J Cult Cogn Sci (2022) 6:97–117
https://doi.org/10.1007/s41809-022-00103-1

REVIEW

Toward a script relativity hypothesis: focused research agenda for psycholinguistic experiments in the science of reading

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Received: 12 August 2021 / Revised: 26 April 2022 / Accepted: 30 April 2022 / Published online: 30 May 2022

Abstract The purpose of this paper is to extend the linguistic relativity hypothesis (i.e., the language we speak affects the way we think) to a *script relativity hypothesis* (i.e., the script in which we read influences our thought). Based on the rich body of knowledge in the science of reading that shows the effects of literacy on our cognitive processes, the foundation, rationale, and converging evidence of script relativity are discussed. The tenable notion of script relativity is anchored in previous research into the connection between language and thought as well as a causal relationship from language to cognition. Further discussed is the application of linguistic relativity to reading in both first and second languages to elucidate the reading-to-cognition link and how reading affects our attention, perception, and thought. Focused research for script relativity is suggested in the areas of the operating principle of script (alphabetic vs. morphosyllabic), reading directionality (left-to-right vs. right-to-left), word configurations (linearity vs. block), literacy experience (literates vs. illiterates), and interword spaces (presence vs. absence of interword spaces). The article ends with further recommendations and future directions. It is suggested that linguistic and cultural effects on cognition be controlled in future studies to disentangle the true effects of script.

Keywords Linguistic relativity · Language · Cognition · Reading · Script relativity · Trans-scriptal transfer

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Introduction

In human history, the invention of written signs dramatically changed not only the trajectory of civilization (Diamond, 1999), but also the way we think (Logan, 2004; Pae, 2020). Writing systems are only 5000 years old, which is a relatively short history compared to that of other inventions, such as fire, beer, musical instruments, and so on. Preliterate days comprise 99.9% of human history (Diamond, 1999). All remarkable advances made in the course of human civilization, such as the alphabet, printing press, the Internet, and digital text, to name a few, have emerged within the 0.1% of human history after writing systems were invented. Due to the significance of reading, notwithstanding the small segment of human history on an evolutionary scale, the aim of this paper is to elucidate the consequences of reading and the differential effects of the scripts in which we read on our thinking (action of reasoning) and thought patterns (product of thinking). The consequences of reading are explained through a lens of a

script relativity hypothesis (i.e., the script in which we read influences our thinking and cognition).

At the core of reading is the script as multifaceted written codes. The term *script* refers to the grapho-phonic form of written language (Sampson, 2015). A script consists of a set of principles by which arbitrary signs are combined into linguistic units or words, which is in line with Weingarten's (2011) definition of the script as a "set of graphic signs with prototypical forms and prototypical linguistic functions" (p. 16). A writing system refers to "the principles reflected in the fundamental writing-language relationships" (Perfetti & Liu, 2005, p. 194). Relatedly, an orthography is defined as a physical form or "graphic format in which writing is represented" (Joshi & Aaron, 2006, p. xiii).

Building upon the linguistic relativity hypothesis (Carroll, 1956) and existing studies (Ben-Yehudah et al., 2019; Cook et al., 2006; Dolscheid et al., 2013; Sato & Athanasopoulos, 2018), the *script relativity hypothesis* is predicated on the premise that the script being read affects the reader's perception and thinking above and beyond linguistic effects. Specifically, the *script relativity hypothesis* refers to the tenable notion that the graphic forms and extralinguistic characteristics of writing systems—such as letter shapes (e.g., ascenders, descenders, dots, and curves as well as geometric- or angular-shape graphs in Korean Hangul), letter/graph configurations (Roman letters vs. non-Roman graphs), syllable or character writing (linearity vs. block), diacritics or circumflexes (signs written above, below, or next to a letter to indicate lexical stress, contractions, or tone), spatial density (visual complexities or the degree of crowdedness within a character), syllable format (horizontal or vertical syllabic format as particularly found in Korean Hangul and some Chinese characters), text direction (horizontal text vs. vertical text), and interword spaces (presence or absence of spaces between words)—may affect cognition beyond linguistic features. *Cognition* refers to the mental action and processes of incoming information, including thinking, thought, perception, recognition, conception, reasoning, and discriminant skills (e.g., visual discrimination). Script relativity can lend an additional avenue of research by disentangling the true effects of script for both first language (L1) and second language (L2) studies in the science of reading. To this end, we draw upon the linguistic relativity hypothesis due to the interlocking relationship between spoken language and written language as well as the close connection between language and cognition. It is impossible to discuss the nature of reading without discussing spoken language because a writing system encodes spoken language (Perfetti & Liu, 2005). As the most powerful cultural and cognitive tool, language serves as the medium of conceptual thinking and reasoning (Carruthers, 2002; Perszyk & Waxman, 2018).

In this article, the term *reading* refers to a process of extracting meaning from written symbols by drawing on linguistic and cognitive abilities. It is used in a narrow sense excluding context, affect, metacognition, and discourse because confounding variables associated with these factors are difficult to control for in a study and because reading in the narrow sense provides sufficient evidence for the script-thought nexus. Such a bottom-up approach is also consistent with the *reading systems framework* (Perfetti & Stafura, 2014), which places word reading at the center of the processes of word-to-text integration. The significance of the script relativity hypothesis rests on the importance of visual processes in reading to facilitate integration and establish the reader's mental model of the text. Script relativity serves as a framework that explicates the cognitive dynamics of reading and consolidates the effects of script specificity or a script's unique characteristics (e.g., letter shape, text direction, and presence or absence of interword spaces) addressed in a multitude of studies in various writing systems, such as English, Chinese, Japanese, Korean, Thai, and Hindi/Davanagari (Akamatsu, 1999; Ben-Yehudah et al., 2019; Das et al., 2011; Sun et al., 2022; Winskel et al., 2009). Notably, the findings of these studies are at the confluence of linguistic effects and scriptal effects on cognition. For the script relativity hypothesis, script effects need to be separated from linguistic effects.

