraint that language places on writing and through the tuning of reading procedures imposed by specific features of writing systems. Children acquire skill in reading through increasing specialization of procedures tuned to their writing system, while also acquiring more general (universal) procedures that serve language mapping and cognitive control. For the second adaption (writing to language), we present examples from several languages to suggest that writing systems tend to fit their linguistic properties, thus providing adaptive variation in writing-to-language mapping. We suggest that this writing-language fit facilitates the child's learning how his or her writing system works.

The assumption that reading is based on language appears to be universally shared. Reading may also depend on the writing system that encodes the language. The exact sense in which these two dependencies are true may not be so clear, or at least not so universally ascribed to. On one perspective, reading is "parasitic" on language and only the relatively trivial achievement of learning to decode print into spoken language stands between the linguistically sophisticated 5-year-old and the achievement of fluent reading. Alternatively, written language may have specific influences (beyond decoding) on cognitive processes that make it something more than language "writ down." How the language is written may matter for reading processes—or it may matter only in details about how universal processes are implemented.

These issues are not new. The complex relations between spoken and written language have been examined at multiple levels (e.g., Mattingly, 1972; Olson, 1977). Analyses of the influence of writing systems on reading processes have emphasized universal principles and specific variations (e.g., Perfetti, 2003; Ziegler & Goswami, 2005). Finally, the idea that a language and its writing system are intertwined in some way (Halliday, 1977; Mattingly, 1972) has been renewed in claims that this intertwining influences reading processes (Seidenberg, 2011; Frost, 2012). In what follows, we examine this complex of issues among language, writing, and reading with the hope of not adding too much additional confusion.

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THE LANGUAGE-READING DIVIDE

There is a great divide between language and reading in how they are acquired. As Alvin Liberman (1991) once put it, "in a state of nature, everybody speaks, nobody reads" (p. 241). Thus, when we study language development we are impressed by the biological head start of infants. They come with a brain that, depending on one's point of view, either has a universal grammar that needs only some modest amount of language-specific input or has impressive statistical learning procedures that, either separately or in combination, lead to very rapid development of language. And so in language development, we ask how development happens so fast.

We talk about reading differently, referring to it (correctly) not as the development or even the "acquisition" of reading, but as learning to read. Learning to read does not seem to be natural and biologically determined in the way that language development does. Furthermore, in contrast to the normal course of spoken language development (which, of course, is impaired for some children) reading is sometimes *hard* to learn. The thriving field of dyslexia research is aimed at trying to understand why learning to read fails for some children.

This contrast between rapid, painless development and more effortful and failure-prone learning is mirrored in the time lag of a hundred millennia of human history between language capacity and the development of writing. The history of human writing has seemed relevant to understanding the differential cognitive demands of language and reading. Whereas meaning-based graphs (pictographs) were common as initial attempts to communicate visually, the graphs became more abstract, less picture-like, in both Middle Eastern writing, for example, the development of Sumerian Cuneiforms, and in Chinese writing (DeFrancis, 1989). Most important, the graphs over time—perhaps suddenly (De Francis, 1989, p. 74)—started to be used to represent not meaning, but language in its spoken form.

The cognitive advantage of coding language form rather than meaning is productivity, a universal feature of human languages (Hockett, 1960) that allows creation of an infinity of messages (sentences) from finite means (syllables, phonemes). Applied to written language, productivity carries a cognitive advantage, relieving cognitive resources that would otherwise have to store and remember an indefinitely large number of graph-meaning associations. Instead, one needs to learn and remember a small number of graph-form (syllable or phoneme) associations. By moving to productive form mapping, writing inherited the productivity of language, able to produce all the messages that a language allowed.

HOW DOES READING ADAPT TO THE VARIETY OF WRITTEN LANGUAGE?

In principle, one writing system could serve the vast variety of the world's spoken languages. Indeed, the international phonetic alphabet (IPA) or other forms of phonetic transcription do exactly that. A universal set of graphs allows the sounds of all languages to be written down, at least in principle. Actual written languages, unlike IPA, were not invented for the purpose of universal transcription, but rather followed the more complex routes of cultural artifacts. The result is wide-ranging variety in the appearance of the graphs (see Figure 1) across languages as well in how the graphs map onto units of language. Of course, appearances are not everything, and this variety is commonly considered to reflect only three basic writing types according to their basic unit of mapping: morpho-syllabic or logographic; syllabic, and alphabetic. It is further