Following an account of the linguistic relativity hypothesis, script relativity is discussed below as an extension of linguistic relativity. Focused areas of research are then delineated in light of testing script relativity. The article concludes with a call for research into script effects on cognition using scripts other than Roman alphabets, such as abjads, abugidas, Chinese, Korean, and mixed scripts.

Beyond the linguistic relativity hypothesis

The linguistic relativity hypothesis (a.k.a., Whorfianism or Sapir–Whorf hypothesis) refers to a proposition that the language we speak affects the way we think (Carroll, 1956). Since Whorf's claim that language could shape cognition emerged as a theory in the 1940s, heated debate over its plausibility and generalizability had continued in anthropology, psychology, linguistics, and philosophy until the late 1990s. Few ideas have evoked as much controversy and interest as the linguistic relativity hypothesis in such disciplines (Lucy, 1997). The claim that language shapes cognition has two versions, comprising linguistic determinism (i.e., strong version; language *determines* our cognition) and linguistic relativism (i.e., weak version; language *affects* our cognition), although Whorf did not claim as such. This classification was posthumously made by Roger Brown after Whorf's premature death in 1941 (Danesi, 2021). Although the strong version of determinism has hardly gained acceptability, the weak version of relativism has continuously been supported by a multitude of studies in psychology and applied linguistics (Bylund & Athanasopoulos, 2017; Dolscheid et al., 2013; Imai & Mazuka, 2007; Roberson et al., 2000).

Language-on-cognition effects: linguistic relativity hypothesis

Carruthers (2002) notes that *language* involves a "distinct input–output module of the mind" (p. 658), while *thought* concerns "discrete, semantically-evaluable, causally-effective states, possessing component structure" (p. 658). His delineations suggest an instrumental role of language that deals with the "module of the mind," which, in turn, links to "semantically-evaluable" language. From this view, language and thought are essentially interrelated.

To better explicate linguistic relativity, there are at least two ways to examine relations between language and cognition. One way is to look at causation. The central tenet of linguistic relativity lies in causality from language to cognition. For a thorough analysis to ascertain comparative plausibility, *causation* and *reverse directionality* as well as *independence* should be noted. Another way is to look at the flipped side of this inquiry; that is, whether thinking can be restructured by language or whether language can be restructured by thinking.

Causation, reverse directionality, and independence

At the kernel of the debate over linguistic relativity are causal relations, which involve whether *language affects thinking* or *thinking affects language*. The debate can be summarized in three modes of relationships between language and thought as follows: (1) a causal relation from language to thought, (2) a causal relation from thought to language, and (3) no relation between them. The first relationship (i.e., *language affects thought*) directly accords with the linguistic relativity hypothesis. This hypothesis posits that all languages vary in terms of grammar and semantic categorizations and that the structure of a given language affects thinking and behavior (Carroll, 1956; Lucy, 1997, 2016). Whorf adopted the term *linguistic relativity* analogous to the physical theory of relativity, noting that different linguistic backgrounds lead observers to different views and interpretations of the universe (Danesi, 2021). According to the linguistic relativity hypothesis, the habitual use of language shapes the speaker's habitual thinking and behavior.

The linguistic relativity hypothesis has been challenged mostly by nativists, particularly Pinker (1994, 2007), in the 1960s through the 1980s. Whorf's work was also criticized after the publication of Berlin and Kay's (1969) study of basic color terms. Berlin and Kay (1969) reported that lexical labels for basic color terms followed universal principles and the order of universal properties in focal colors. They also asserted that the typological patterns of basic color terms were the product of cultural evolutionary processes. However, a series of subsequent studies have led to modifications of their claims due to the language-dependence categorical perceptions of color (Kay & Regier, 2006; Roberson et al., 2000).

As cognitive linguistics ushered in the late 1980s and the early 1990s, many research findings were in support of the linguistic relativity hypothesis (Fishman, 1982; Lakoff, 1987; Levinson, 2003; Lucy, 1997). Levinson (2003) notes "… the ways we speak —the kinds of concepts lexically or grammatically encoded in a specific language—are bound to have an effect on the ways we think" (p. 37). Linguistic influences on our perceptual and cognitive domains in

different language groups have been addressed in a wide range of domains from color (Masharow & Fischer, 2006; Roberson et al., 2000), number (Miura et al., 1994), time (Bylund & Athanasopoulos, 2017; Everett, 2005), motion conceptualization (Flecken et al., 2015), and nonlinguistic classifications (Imai & Mazuka, 2007) to musical pitch (Dolscheid et al., 2013). The overall findings of various studies[1] point toward the endorsement of the weaker version of linguistic relativity, which is unfalsifiable to a great extent.

The second relationship (i.e., *thinking affects language*) has received much less attention than the first relationship. Although this possibility was raised (e.g., Pinker, 1994, 2007), no research has been carried out to investigate this relationship. The lack of research in this line might have to do with the difficulties of testing and the implausibility or unfalsifiability of this claim. Studies of infants or toddlers can shed light on the understanding of links between thinking and language, given the lack of studies in this respect. A review of studies on infants' conceptual development demonstrates that language serves as a hidden medium that facilitates infants' concept learning through words and object categories (Perszyk & Waxman, 2018). Infants' knowledge of object categories seems to be a fundamental step for their cognitive development from the age of three months onwards. Considering the notion that words are an invitation to the formation and expansion of cognition, language is considered an antecedent to the mind's action (i.e., thinking), especially for high-level thinking. From this view, the assertion that thinking affects language is a moot point.