Language	Writing System	Script Example
English	Alphabetic	All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood.
Dutch	Alphabetic	Alle mensen worden vrij en gelijk in waardigheid en rechten geboren. Zij zijn begiftigd met verstand en geweten, en behoren zich jegens elkander in een geest van broederschap te gedragen.
Spanish	Alphabetic	Todos los seres humanos nacen libres e iguales en dignidad y derechos y, dotados como están de razón y conciencia, deben comportarse fraternalmente los unos con los otros.
Korean	Alphabetic (Hangul)	모든 인간은 태어날 때부 터 자유로우며 그 존엄과 권리에 있어 동등하다. 인간은 천부 적 으로 이성과 양심을 부여받았으며 서로 형제애의 정신으로 행동하여야한다.
Arabic	Alphabetic (Consonantal)	يولد جميع الناس أحراراً متساوين في الكرامة والحقوق. وقد وهبوا عقلاً وضميراً وعليهم ان يعامل بعضهم بعضا بروح الإخاء.
Hebrew	Alphabetic (Consonantal)	כׇּל בְּנֵי הָאָדָם נוֹלְדוּ בְּנֵי חוֹרִין וְשָׁוִים בְּעֶרְכָּם וּבִזְכֻיּוֹתֵיהֶם. כֻּלָּם חוֹנְנוּ בַּתְּבוּנָה וּבְמַצְפּוּן, לְפִיכָךְ חוֹבָה עֲלֵיהֶם לִנְהֹג אִישׁ בְּרֵעֵהוּ בְּרוּחַ שֶׁל אַחֲוָה.
Lao	Alphabetic (Tonal)	ມະນຸດທຸກຄົນເກີດມາມີກຽດສັກສີ, ສິດທິ, ເສລີພາບແລະຄວາມສະເໝີພາບເທົ່າທຽມກັນ. ທຸກໆຄົນມີເຫດຜົນແລະຄວາມຄິດຄວາມເຫັນສ່ວນຕົວຂອງໃຜຂອງມັນ, ແຕ່ວ່າມະນຸດທຸກໆຄົນຄວນປະພຶດຕໍ່ກັນຄືກັບເປັນອ້າຍນ້ອງກັນ.
Khmer	Alphabetic (Syllabic)	មនុស្សទាំងអស់កើតមកមានសេរីភាពនិងភាពស្មើៗគ្នាក្នុងសិទ្ធិនិងសេចក្ដីថ្លៃថ្នូរ។ មនុស្សគ្រប់រូបសុទ្ធតែមានវិចារណញ្ញាណនិងសតិសម្បជញ្ញៈ ហើយត្រូវប្រព្រឹត្តចំពោះគ្នាទៅវិញទៅមកក្នុងស្មារតីរាប់អានគ្នាជាបងប្អូន។
Kannada	Alphabetic (Syllabic)	ಎಲ್ಲಾ ಮಾನವರೂ ಸ್ವತಂತ್ರರಾಗಿಯೇ ಜನಿಸಿದ್ದಾರೆ. ಹಾಗೂ ಘನತೆ ಮತ್ತು ಹಕ್ಕುಗಳಲ್ಲಿ ಸಮಾನರಾಗಿದ್ದಾರೆ. ವಿವೇಕ ಮತ್ತು ಅಂತಃಕರಣ ಗಳನ್ನು ಪಡೆದವರಾದ್ದರಿಂದ ಅವರು ಪರಸ್ಪರ ಸಹೋದರ ಭಾವದಿಂದ ವರ್ತಿಸಬೇಕು.
Chinese	Morphosyllabic (Logographic)	人人生而自由，在尊嚴和權利上一律平等。他們賦有理性和良心，並應以兄弟關係的精神互相對待。

FIGURE 1 Variation in the appearance of writing.

argued by writing scholars that, in the order given above, these three types reflect the evolution of writing systems (e.g., Gelb, 1952).

The three basic writing systems can be exemplified by three Asian languages: the logography of Chinese (文本), in which each grapheme (i.e., character) corresponds to a syllabic morpheme (often a word) in the spoken language; the syllabary of Japanese (かな), in which each grapheme corresponds to a syllable in the spoken language; and the alphabet of Korean (. .), in which each grapheme corresponds to a Korean phoneme. Note that, although the graphemes of Chinese and Japanese both represent spoken syllables, Japanese graphemes map to the phonetic building blocks of words, whereas the morpheme or word to which a Chinese character maps happens to be a single syllable—there is no completely reliable cue to "sounding out" a character/word. Note also that, despite its visual resemblance to the other two Asian scripts, the Korean writing system is alphabetic, like the more familiar Roman alphabet. In short, it is not how the graph looks, or the size of the chunk of spoken language to which it corresponds, but how it maps structurally to the spoken language that matters.

These Asian examples also draw attention to "Anglocentrism" (Share, 2008) in reading research. Share argues that models of word reading were developed by exclusive attention to English and that at least some theoretical explanations (of word reading and dyslexia) would be different had there been attention to the variety of languages and orthographies from the beginning. Although this may be true, research on languages other than English has flourished in the last 10 years, bringing a broader perspective and many new results. Indeed, the possibility of viewing universals in reading has been enabled by this broadening of language and writing samples.

Universals in Reading

The major adaption of reading to variation in writing is through universal reading procedures. Put more carefully, the claim is that writing itself developed its variations within constraints that honored the procedures by which human brains could get linguistic meaning from print. The key is the language constraint, that all true general-purpose writing systems encode language, not concepts. From this constraint it follows that reading must engage the language of the reader, a fact that builds into reading a highly general adaptation. Whatever the appearance of the writing, reading processes engage the linguistic system.

Beyond the logic of the language constraint, the search for universals becomes an empirical question. For example, does Chinese writing, a system that does not represent phonemes, nonetheless evoke phonology during reading? Chinese does not strictly require activating phonology, and it does not even encourage it as a matter of writing system design—even at the syllable level. Figure 2 shows why this is true. Because of a high level of homophony, many different written characters map onto given syllable, even when tones are taken into account. In such a system, a process that links characters only with their meaning seems to be encouraged. Thus Chinese does not represent phonology at the phoneme level, and its representation of phonology at the syllable level seems to discourage its use.

The formal separation of orthography from phonology, which ranges from difficult (English) to nearly impossible (shallow orthographies such as Finnish or Korean) in alphabetic writing, is built into Chinese, as Figure 2 illustrates. Accordingly it has been possible for experiments to vary orthography and phonology independently to study whether phonology is activated during Chinese reading. These experiments, by and large, found that when characters are read for meaning, their phonology is activated. In making a decision about whether two characters are related in meaning, decisions are slowed when the characters with different meanings have the same pronunciation (Perfetti & Zhang, 1995). Decisions about whether a single character belongs to a semantic category are also slowed when a non-category character with the same pronunciation as a category member is presented (Xu, Pollatsek, & Potter, 1999). Such results led to an empirical generalization, that is, the Universal Phonological Principle (Perfetti, Zhang, & Berent, 1992), that phonology is part of reading across all writing systems. As with alphabetic experiments, there are task-specific conditions that seem to influence the emergence of evidence for phonology relative to semantics, but the generalization that phonology is part of written word identification seems to hold in Chinese, just as it does in alphabetic languages. (See Perfetti, Liu, &Tan, 2005, for a review and a theoretical treatment of Chinese reading.).