The third view of independence between language and cognition (i.e., *language has no relation with thought*) is hardly conceivable based on research into infants as well as a host of philosophical accounts on the relationship between language and concept formation (Carruthers, 2002; Gauker, 2011; Gliga, et al., 2009; Perszyk & Waxman, 2018). Although Gauker (2011) essentially disavows linguistic relativity, he not only advocates for the language-dependence account of the origin of concepts, but also claims that we think in language. However, Pinker (2007) alluded to the view of independence, as in "… people understand reality independently of the words used to describe it" (Pinker, 2007, p. 124) and noted "[s]ince mental life goes on independently of particular languages, concepts of freedom and equality will be thinkable even if they are nameless" (Pinker, 1994, p. 82). However, he has not provided evidence for that in part because he has never conducted empirical research to test linguistic relativity and in part because this claim is not easily falsifiable. Carruthers (2012) noted that "[i]t is unclear whether anyone has ever really endorsed the thesis of the independence of thought from language in its most extreme form" (p. 383). As opposed to Pinker's view, Fodor (2001) argues that we still do not know how human mental processes work, by claiming that a computational theory of the mind explains only a fragment of the mind. In Fodor's (2001) view, cognitive science has not yet embarked on its journey to explaining the mind. Hence, this line of research needs to continue.

Can thinking be restructured by language? versus Can language be restructured by thinking?

As hinted earlier, another way to look at the relationship is through questions of whether we can think without language or not. Although the answer to this conundrum can vary depending on how thinking and language are defined, the notion of interdependence between language and thinking needs to be critically examined, especially considering infants' category learning through language, as reviewed in Perszyk and Waxman (2018). Given that cognitive functions are acquired through language, not only are thought and language closely related (Carruthers, 2002, 2012; Gauker, 2011), but language is also a means to express specific conceptualization of thoughts or ideas.

Because it is not easy to determine causation between language and cognition, it would be useful to look at the flip side of the two causal relationships by focusing on the outcome of the causation. The first flipped question is whether thinking can be changed or restructured by language. Evidence for this question can be found in the bilingual mind. Research shows that bilinguals' and monolinguals' attention, problem-solving strategies, and visual discrimination skills are different from each other (see Cook, 2015, 2016 for review). This can serve as evidence

[1] In consideration of space constraints, an exhaustive review is not provided here. See Chapter 3 of Pae (2020) for a more detailed review.

for the claim that the mode of thought is/can be restructured by the consequence of language use. The second flipped question is whether language can be changed by thinking. There is no evidence for the affirmative answer to this question. Hence, this view has not been accepted in the literature, although it can be a topic of further discussion. Table 1 summarizes philosophical, anthropological, and psycholinguistic accounts by means of questions, answers, evidence, and conclusions for the relationship and the flipped queries that have been discussed so far. It begins with a fundamental question of whether all humans think alike. Linguistic diversity and cognitive diversity have been well documented (see Lucy, 1997). Considering research findings of bilingual or multilingual studies (Cook, 2015; Das et al., 2011; Sato & Athanasopoulos, 2018; Sun et al., 2022; Vanek & Selinker, 2017), it is difficult to dismiss language effects on cognition.

Extending linguistic relativity to bilingualism or multilingualism

The linguistic relativity hypothesis has been incorporated into L2 research, as fluid translinguistic influences from L1 to L2 help us understand the cognitive functions of language. A bilingual is viewed as a "many-sided whole" (Cook, 2015, p. 154) who possesses multicompetence and shows complex relationships between language and cognition. Cook's (2016) view of multicompetence involves the total system that functions for all languages in the single, but whole, mind of a bilingual. Research on linguistic relativity needs to continue because it allows us to better understand the boundaries of human biological and cultural diversity through cataloging translinguistic cognitive differences (Casasanto, 2008). We can understand how thinking works and how we acquire new knowledge through language experience by looking at cognitive differences among different language speakers. In a similar vein, Bylund and Athanasopoulos (2014) propose a new research program that applies linguistic relativity to L2 studies by recommending methodological and theoretical requisites for that direction.

There are a number of studies addressing the interaction between L1 and L2 (Ben-Yehudah et al., 2019; Cook et al., 2006; Sato & Athanasopoulos, 2018). Cook et al. (2006) found that learning L2 English influenced Japanese bilinguals' categorization of objects and substances (shape or material), which were different from English and Japanese monolinguals. These results indicated that learning an L2 categorization had a significant impact on bilinguals' conceptual representations, which provided support for the tenet of the linguistic relativity hypothesis.

More recent bilingual research has shown findings that support linguistic relativity. In a bilingual study,

Table 1 Questions, Answers, and Implications

Question	Answer	Evidence	Conclusion
Fundamental Question			
Do all humans think alike?	No	Linguistic diversity	Cognitive diversity
Relationship			
Can we think without language?	(Yes)*		
	No	Infants' category learning	Interdependence between thinking and language
Can we use language without thinking	No	Speculation	Marginal interdependence between language and thinking
Flipped Inquiry			
Can thinking be restructured by language?	Yes	Bilingual mind	Linguistic Relativity Hypothesis
Can language be restructured by thinking?	No	None	None

*It depends on how *thinking* and *language* are defined

French–English bilinguals' grammatical gender perception exerted a robust effect on the bilinguals' judgments, indicating that the retrieval of prior knowledge associated with required grammatical properties was automatic and affected perceptual judgments, which was independent of task requirements (Sato & Athanasopoulos, 2018). Vanek and Selinker (2017) reported that Chinese speakers' nonverbal event categorization was influenced as a result of learning temporal references in linguistic expressions in L2 English. They found that L1-modulated preferences also affected nonverbal judgments. These studies underscore interactions among language, cognition, conceptualization, memory, and L2 learning (Athanasopoulos & Bylund, 2014; Cook, 2016; Vanek & Hendriks, 2015), especially supporting the claim that different languages are likely to facilitate different patterns of nonverbal behavior beyond linguistic influences (Athanasopoulos & Bylund, 2014).

Toward the script relativity hypothesis

If spoken language is viewed as the most profound reflection of thinking, written language can also be viewed as the most profound reflection of what we think. Reading is a cognitive and metalinguistic process encompassing multiple componential skills, which involves visual discrimination, graphemic and phonological processes, retrieval of pertinent information from the mental lexicon, working memory, executive control, and prior frames of reference. Importantly, none of these skills is specialized or hardwired for reading.

Since reading is a neurobiologically demanding endeavor, habitual reading can shape and reorganize our cognitive structures, neural circuitry, and the brain's inner-workings (Castro-Caldas et al., 1998; Dehaene et al., 2015; Huettig & Mishra, 2014). Because we are not born to read, we need to deliberately learn to read. As a consequence of many years of effortful practice of reading, the brain becomes rewired and restructured for reading due to innate neuroplasticity. In the journey toward gaining automaticity of reading, our brains accommodate the demand of reading by "recycling" the brain's networks and pathways to tailor existing brain circuitry to the reading brain. To address this, Dehaene et al. (2015) call reading a process of "neuronal recycling," which means that the brain recycles innate neuronal circuits to be able to read. The *neuronal recycling hypothesis* postulates that the architecture of the brain is highly constrained, but some networks are rewired to form new neuronal networks to meet the demands that are required for reading. Das et al. (2011) have reported that simultaneous bilinguals' reading in different orthographies yields different brain networks showing script-specific plasticity, which operates through adulthood. Recent brain imaging studies also support the brain's accommodation and adaptation to the script being read, suggesting that reading has remolded the brain's circuitry in a certain way over time (see Huettig & Mishra, 2014; Kim et al., 2017). In short, the reading brain works as an engine that drives our minds, in that reading has essentially rewired the human brain and changed the trajectory of human civilization and history by transforming the architecture of our thinking.

Reading-cognition nexus: *Script relativity hypothesis*

Although about 7000 different spoken languages exist on the globe, commonalities are found in the relationship between spoken language and its writing system as well as literacy; that is, each writing system represents its spoken language (Perfetti & Liu, 2005; Verhoeven & Perfetti, 2021). The fact that the writing system closely aligns with its spoken language[2] suggests that the notion of script relativity fundamentally relies on the tenet of linguistic relativity. However, acquiring spoken language and learning to read are essentially different from each other. The former is acquired naturally with three conditions of exposure, time, and interaction, due to our innate ability to learn a mother tongue, while the latter requires conscious effort with no endowed ability that is prewired for reading. Hence, it is natural to deduce that habitual reading in a particular script over time

[2] The Korean writing system, Hangul, is a good example for the claim that a writing system aligns with its spoken language, as it was deliberately invented to be a writing system that was compatible with spoken Korean language by King Sejong in the fifteenth century as a way to combat illiteracy resulting from the incongruency between the Korean language and Chinese characters (see Pae, 2020 for more information).

affects the reader's perception, reasoning, and thinking, which are the consequences of reading.

As a cognitive mechanism, reading involves the integrated use of graphophonic, syntactic, and semantic cues provided in written text. The interdependent relationship among these cueing systems is depicted in Fig. 1. The graphophonic code refers to the visual cues provided through the sound-symbol correspondence and mapping. The syntactic code relies on the structure and grammar of a given language. The semantic code allows the reader to make sense of a text through context-dependent and language-dependent cues. These three cueing systems serve as an interdependent cueing system for comprehension. The componential processes of reading include decoding, word identification, meaning retrieval, sentence parsing, inferencing, monitoring, and comprehension. These knowledge sources are utilized in both constrained and interactive ways (Perfetti & Stafura, 2014).

Given that the goal of reading is comprehension, the initial step to comprehension is efficient decoding and word identification. This aligns with the gist of the *reading systems framework* (Perfetti & Stafura, 2014), which explains the processes of word-to-text integration by placing word identification and word knowledge at the center of the model. This model links the word identification system to the comprehension system through the lexicon, which further explains the integration of word meaning into the reader's mental model of the text. The processes of form-meaning mapping are central to reading, which in turn becomes a pressure point for reading comprehension. The integration processes further encompass orthographic knowledge, linguistic knowledge, and general knowledge (knowledge about the world, including knowledge of text forms such as text genres; Perfetti & Stafura, 2014). Lexical and sentence processing is considered to be different across scripts due to the specificity of a script.

With the influence of each script's specificity, the automaticity of reading we acquire in childhood is likely to affect and shape our subsequent cognitive functioning and filter visual input, which yields a solid reading-cognition connection. The reading-cognition nexus varies according to the script being read. The reading-cognition nexus implicates a cognitive framework comprising *visual perception* (the process or awareness of visual information by means of semiotic and writing systems), *reasoning* (the process of understanding and forming inferences from premises expressed in text), *memory* (the mental capacity of recalling and recognizing information via writing systems), *conception* (an idea of reality shaped by the semiotic and writing systems acquired in childhood), and *worldview* (a comprehensive viewpoint of the individual's interactions with the outer world).

Reading research agendas to test *script relativity*

Although the script relativity hypothesis draws on the linguistic relativity hypothesis, it is important to differentiate script effects from linguistic effects on the cognitive mechanism to identify true scriptal effects. A multitude of studies have investigated reading in various writing systems and its cognitive effects. However, existing studies have not controlled for linguistic effects in analysis. More systematic research designed to control for confounding variables is warranted to disentangle the true effect of script.

The impact of script relativity on thinking and cognition can be demonstrated at both micro and macro levels. The micro-level impact of script relativity refers to scriptal or semiotic influences on the reader's cognitive functions. The macro-level impact goes beyond the individual level to the extent of discourse, rhetoric, and cultural and societal realms. To maintain the scope of a focused discussion, given that the proposal of script relativity starts from the graphophonic cuing system and visual processing, the micro-level impact of script relativity, primarily focusing on the graphophonic codes and orthographic systems, is discussed below.