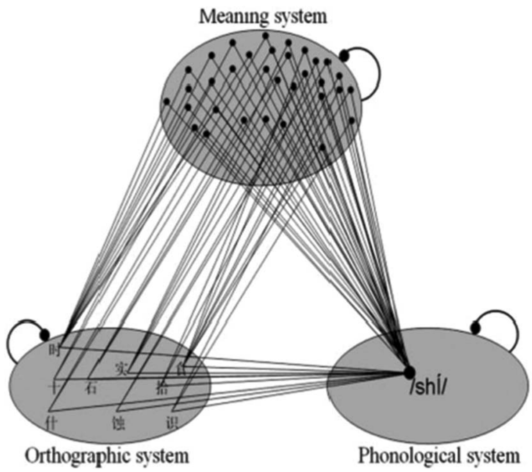

FIGURE 2 Homophony in Chinese. A single syllable (Phonological system) is associated with many different meaning–bearing morphemes (Meaning system). Many different characters (Orthographic system) share a given syllable, thus making phonological mediation of meaning difficult. However, a given character identifies the meaning-bearing morpheme.

Thus, one way that reading adapts to variety in writing is through a universal attachment to *language*. The phonological system of a language provides multiple units for this attachment, syllables as well as phonemes, and which unit is selected does matter for reading (Perfetti, 2003). The larger syllable units are attached to orthographic units in Chinese (and Japanese), whereas the smaller phoneme units are attached in alphabetic writing. Ziegler and Goswami (2005) generalize the importance of such variability in the size of the language units in a "grain size theory" of how reading differs across languages.

This emphasis on phonology reflects its importance as the surface form of language. Because it sits at the surface of language, phonology allows a potentially simple mapping onto surface features of the writing system. Nevertheless, phonology is not the whole story, and writing systems and orthographies may negotiate trade-offs between phonology and morphology (a language's form-to-meaning mappings, which include grammatical and lexical formation components) to make reading efficient as well as effective. For example in English, the *b* in the word *debt* is not pronounced, an example of English's failure to map graphemes consistently to phonemes. However, the presence of the *b* reflects a meaning connection to *debit*, where the *b* is pronounced. In developing parallel distributed processing models of learning to read, Harm and Seidenberg (2004) refer to the division of labor between phonology and morphology/semantics. Writing can code mainly morphology, mainly phonology, and strike balance points in between.

Reading Procedures are Tuned by Writing Systems and Orthographies

In addition to language-based universals in reading, there appear to be some writing-specific procedures that are tuned to the features of the writing system. The well-known variation among alphabetic orthographies illustrates the potential need for tuning to a rather narrow range of differences. The continuum runs from shallow orthographies, illustrated by almost pure alphabets in Finnish and Welsh, where each letter corresponds to one phoneme (and vice versa) to the impure English, where letters show a one-to-many mapping to phonemes. The consequences of these variations have been shown in studies of reading, for example, by Aro and Wimmer (2003), who compared English reading (by children in the United Kingdom) with reading more shallow European orthographies (Finnish, Swedish, Spanish, Dutch, German, and French). They found a dramatic difference in the ability to read pseudowords, which requires the use of grapheme-phoneme connections (as opposed to whole word strategies that can be applied to real words), with English first graders way below first graders of all other comparison countries. By fourth grade, English language children were comparable to first graders who read the more shallow orthographies. These kinds of differences have been seen in other comparative studies (e.g., Landerl & Wimmer, 2008) that have ruled out alternative explanations for the differences.

The conclusion is that reading procedures, in particular the relative use of grapheme-phoneme mappings in decoding printed words, have been tuned to features of the orthography, an idea expressed by Katz and Frost (1992) as the orthographic depth hypothesis. In addition to behavioral studies, brain imaging studies have shown differences between activation patterns for Italian (a shallow orthography) reading compared with English reading (Paulesu et al., 2000), differences that were consistent with more grapheme-phoneme based reading in Italian and more word retrieval reading in English.

With such adaptations within the relatively narrow range of alphabetic orthographies, we also expect adaptations across the wider gulf that separates alphabetic and nonalphabetic writing. Indeed, reading Chinese (again the high-contrast case) shows differences from reading alphabetic English. One characterization of the basic difference—keeping in mind that phonology is activated in Chinese as well as English—is that in Chinese characters are recognized "threshold" style while in alphabetic reading words are recognized "cascade" style (Perfetti et al., 2005). The threshold-cascade distinction, which was introduced by Coltheart, Curtis, Atkins, and Haller (1993), centers on the timing of phonological activation relative to orthographic. In alphabetic cascaded processing, phonemes are activated with grapheme activation based on links between them, and this can happen prior to the moment of word identification. In Chinese, this cascading is not possible, and phonology instead is activated only when an orthographic recognition threshold is reached. Thus, in Chinese, as characters are recognized, there is immediate activation of the corresponding syllable. This threshold-style processing also allows the activation of meaning directly by the character and reduces the likelihood that activation of phonology during reading mediates meaning in Chinese, except for characters with very few homophones (Tan & Perfetti, 1999).

As in research on reading in alphabetic systems, these properties of Chinese reading are mirrored in brain imaging research. Meta-analyses of word reading studies (Bolger, Perfetti, & Schneider, 2005; Tan, Laird, Li, & Fox, 2005) show both shared and nonshared activation patterns across writing systems, a finding consistent with the existence of both universal (i.e., the general need to map graphic forms to linguistic units) and writing system-specific (i.e., the detailed implementation of phonological and semantic processes) reading procedures. Word reading in all writing systems, for instance, activates the left-hemisphere occipital-temporal area around the fusiform gyrus. This visual "word-form area" shows enhanced responsivity to written language with the development of expertise with a specific orthography (McCandliss, Cohen,

& Dehaene, 2003). Recent evidence suggests also a universal premotor area that is involved in reading handwritten input in both Chinese and alphabetic writing (Nakamura et al., 2012). Nonuniversal activation patterns include the bilateral activation of posterior visual-orthographic areas in Chinese compared with left-lateralized areas in alphabetic reading. In addition, less activation of temporal-parietal (phonological) areas occurs in Chinese, while more activation occurs in the left mid-frontal gyrus compared with English (Tan et al., 2005). The visual-orthographic activation difference may reflect the specific demands of the layout of the Chinese script, while other differences in temporal, parietal, and frontal areas suggest differences in how phonology and meaning are associated with the orthography during recognition.