Although trans-scriptal influences have been found and discussed in a multitude of studies in reading science (Akamatusu, 1999; Ben-Yehudah et al., 2019; Pae & Lee, 2015; Sun et al., 2022), the interpretation of previous findings has not been directed toward script relativity. Hence, it is time to systematically consolidate them into script relativity, and further test its validity in order to advance the theory in the science of reading. Results of L2 studies are particularly of interest, as trans-linguistic and trans-scriptal transfer is a manifestation of subconscious use of native or dominant linguistic skills in the face of the additional demands of L2

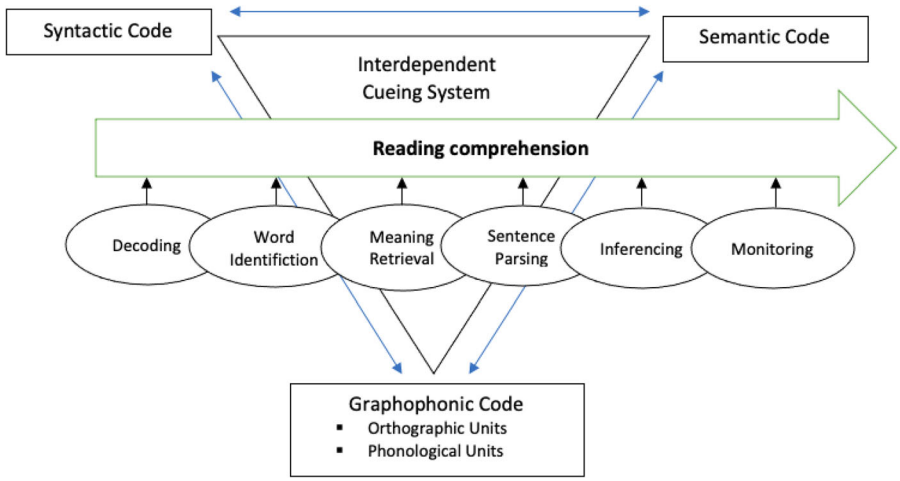

Fig. 1 Componential Cueing Systems and Word-to-Text Integration

performance. Perfetti (2020) acknowledges that the thrust of the script relativity hypothesis is to open up a new quest in the science of reading. This quest needs to fulfill certain necessary conditions, which are summarized in a later section.

Below are areas for research, which are not mutually exclusive, that could further advance our understanding of how the script being read as L1 or L2 shapes our attention, perception, and cognition at the micro-level above and beyond linguistic effects. These research agenda items possess the potential to exert anticipatory and consequential effects of habitual reading. The effects of the script being read are discussed with respect to various scriptal characteristics, including the operating scriptal principle, psycholinguistic grain size, script shape, linearity, text direction, and text influences. Although previous studies did not directly test script relativity nor controlled for linguistic effects, they are worth mentioning below.

The operating principle of script: analytic alphabet versus holistic logography

The alphabet is governed by the alphabetic principle, meaning that letters or graphs (i.e., the general term for the smallest unit of written language; Sampson, 2015) represent sounds rather than meaning and that a cluster of graphs is used to represent a syllable. The alphabetic principle is the underpinning rule of alphabetic writing systems, such as Roman alphabets and Korean Hangul. Although the grapheme-phoneme correspondence varies across alphabetic writing systems, the smallest unit of the sound is the phoneme. Based on the regularity in the grapheme-phoneme correspondence, orthographies are classified into deep orthographies (i.e., the letter-sound correspondence is irregular; e.g., English, French) and shallow orthographies (i.e., the letter-sound correspondence is regular and consistent; e.g., Finnish, Spanish, Italian, and Dutch).

In contrast, Chinese characters and Japanese multi-scripts do not subscribe to the alphabetic principle. The Chinese writing system is logographic or morphosyllabic such that a written symbol represents a word or morpheme, not a phoneme. The Japanese use multi-scripts, including Kana and Kanji. Kana are syllabaries comprising cursive Hiragana (ひらがな) and angular Katakana (カタカナ). Kanji (漢字) are Chinese-derived logograms. Additionally, Romaji (the use of letters of the Latin alphabet) and furigana (used for glosses) are also used. Notably, all these scripts represent syllables, not phonemes.

The operating principle of the writing system is likely to affect how readers process written words. Since alphabets rely on phonology for the representation of written signs, readers of alphabetic scripts tend to rely more on phonology than other components of the word. This explains why phonological awareness skills are a dominant predictor of efficient reading in alphabetic orthographies.

A handful of studies have investigated trans-scriptal influences (Akamatsu, 1999; Pae & Lee, 2015; Sun et al., 2022). Ben-Yehudah et al. (2019)

showed Chinese-English bilinguals tended to rely on holistic lexical information in recognizing upright and inversed stimuli, whereas Korean-English bilinguals were more likely to rely on analytic, sublexical orthographic information.

There is more evidence showing that different scriptal characteristics yield different cognitive processes. For example, a review of behavioral and functional neuroimaging studies shows that learning the auditory-verbal language system is significantly modulated by reading alphabetic orthographies (Petersson et al., 2001). Reading skills in alphabetic orthographies facilitate the awareness of sublexical phonological structures, which yields accommodated language pathways in the brain to efficiently respond to script characteristics.

Since the way in which visual information is extracted from text affects both word recognition and comprehension, script characteristics are an essential factor influencing reading. In particular, research into Chinese text can offer valuable information for the understanding of visual span and the way readers parse characters into meaningful units (i.e., words), as Chinese text shows no space between words. Yan and colleagues (2020) examined the perceptual span of typically-developing Chinese third graders who read age-appropriate text and found that their visual span was one character leftward and two characters rightward from the fixation point. Results also showed that higher reading fluency was associated with wider visual spans. A study of eye movement patterns of native Chinese readers in reading text with and without word boundary spaces showed similar findings (Bai et al., 2008). Bai and colleagues (2008) used texts of four types of spacing, including typical text with no-space, text with irregular spaces between words, text with spaces resulting in nonwords, and text with a space after each character. Results showed that Chinese readers did not show differences in reading text with and without space between words. However, reading text with nonword spacing and each-character spacing yielded a significantly slower reading time than that of the other two conditions. The results indicated that words, regardless of whether word boundary was implicit or explicit, were the unit of reading in Chinese rather than individual characters. These findings support the claim that readers of each writing system adapt their own visual exploration strategy to the script being read (Dehaene et al., 2015). Attention to this area calls for further systematic research or comparative research addressing the operating system across scripts by controlling for linguistically related variants.