The System Accommodation Hypothesis (Perfetti & Liu, 2006), based on such neuroimaging results and ERP studies that show detailed temporal processing differences between Chinese and English, captures the generalization that reading processes and the neural structures that support them accommodate to specific visual and structural features of writing systems. Adding complexity to the picture is evidence that whereas Chinese reading, compared with alphabetic reading, engages distinctive areas in normal readers, Chinese dyslexics show activation patterns that are highly overlapping with what is shown by alphabetic dyslexics (Hu et al., 2010).

Children's Development of Universal and Specialized Procedures

Despite the difficulty many children have in learning to read, the typical course is one of learning print-language mappings through generalized decoding procedures (for alphabetic and syllabary writing) and word-specific learning (all writing systems). If the general nature of reading is a combination of universal language-general procedures and language-specific procedures, a question becomes the acquisition and refinement of these procedures with learning to read. A starting point is the assumption that increased reading skill must bring increased specialization, such that a Chinese-speaking child becomes very good at reading Chinese and an English-speaking child becomes very good at reading English, with no corresponding increase in the ability to read some other language. (This is not to say that reading in a second language does not benefit from being a skilled reader in a first language. It does [Wade-Woolley & Geva, 2000; Wang, Perfetti, & Liu, 2005; Geva & Siegel, 2000; Durgunoğlu et al., 1993].)

Based on developmental studies of reading in Chinese (Cao et al., 2009, 2010) and in English (Booth et al., 2002), Perfetti, Cao, and Booth (2013) hypothesized distinctive developmental courses of increased specialization. In English, the superior temporal gyrus (STG), which is associated with phonological (phoneme-level) processing in alphabetic reading (Simos et al., 2000), shows increased activation with experimenter-designed phonological training (Shaywitz et al., 2004). However, this area shows decreased activation with age for Chinese readers (Cao et al., 2010). Thus, if phonological assembly is part of reading English but not Chinese and if the STG supports this process, then, at least early in reading development, adaptation to the specific demands of English increases the demands on this area, while adaptation to the specific demands of Chinese decreases them.

Complementing this trend, increased experience in Chinese reading leads to more involvement of right hemisphere visual-orthographic areas, including the right fusiform gyrus (Cao et al., 2010). This area supports the visual-spatial processes of word identification, which are needed more for Chinese characters than for linear alphabetic words. Experience-related increases for

Chinese were also observed in the right superior parietal lobule. These changes with experience suggest increased specialization to accommodate both the visual demands of Chinese characters (seen in increased activation of bilateral visual-orthographic areas) and their syllabic phonological mapping demands (seen in right superior parietal lobule activation). With experience, orthographic representations become higher in quality, both as familiar and precisely detailed graphic forms and as tightly linked linguistically mapped units. Specialization serves this purpose.

However, there are universal developments as well, beginning with the importance of the left occipital-temporal area that comes to support orthographic word identification and link it to language areas. Despite the differences between the two writing systems in the level of mapping between orthography and language, they share the basic need to map graphic units to spoken language units. It is possible that a universal function is also served by the left inferior parietal lobule (IPL), which shows age-related increases in both writing systems (Cao et al., 2009, 2010; Booth et al., 2002, 2004) and may be associated with a more writing-independent mapping function that is word-specific. Finally, the left-middle frontal gyrus (LMFG) has been consistently found to be involved in Chinese reading, with various interpretations offered for its function in reading (e.g., Perfetti et al., 2012; Tan et al., 2005). Because of the LMFG's involvement in English reading under some conditions, it may serve an increasing control function in both writing systems (Perfetti et al., 2012).

Thus with increased reading experience, one sees both universal paths of skill development and more specialized paths that accommodate the demands of the writing system. The universal paths may reflect the strengthening of the connections from posterior areas that handle graphic input with the left hemisphere language areas and the increased use of control areas to shift attention and processing resources to specific processing demands of phonology, orthography, and meaning, which can vary with task demands and with the difficulty or complexity of the written input. Both of these developments serve reading skill, no matter the writing system.

So far, we have examined how reading accommodates to writing system variation. However, the overall story of adaption involves not just the writing system, but also the language. We turn to this question in the next section.

HOW DOES WRITING (AND THUS READING) ADAPT TO LANGUAGE?

It is possible, by the logic of experimental control, that variations in reading that we have attributed to different writing systems are actually due to differences (wholly or in part) between languages. Chinese writing encodes the Chinese language, English writing encodes English, and so forth. Although Japanese offers intriguing complexities, allowing a single language to be expressed by multiple writing systems, the general situation is that writing systems and orthographies are not arbitrarily assigned to languages, leaving, from an analytic perspective, a confound of variables. One way through this confound is to consider how writing encodes language and whether it does so adaptively to the character of the language.

Alphabetic writing in its purest form could approximate a notation system for speech. Letters denote phonemes and writing is written speech. This characterization, in practice, would apply only narrowly to very shallow orthographies (pure alphabetic writing). A broader characterization is that writing is encoded language, not just encoded strings of phonemes. On this view, the adaptations that writing makes to language are based on the linguistic system, not just its phonemic inventory.

The idea that writing adapts to linguistic systems is captured in the expression "Languages get the writing system they deserve." This idea has had a number of expressions, most recently by Frost (2012) and Seidenberg (2011). Much earlier, M.A.K. Halliday pointed out that the development of writing occurred over long periods of time, allowing a language to get "the sort of writing system it deserves" (Halliday & Webster, 2003, p. 103, reprinted from Halliday, 1977). Behind this memorable expression lie the ideas of trade-off and optimization. Seidenberg (2011) argued that what is traded off is the weight given to the language's phonology compared with its meaning/morphology. The point of "grapholinguistic equilibrium" is the final resolution of the conflicting goals of having writing encode phonology as well as morphology. At the equilibrium point, "spoken languages get the writing systems they deserve" (Seidenberg, 2011, p. 169).

To demonstrate the feasibility of the hypothesis that writing adapts to language requires some particulars about the linguistic resources of a language. We have sampled a range of languages to reflect a wide range of variety and hypothesized what features of writing would accommodate the language features. Table 1 summarizes this effort.

The table provides estimates of the linguistic inventories of seven languages that represent the three major writing systems, including two shallow alphabetic orthographies (Korean and Finnish), one deep alphabetic orthography (English), two vowelless alphabetic orthographies (Hebrew and Arabic) plus Chinese and Japanese. The inventories are based on various sources, but especially, because counts of vowels, consonants, and syllables vary widely, the encyclopedic work of Comrie (2009). The analysis specifically targets the phonological structure and the morphological structure of each language.

If there is a trade-off between phonology and morphology in the writing systems, this should be visible in the pressures that the phonological and morphological structures put on writing, which are suggested in the "implications" column of Table 1. English has a large phoneme inventory and a very large syllable inventory with little constraint on the formation of syllables. The large phoneme inventory of English might work against pure alphabet coding of about 40 phonemes, but there does not seem to be some natural stop-point for a grapheme set. English gets by with 26 letters, but Slovak expands the same Latin alphabet used by English to 45 letters. Russian gets 33 letters from the Cyrillic alphabet, but Karbadian expands that to 60 and Modern Hindi (Devanāgarī alphabet) has 58 letters. These are all highly transparent, shallow orthographies—there would be little point to a large set of graphemes if they were not—expanded by the use of diacritic marks attached to letters. So one might suppose that when a one-to-one mapping of graphemes-to-phonemes would require some large enough number of graphs (e.g., over 60), alphabetic writing becomes burdensome. However, there are examples of orthographies for languages with large phoneme inventories that expand graphic resources to maintain a close mapping, as in Khmer (Cambodian), whose phonology is captured by an alphabet with syllabary components. So the implication for the phonology inventory is that a very large inventory might discourage alphabetic mapping, but this, by itself, cannot be decisive. The point of a trade-off is that there is some other factor that also creates pressure, and the result is a negotiation between these factors.

In the case of English, the combination of phonemes into syllables with relatively few constraints (e.g., phonotactic limits on strings of consonants) allows for many syllables (12,000 in

TABLE 1
How Writing Systems May Accommodate Languages

	Phonological structure of spoken language			*Morphological structure of spoken language*		*Implications for writing system*	
Language *(language family)*	*No. vowels; no. consonants*	*Approximate no. syllables used in language*	*Maximal syllable structure*	*Representative morpho-phonological processes*	*Complexity of inflectional morphology*	*How phonology and morphology constrain writing system*	*Mapping principle of writing system*
English (Indo-European)	14–16; 24 ≈ 40 total phonemes	12,000	CCCVCCCC (e.g., *strengths*)	*heal* → *health; nation* → *national*	Low	Phonological complexity leads to a large number of syllables, making an alphabet efficient. Simple inflectional morphology and large number of morphophonemes, combined with a mismatched letter-to-phoneme ratio, lead to deep orthography.	Alphabet (deep)
Arabic (Afro-Asiatic)	6; 30 = 36 total phonemes	4,000	CVVCC (e.g., شَابّ "young" [shaabb])	[āw] → [āʔ] in [qāʔilun] "speaker"	High	Syllabary inappropriate because morpheme boundaries and syllable boundaries do not overlap. Abjad allows morpheme roots (distributed consonants) to be seen.	Abjad (conso-nantal alpha-bet)
Mandarin Chinese (Sino-Tibetan)	11; 23 = 34 total phonemes	400 (disregarding tones)	CVC (final consonant restricted to [n] or [ŋ])	11% of most frequent characters have context-dependent pronunciations	Low	Small number of syllables paired with a predominance of monosyllabic words creates extensive homophony. Logographs differentiate between large number of homophones that are distinguished by tones in spoken language.	Logography (morpho-syllabic)

(*Continued*)

TABLE 1
(Continued)

	Phonological structure of spoken language			*Morphological structure of spoken language*		*Implications for writing system*	
Language *(language family)*	*No. vowels; no. consonants*	*Approximate no. syllables used in language*	*Maximal syllable structure*	*Representative morpho-phonological processes*	*Complexity of inflectional morphology*	*How phonology and morphology constrain writing system*	*Mapping principle of writing system*
Korean (probably Altaic)	10; 21 = 31 total phonemes	2,000	CVCC	[got] → [gochi] (see Table 2)	High	Relative phonological complexity leads to larger number of syllables, making an alphabet efficient. Near one-to-one grapheme-phoneme correspondence and complex inflectional morphology result in shallow orthography.	Alphabet (shallow)
Hebrew (Afro-Asiatic)	5; 22 = 27 total phonemes	3,000 morpheme roots (not syllables)	CCVC	Root morpheme [KTB] alternates to [XTB] in certain conjugations (e.g., [tixt'ov], future masculine of [ktiv'a] "writing")	Medium	Syllabary inappropriate because morpheme boundaries and syllable boundaries do not overlap. Abjad allows morpheme roots (distributed consonants) to be seen.	Abjad (consonantal alphabet)
Finnish (Uralic)	8; 15 = 23 total phonemes	3,000	CVVC or CVCC	Frequent morpho-phonemic alteration at juncture of word stem, e.g., sydän "heart" → sydämeni "my heart"	High	Extensive homophony avoided, despite small number of phonemes, through long words of several syllables. Complex inflectional morphology requires shallow orthography.	Alphabet (shallow)