Processing unit: phonemes, subsyllabic units, or syllables

Reading is related to psycholinguistic grain sizes and processing units. The minimal unit of sound in script varies across languages from phonemes to syllables. The alphabet has the minimal sound unit at the phonemic level, while the minimal sound unit of the Chinese and Japanese writing systems represents syllables. Within alphabetic scripts, the dominant psycholinguistic grain size further varies as the processing unit. In English, a consonant preserves its sound value even without a vowel, which allows for a consonant string within a word. For example, the word *strong* can be segmented into the onset *str* and rime *ong*; the onset *str* is divided into individual phoneme /s/ /t/ and /r/; the rime *ong* is divided into /o/ and /ŋ/. Research shows that English-speaking children show a tendency to segment a word into the onset-rime unit (Treiman et al., 1995). In this regard, the popularity of Dr. Seuss' rhyme books for emergent readers in the U.S. is not coincidental.

However, the onset-rime primacy is not universally found in alphabetic script readers. One example is found in Korean readers. Korean Hangul is an alphabetic script, but is written in a syllabic block (e.g., 학생, not ㅎ ㅏ ㄱ ㅅ ㅐ ㅇ, /hɑk sæŋ/ meaning *student*). Furthermore, the Korean language does not allow for consonant strings as in English because each vowel should glue with a consonant. In other words, consonants and vowels function complementarily to each other. An extreme case is found in the word *strike*, wherein the word is a one-syllable word

in English, but it becomes five syllables when the sound of the word is written in Korean. Because each consonant should take a vowel as a combinatory rule, each consonant within the consonant string in the word *strikes* takes an epenthetic vowel, resulting in six syllables with the diphthong broken into two syllables (i.e., 스트라이크스 /su[3]/ /tu/ /rɑ/ /i[4]/ /ku/ /su/). The writing convention in Hangul appears to yield a different processing unit than that in English. In contrast to the dominant onset-rime segmentation, Korean readers show preference for segmenting in the body-coda unit (Yi, 1998). Since this tendency seems to carry over to L2 processing, the role of the L1 grain size in L2 reading also points toward script relativity.

McBride-Chang and colleagues (2004) reported that different levels of phonological awareness are involved in reading across different cultures (i.e., China, Hong Kong, and Canada). They suggested that "the Chinese language [might] promote syllable-level awareness in children" (p. 93) due to Chinese being a morphosyllabic language. This line of studies should continue to test script relativity. Although comparative studies on English and Chinese languages have been copiously carried out, juxtapositions between alphabetic scripts and Chinese morphosyllabary are still useful to understand underlying mechanisms involved in reading and its effects on our attention, perception, and cognition.

Beyond the contrast made for grain sizes and processing units, alphasyllabaries (a.k.a., abugidas or akshara scripts) primarily belonging to Brahmi-derived Indic scripts, such as Bengali, Hindi, Kannada, Tamil, Tibetan script, and Thai, have a special status on the spectrum of grain size and processing unit. Such alphasyllabaries simultaneously represent sound at both levels of phonemes and syllables (Nag & Snowling, 2010). The duality of syllabic and phonemic representations in these writing systems, which make the script being referred to as semi-syllabic and semi-alphabetic, tends to yield differential contributions to children's reading skills. Nakamura and colleagues (2017) have found increasing contributions of syllabic awareness through Grade 5, but steadily decreasing contributions of phonemic awareness to Kannada and Telugu decoding over time.

Grain size is also related to orthographic depth, which indicates the extent to which an orthography deviates from the one-to-one letter-sound correspondence. Depending on the degree of one-to-one or one-to-many correspondences on a scale, shallow orthographies (e.g., Spanish, Italian, and Finnish) or deep orthographies (e.g., English) are differentiated. The effects of orthographic depth and processing units on readers' thinking, thought patterns, and cognition are a reasonable candidate for testing script relativity effects especially for comparative research. Although orthographic depth and processing units are coalesced with linguistic characteristics, these variables can be investigated in contrast to other script-specific variables in a study.

Script shape: Roman script versus non-Roman script within the alphabet

Most alphabetic scripts use Roman letters. One exception is the Korean alphabet, Hangul. Although Hangul is an alphabet, in appearance, Hangul looks more like Chinese characters than English partly because Chinese and Hangul are written in syllabic blocks and partly because they use geometric- or angular-shape graphs or characters (e.g., 미국 /mɪ guk/ in Hangul, 美國 in traditional characters or 美国 in simplified characters, meaning *the United States*). Given that the shapes of Hangul graphs represent articulatory organs (e.g., the first consonant, "ㄱ" /g/, reflects the shape of the tongue upon articulating the sound ), it is referred to as a featural script (Sampson, 2015). Chinese characters are known as a morphosyllabary such that each character represents a morpheme. In this regard, both Hangul and Chinese characters have an iconic quality to a certain extent. For example, a partial inventory of Chinese characters constitutes pictograms (e.g.,:  月 (/yuè/, meaning *moon*);  山 (/shān/, meaning *mountain*); 水 (/shuǐ/, meaning *water*; Lin et al., 2018). Pictograms mean that the shapes of characters represent the physical aspects of objects as well as their meanings. These pictograms are iconic, in comparison to arbitrary Roman letters.

[3] Although this sound is not the exact sound in Korean, it is an approximate sound, which is the closest among the IPA phonetic symbols.

[4] When this sound is written in Korean, a dummy consonant is written before the vowel sound /i/ (i.e., ㅇ + ㅣ = 이).