Japanese (probably Altaic)	5; 16 = 21 total phonemes	110	CVC (final consonant restricted to [n])	人 "person" [hito], but 人人 "people" [hitobito] (not [hitohito])	Medium	Logographs manage homophony resulting from extremely few syllables.	Logography
						Scarcity of syllable types (almost all V and CV) and small number of syllables lends language to syllabary. Prevalence of multisyllabic words makes tones unnecessary but makes it difficult to match words to logographs. Syllabic *kana* are paired with logographs to convey inflectional and derivational information.	Syllabary

Sources include: Chen et al. (2011), Levelt et al. (1999), Graf & Ussishkin (2003), Taylor & Taylor (1995), Seidenberg (2011), Frost (2012), Halpern (2009), El-Imam (1990), and Wiik (1977). Estimates for number of vowels, consonants and syllables in a language, and even of maximal syllable structure, vary widely; we turned to Comrie (2009) for this information whenever possible.

the Table 1 estimate). So a syllabary that maps a graph to a syllable is not going to be privileged over an alphabet, no matter how many phonemes the language contains. Because of this, English is better adapted to an alphabet, but its adaptation takes into account morphology. English has a rather simple inflectional morphology, lacking both case marking and gender on nouns. However, it makes use of morphophonemes; that is, it allows for a single morpheme to be expressed with varying phonemes. The past tense morpheme /ed/ attached to English verbs, for example, has variable (but completely predictable) expressions at the phoneme level: /t/ in *jumped*; /d/ in *robbed*; and /Id/ in *added*. Written English spells all three variations with –ed, the past tense morpho-phoneme. So it's *jumped*, not *jumpt*, preserving the morphology in the spelling at the expense of phonemic transparency. To some extent, the preservation of morphemes in English spelling may justify its opacity (Chomsky & Halle, 1968). English spelling reflects derivational as well as inflectional morphology: the "d" in "judge" /jj/ preserves its link to "judicial," and use of the letter "a" in both "nation" and "national" keeps their morphemic link visible. The argument that such spellings are also adaptive for English might be correct, although examples are not proof. The conventions of writing have complex origins and do not simply reflect an insightful balancing of the morphology-phonology scales; the irregularities of English spelling in particular have a number of sources (Venezky, 1970).

Turning to a more transparent shallow orthography, Table 1 shows Korean and Finnish as examples. Korean shows a manageable number of phonemes and about 2000 syllables, making it a poor candidate for a syllabary and a relatively good candidate for an alphabet. No historical reconstruction is needed, because the Korean alphabetic Hangul was invented by King Sejong in the 15th century. It served as a pure alphabetic system, a graph for every phoneme. However, the system must have been slightly out of balance, not at its "equilibrium point," because regressive changes were eventually made. The changes reflected a shift in the weighting from 100% for phonology and 0% for morphology to a weighting that sacrifices a small portion of the phonological transparency to preserve morphological relations in the spelling. Changes were made in Korean that led to preserving graphs that carried morphological connections even though their pronunciation changed. Table 2 (adapted from Perfetti, 2003) illustrates this for the family of words related morphologically as case variations to the core sense of "flower." When the Korean word for flower takes on agentive case, the final consonant changes, and in the classical Korean orthography this led to a change in spelling. Thus, the classical spelling reflected phonology

TABLE 2
Korean moved from pure alphabetic to a morphologically sensitive alphabet (based on Perfetti, 2003). The pronunciation of the Korean word for "flower" varies with grammatical context, and in classical times the spelling changed with the pronunciation, thus serving phonemic transparency. Modern written Korean, however, privileges morphological transparency, and retains a single spelling across contexts

Spoken form	*Meaning*	*Classical orthography (15C−19C)*	*Modern orthography (20C−)*
/got/	$[\text{flower}]_{\text{neutral}}$	곧	꽃
/got/	$[\text{flower}]_{\text{agent}}$	꼬치	꽃이
/gotkwa/	$[\text{flower}]_{\text{with}}$	곧과	꽃과

purely, but at the cost of making invisible the morphemic relation of the word to its root *flower* morpheme. Later spelling changes brought morphemic spelling, so that the graph for flower /got/ was retained despite the pronunciation change in the agentive.

Finnish did not have a king to impose its pure alphabet, although it did have a bishop (Mikael Agricola) who, some 100 years after King Sejong in Korea, wrote Finnish as a not-quite pure alphabet, which was later moved farther toward the purity point ("Uralic languages," 2012). Its relatively small number of phonemes and large number of syllables favor an alphabet over a syllabary. Its morphology can be expressed through agglutinative processes that join morphemes together in word strings, and because changes to phonology are minimal in Finnish with this process, alphabetic writing continues to be favored. In a sense, Finnish does not need to negotiate much. It gets morphological transparency more or less free with its phonology.

Within the alphabetic family, but with distinctive deviations, are Hebrew and Arabic, West Semitic languages with root morphemes represented by distributed (noncontiguous) consonants. The idea of a morpheme taking the form of a consonant skeleton, with vowels dropped into slots between and around the consonants, can be perplexing for speakers of languages whose morphemes come packaged in neat, unbroken strings. ***S**ke**l**eto**n***, for instance, shares the distributed S-L-N pattern with the English words ***s**a**l**vatio**n*** and ***s**ub**l**imi**n**al*, but the triad of letters itself holds no meaning and the three words are not related. In both Arabic and Hebrew, by contrast, the root K-T-B expresses the idea of writing. ***K**a**t**a**b**a* in Arabic means 'he wrote' and *ya**kt**u**b**u* is 'he writes', with ***kitāb*** signifying 'book', *ma**kt**a**b**a* signifying 'library', and so on. Vowels are traditionally not expressed in either written Hebrew or written Arabic, as context is generally sufficient to indicate how the empty slots should be filled, although diacritics or "points" can be used to designate missing vowels for children who are just learning to read.

In contrast with these variations on the adaption of alphabetic writing is Chinese. Its inventory of segmental phonemes is not particularly large, but with the addition of tones the number of functional (i.e., morpheme distinguishing) speech units is substantial. The use of pin-yin, an alphabet that can be used to write Chinese and is used for beginning reading instruction, demonstrates the possibility of an alphabetic Chinese. However, the large number of homophones works against the alphabetic solution. A syllabary, likewise, would not eliminate the problem of homophony. The character system provides a resolution of homophonic ambiguity, as Figure 2 illustrates. But it does so at a price. Thousands of graphic units need to be learned. Still, one can argue that the Chinese language found a system that is reasonably adaptive.

Japanese has a very small syllable inventory that favors a syllabary solution. It has even fewer phonemes, which is again a hint that phoneme number is not a critical feature by itself. Because Japanese is multisyllabic, the syllabary presents a much neater (more efficient) representation for its longer words. Kana, the graphemes of the Japanese syllabary, are extremely transparent phonologically; as syllable units, they are morphologically opaque. However, Japanese also has Kanji graphs, based on the Chinese logographic system. Japanese was not written down until about the 5th century AD, when Chinese characters began to be used to encode Japanese. In most cases, a character retained something like its Chinese pronunciation at the time it was borrowed, in addition to having a comparable Japanese translation applied to it. Thus, most Japanese characters in use today have at least two pronunciations, or readings, and often many more.

This system presents obvious complications. For instance, one might argue that multisyllabic Japanese is ill-suited to characters designed for monosyllabic Chinese. In addition, a reader of Japanese is faced with multiple potential pronunciations of every character he encounters. Both of these concerns are addressed by supplementing Kanji with Kana. Take, for example, the character 大, *big*. Its “Chinese reading” is *dai* (which is, incidentally, still its pronunciation in modern Mandarin). The native Japanese word for ‘big’ is *ookii*, a four-syllable word. Kanji are rarely asked to “hold” four syllables; instead, the first two syllables, “oo”, are applied to the character and the final two, “kii”, are appended as Kana: 文本. The Kana help to clue in the reader to which reading should be used. Alternatively, 大 followed immediately by another Kanji indicates that its Chinese reading is required, as in the character for *university*, 大学 (*daigaku*, literally, ‘big study’).

In theory, Japanese could long ago have dispensed with Kanji and adopted Kana as its sole writing system. It might be the case that the prestige of Kanji has prevented this from happening. But it is also possible that reducing morphological transparency in favor of phonological transparency is a step the Japanese have been unwilling to make. Such reluctance to abandon Kanji mirrors the American reluctance to reform spellings such as *health*, which are phonologically misleading but morphologically illuminative. (We return to the discussion of spelling reform in a moment.)

These examples suggest that writing systems have some degree of compatibility with the languages they encode. However, the range of languages with widely varying phoneme and syllable inventories that are served by an alphabet suggests the alignment of writing system and language is not perfect. More generally, the literal reading of the claim that languages get the writing system they deserve has to go untested. (Frost, 2012, seems to make this stronger claim.) Writing system development includes too many factors (variations in technology and other cultural factors) to allow one to say that over time, the written language “settles” into an optimal alignment with the spoken language. Furthermore, while languages continue to undergo change indefinitely, written language, once established, is resistant to further change. This is part of the reason that written English does not align perfectly as a pure alphabet with spoken English.

This resistance to change has many examples in the history of writing reform. Where governments have been able to impose changes, as in the periodically updated Dutch *Het Groene Boekje* (The Little Green Book), there has been some success, although never without organized resistance even in the Dutch case. English examples of reform abound, although the extent to which the reform movements were serious endeavors might not be widely appreciated. In the early 20th century, Andrew Carnegie funded an English spelling reform project, convening a well-paid commission in the United States. The commission, known as the Simplified Spelling Board, made serious efforts to bring about change, recommending a broad set of more transparent spellings. The Board’s recommendations actually gained some official acceptance when President Theodore Roosevelt ordered the government printing office to use the new spellings. Thus, Roosevelt’s message on the Panama Canal War Declaration was written in the simplified English spellings recommended by the Board, spelling "honor," and "thru" instead of “honour” and “through.” Eventually, the reform fell to political opposition within the Congress and also the Supreme Court. Some of the spelling changes have survived in American English to this day—“anemia” instead of “anaemia” and “mold” instead of “mould.”

It is informative to consider what distinguishes the recommendations from the Spelling Board that survived to modern American English from those that perished with the Board in 1906. In addition to “mold,” we have “catalog” as an alternative to “catalogue” and “gage” as alternative to “gauge,” with spelling choices rather than simple no-choice correctness being typical. The losers, the changes that failed to survive, are well represented by “addresst,” “claspt,” “dasht,” and “wisht.” In each case, the proposal to make spelling correspond to sound failed, predictably from an equilibrium point of view. The ability to see past tense—the English morphophoneme —trumps the need to see the voiceless alveolar [t]. To be able to immediately decode “wished” as the past tense of “wish” is efficient for morpheme identification (and thus sentence comprehension), even if it is disrespectful to phonology. American English has settled on a point of grapho-linguistic equilibrium (Seidenberg, 2011) that allows morphology to shine through its orthography.

Notice, however, that equilibrium (if that is what it is) is not reached through purely natural forces, whatever those might be in the case of writing, but rather through the push and pull of cultural forces. The idea of an optimization in which a language acquires a writing system that is the best possible fit for its linguistic features is flawed, because of the multitude of influences at work. Instead, we believe a more modest fit-hypothesis is in order: The character of a language contributes to the development of a writing system so that the language is efficiently encoded. Efficiency must refer to the ability to express the language in the writing and the ability to decode the writing into the language. So a language tries on a writing system that fits OK and then keeps it, even if the fit tightens or loosens with age, bringing it in or letting it out, but never throwing it away.

If Writing Fits Language, What Are the Implications for Reading?