Because visual cues are involved in the first phase of reading, script shape can exert an effect on its processing. Although the iconic quality of script has not been directly investigated in word recognition and reading in general, this line of inquiry needs to be addressed in the science of reading. The Japanese writing system can be of particular interest in this line of research. Japanese text can have a mixture of scripts within one sentence, including Chinese-derived Kanji, Katakana, and Hiragana. Research into the effects of visually more or less complex scripts as well as mixed scripts should continue to explore mechanisms behind visual cuing systems at the semiotic level, which also has the potential to extend to script relativity.

Configuration: linearity vs. nonlinearity

Relatedly, the ordering of graphs in a linear versus nonlinear manner also has an implication for the differential patterns of word recognition and long-term effects on cognitive processes. Roman script has linear letter ordering. However, non-Roman scripts, such as East Asian scripts (Chinese, Japanese, and Korean) and South and Southeast Asian alphasyllabaries (Devanagari, Kannada, Sinhala, and Thai) have nonlinear (or multilinear) orderings wherein graphs are packaged within syllabic blocks.

In particular, alphasyllabaries or abugidas are represented in symbol blocks at the syllabic level, which are composed of distinct marks representing phonemic-level sounds. Since vowels and consonants are stacked within a symbol block, the alphasyllabic writing systems are nonlinear or multilinear. The vowel marks or diacritics are secondarily ligatured to the base consonant to the right, left, above, below or around a base consonant, which makes the script visuospatially complex. Such scriptal characteristics require additional visual processing on top of phonological skills for efficient reading to abstract the *alphasyllabic principle* in reading (Nag & Snowling, 2010). This is consistent with a finding that Hindi written in Devanagari showed more increased demands for visuospatial processing than in English (Kumar et al., 2010). Although a considerable body of knowledge has been established in reading nonlinear scripts, an attempt to understand how such scriptal features function in the script-to-cognition nexus has been lacking.

Text direction: left-to-right versus right-to-left or horizontal versus vertical orientation

Another way to examine script relativity is to look at the effect of text direction. Although most scripts are written in a left-to-right sequence, there are a few scripts that are written in a right-to-left fashion. The investigations of text directionality (i.e., right-to-left Arabic, Hebrew,[5] and Urdu vs. left-to-right alphabets) can offer particular insights into the consequences of habitual reading. Vaid and Singh (1989) examined the influence of reading habit on the perception of chimeric facial affect (a half of the face is smiling, while the other half is neutral) among four groups of left-to-right readers (Hindi), right-to-left readers (Arabic), bidirectional readers (Hindi-Urdu[6]), and illiterate subjects. Results showed no handedness effect among the groups. Left-to-right Hindi readers' preference for the left hemifield was more pronounced than those of the other groups. Friedrich and Elias (2016) also found the effect of habitual reading direction on aesthetic preferences by comparing native Hindi and Urdu readers. Given that these two groups share linguistic similarities and geographical and cultural characteristics, a comparison of their aesthetic preferences would "reduc[e] the potential influence of confounding cultural differences on aesthetic preference biases" (Friedrich & Elias, 2016, p. 128). Their results showed that native Hindi readers demonstrated a strong preference for stimuli that had the same directionality, while Urdu readers did not show this bias. They indicated that scanning habits as well as neural and anatomical asymmetries in spatial attention mechanisms were likely to be developed by habitual reading direction. These findings were consistent with other studies (Castelain & Van der Henst, 2021; Padakannaya et al., 2002;

[5] Vaid and Singh (1989) pointed out the inadequacy of using Hebrew in writing directionality research in that many individual letters in Hebrew are written from left-to-right when they are written in a non-cursive style. Arithmetic and musical notations are also written in a left-to-right fashion, which may weaken directionality effects due to the exposure of left-to-right directions.

[6] Hindi and Urdu (a derivative of Arabic used by Muslims in India and Pakistan) are identical spoken common lexicons, phonology, and grammar, but are different in the direction of reading and writing; Hindi are written and read from left to right, while Urdu are written and read from right to left (Vaid & Singh, 1989).

Pae et al., 2021; Singh et al., 2000; Vaid & Singh, 1989) that found effects of text directionality on perceptual and performance asymmetries, arithmetic tasks, spatial scanning, and spatial reasoning.

The effect of text directionality on graphic representations was also addressed in a more comprehensive study. Tversky and colleagues (1991) investigated reading directionality in graphic productions in terms of trans-cultural and developmental trends. Speakers of English, Hebrew, and Arabic were asked to organize the graphic representations of spatial, temporal, quantitative, and preferential relations. Children indicated *like*, *dislike*, and *favorite* food by putting stickers on blank pages. Results showed the effects of text directionality on their graphic productions. English-speaking children tended to put stickers of their favorite food in left-to-right direction. In contrast, Arabic-speaking children's tendency was skewed toward the right-to-left direction. Hebrew-speaking children's preference was in-between.[7] The direction of top-down was found to be universal in that this tendency was found across all groups and ages (i.e., children and adults).

Eye movement studies provide another piece of evidence regarding the effects of text directionality. Research shows that visual span involved in reading is asymmetrical in identifying three or four letters to the left and seven or eight letters to the right of fixation, on average, totaling 10 or 12 letters per saccade. Pollatsek and colleagues (1981) examined native Israeli readers' eye movements while reading Hebrew and English text. Their perceptual span was asymmetric to the left while reading Hebrew text. In contrast, their perceptual span was asymmetric to the right when reading English text. These findings indicate that the different patterns of attention are shown according to the script being read. This gives rise to script-specific effects of text directionality. This line of research should continue to examine and test script relativity, as reading direction seems to have an impact beyond optical scanning.