If features of a language contribute to shaping its choice of writing system and orthography, there should be consequences for reading, and there are. Frost (2012) provides a telling example concerning the importance of orthographic precision in reading. The transposed letter effect refers to the fact that in lexical decisions, primes (under conditions of masking that limit processing of the prime) are effective even when they are disordered spellings of the target word. For example *slat-SALT* produces nearly as large a priming effect as *salt-SALT,* as if the word processing mechanism were indifferent to exact spelling. This effect, robustly observed in English (Forster, Davis, Schoknecht, & Carter, 1987; Perea & Lupker, 2003; Andrews, 1996), is also reported in Spanish (Perea & Lipker, 2004), French (Schoonbaert & Grainger, 2004), and Japanese Kana (Perea & Perez, 2009). However, it is not found in Hebrew (Velan & Frost, 2007, 2009). The explanation for this lack of universality, as Frost (2012) explains, is the critical role that consonant triads play in Hebrew morphology. To illustrate, using Roman letters in left-to-right order, K-T-B is a root morpheme that, depending on the context, gets expressed as the verb write (katabh; בתכ) or the agentive noun writer (kotebh; תבתוכ), among other morphemically related words. In Hebrew (and Arabic) it would not do to scramble the K-T-B order because only in that order is the morphemic identity preserved. A change in order yields a different morpheme. So out-of-order priming does not work. This is a direct influence of the spoken language on the written language. The consonantal structure of spoken Hebrew and Arabic gets mapped directly onto the consonantal alphabet (abjad). Thus reading is influenced through language structure by way of writing.

It is possible, as we suggested earlier, that some of the reading differences attributed to writing systems alone are partly due to properties of the languages that have tuned the writing system. For example, Wang, Koda, and Perfetti (2003) found differences between Korean and Chinese learners of English as a second language in the degree to which they committed false alarms to phonological foils (*sale*) in an English semantic judgment task (part of a boat: *sail*). (Korean learners made more such errors and Chinese learners made them only when the foil shared most of its letters with the target.) Wang et al. (2003; also Wang & Geva, 2003) suggested that this was because Korean readers transferred their alphabetic reading procedures readily to English. Yamada (2004) argued that, instead, such a difference could be attributed to a closer phonological relation between Korean and English than between Chinese and English. The fact is that there is no clear basis for choosing among these alternatives, and that is a general problem that is predicted by the fit hypothesis.

Beyond the clear demonstration of reading differences across languages and writing systems is the question of whether writing system fit matters for learning to read. We began with the observation that learning to read can be difficult compared with learning language. Do some writing systems make learning to read more difficult than other writing systems? Or, if languages choose writing that fits, then should learning to read face more-or-less similar challenges no matter what the writing system?

Learning to read is often defined as learning to get meaning from print. This is fine as far as it goes, but it begs the question of what, exactly, is learned. From our perspective, a definition proposed by Perfetti and Zhang (1996) is more apt. Learning to read is learning how one's writing system works, that is, how one's writing system encodes one's language. When that learning is achieved procedurally, the child is indeed getting meaning from print. With this definition, the role of language-writing fit can be cast as a meaningful hypothesis: Learning to read (learning how one's writing system encodes one's language) is facilitated to the extent the system is mapped to the language so as to take advantage of its linguistic properties. Whether this hypothesis is true or even testable is another matter, but it at least becomes a sensible question.

Would English be easier to learn as a syllabary instead of an alphabet? Not according to our analysis in Table 1. On the other hand, Gleitman and Rozin (1977) showed that children struggling to read standard alphabetic English found some success when English was written as picto-syllabary, with pictured objects, for example, a can, contributing their pronunciation to a multisyllabic word such as "candy." However, the idea was never that English orthography would become a syllabary for these children, but rather that the syllabary could bootstrap their awareness that writing encoded speech sounds.

Japanese provides a natural test of the fit hypothesis, because whereas Kanji is the traditionally favored system, children learn to read using the Kana syllabary. This strategy implicitly acknowledges the writing-language fit between the Japanese language and the syllabary. Chinese (as taught in the mainland and Taiwan, but not Hong Kong) may seem to do the same thing when it introduces children to reading through alphabetic writing. The switch to character reading comes after 10 weeks (Wu, Li, & Anderson, 1999). However, this strategy for Chinese is not a matter of writing-language fit. It is less like the Japanese use of a syllabary for children, and more like the Gleitman and Rozin use of a syllabary for English: It helps introduce the children to the idea that the written word connects to a spoken word—and, when the alphabetic writing is presented below characters as they are introduced, it supports the learning of the character as representing a Chinese syllable-morpheme.

The general state of affairs may be that, as difficult as reading might be for some children, it would be harder if the writing system did not fit the language to some degree. Beyond this generalization is the important fact that the writing-language fit is really calibrated not with learning but with efficiency. Characters are not easier to learn than alphabetic writing even for Chinese, they are merely more efficiently read once they have been learned (at a very high cost in learning time). Similarly, it is not that the deep orthography of English is easier to learn than a more shallow orthography that could be imposed on English. Rather, the deep orthography (or at least its morphology exposing aspect) is more efficient for skilled reading once all the variable mappings have been mastered.

CONCLUSION

In learning to read, a child must figure out how his or her writing system encodes his/her language. The development of writing systems, while following multiple paths, may make some accommodation to the linguistic features of a language. They do this by trading off one level of language to expose another. The specific trade-offs writing makes affect reading procedures at both behavioral and brain levels. Examples of this are seen across the wide divide between Chinese logographic (morpho-syllabic) writing and alphabetic writing, as well as across narrower differences between deeper and shallower alphabetic writing.

Reading processes respond to writing variability in two ways. First, they take advantage of the fact that beneath the variability is a universal attachment of writing to language. This allows language processes, for example, phonology, to be engaged universally across various kinds of mapping units. Second, reading processes make accommodations to specific features of writing. Procedures that link graphic input to language become tuned to the level of mapping between graphs and language units. Developmental specialization occurs as increased exposure to a single writing system tunes the brain's reading network to deal efficiently with the demands of that writing system—and the language it encodes. Differences observed between writing systems may also reflect difference between languages. Indeed, marriages between writing and language reflect some degree of compatibility. This may help give the child some boost in figuring out how his or her writing system works.

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