Regarding the effects of vertical orientation, more recent research related to Chinese reading has also shown reading direction effects on cognition. Based on the reasoning that readers would apply reading direction to object counting direction, Göbel (2015) investigated how English readers (left-to-right reading) from the U.K. and Cantonese readers (a mixture of left-to-right and top-to-bottom reading) from Hong Kong counted stimuli presented in the horizontal plane and found that reading direction influenced the way of counting direction even within the horizontal plane. Objects were presented in horizontal, vertical, and square arrays. For the horizontal array, both English and Cantonese readers tended to count objects from left to right. For the vertical array, English-speaking children tended to count from bottom to top, while the majority of Cantonese-speaking children and adults as well as English-speaking adults counted objects from top to bottom. For the square array, all groups except English-speaking children started to count from the top left position (Experiment 1). In Experiment 1, the participants were asked to count a square array of objects after reading left-to-right or top-to-bottom text. Although Cantonese-speaking adults tended to begin counting from left to right with no reading of vertical text, they tended to count in the top-to-bottom direction after reading vertical text. This finding indicated immediate as well as longstanding effects of reading direction.

A similar finding was also reported by Chen and Friedrich (2015). They inferred the effect of reading direction on spatial–temporal cognition and compared the performance on a temporal judgment task between Chinese and Taiwanese readers, given that horizontal text orientation is a national policy in China, while vertical texts are fairly common in Taiwan. Based on the participants' self-report, Taiwanese participants' ratings of vertical texts and horizontal left-to-right texts were 5.7 and 6.5, respectively, while those of Chinese were 2.7 and 6.9, respectively. This indicated lopsided text familiarity in the two reading directions across the two groups. For the Taiwanese participants, vertical bias was robust with the vertical presentation but not with the horizontal one. For the Chinese participants, vertical bias was inconsistent with the presentation direction. The findings of the study support the relationship between reading direction and readers' performance on a space-implicated task. Chen and

[7] Young Hebrew-speaking children are taught to write numbers and perform arithmetic operations from left to right and perform arithmetic operations as such, whereas Arabic-speaking children are taught to perform arithmetic operation from right to left (Tversky, Mass, & Winter, 1991).

Friedrich (2015) concluded that reading direction had an impact on temporal thinking.

Vertical reading fluency was also found in experts of Scrabble, which is a board game in which players put letter tiles together to construct words either horizontally or vertically. The findings of van Hees and colleagues' (2017) study suggest that Scrabble experts' vertical fluency has to do with enhanced domain-specific working memory and flexible stimulus classification processes. The findings of the studies reviewed so far converge on the salient effects of text orientation on how readers perform nonverbal and verbal activities. The effect of reading direction particularly dovetails with the notion of script relativity. Further research in other scripts with a more script-focused design would also facilitate our understanding of reading direction effects on our cognition.

The effect of reading: readers versus nonreaders

Reading is an activity in which meaning is extracted from written signs. The ability to convert arbitrary symbols into sounds in the language and to interpret the information that written symbols represent is a complex cognitive process. Illiteracy refers to the inability to elicit meaning from written symbols. The difference in cognitive dimensions between literate and illiterate individuals can be a direct indicator that illustrates the consequence of reading. Given that reading requires conscious effort to acquire the automaticity of reading and that reading itself is a cognitive activity, habitual reading can affect the areas of cognitive functions and discrimination skills as well as rapid retrieval from the mental lexicon. Research shows the robust consequences of literacy that are demonstrated in the efficient access to and retrieval of phonological representations of rapid automatized object naming in a comparison among unschooled illiterate, ex-illiterate (those who learned to read in adulthood with no schooling in childhood), and schooled literate adults (Huettig et al., 2018).

Using fMRI, Dehaene et al. (2010, 2015) indicated that learning to read, even in adulthood, could change or refine the cortical organizations and networks in the brain. Castro-Caldas et al. (1998) reported that learning to read in childhood was likely to shape the functional organization of the adult brain, by comparing word and pseudoword repetition performance between literate and illiterate subjects. When the two groups repeated words, no difference was found in their brains. When pseudowords were repeated, however, the two groups showed different neural structures activated in their brains. Petersson and colleagues (2001) also reported similar findings of fMRI studies in a review of the literature on cognitive processing between literate and illiterate groups. Although fMRI data inherently indicate correlation rather than causation, the findings of these studies give rise to the notion that habitual reading modulates or modifies brain functioning and brain structures, and further the human mind (Huettig et al., 2018). In a similar line, Fernandes and colleagues (2021) study showed the significant effect of the written script on mirror-image discrimination among illiterate, Tamil literate, and Tamil-Latin-alphabet biliterate adults.

Despite the growing literacy rates in developed countries, Sub-Saharan Africa and South Asia still have considerable rates of illiteracy at 35% and 27%, respectively (Statista, 2019). It may not be easy to conduct research into comparisons of literate and illiterate subjects with respect to cognitive profiles. However, this topic is a useful candidate for research to test the script relativity hypothesis. Considering that the findings of previous research have shown the effects of reading, the next attempt should be differential script effects on readers' cognition.

Other scriptal characteristics that exert robust effects

There are at least six other areas of research that can test the script relativity hypothesis. First, the difference in the way of combining graphs or orthotactics beyond linearity versus nonlinearity is a useful option to test script relativity. All Roman alphabetic scripts arrange graphs in a left-to-right linear sequence, while the Korean alphabet, Hangul, is written in blocks with specific orthotactic rules. Since the visual configuration of Hangul is closer to Chinese than to English, Korean readers' performance on visual word recognition is typically placed in between Chinese and English-speaking subjects' performance (e.g., accuracy and response time) on naming, recall tasks, or lexical decision tasks (Ben-Yehudah et al., 2019; Pae & Lee, 2015; Sun et al., 2022).

Second, the degree of arbitrariness of written symbols (e.g., arbitrary symbols for Roman alphabets vs. semi-arbitrary symbols for Chinese characters and

Korean Hangul) can also be a topic of research for script relativity. Signs are largely arbitrary, as they lack natural connections between a sign and its sound or between a sign and its meaning. Since most written signs represent arbitrary sounds associated with their meanings, arbitrariness is one of the linguistic characteristics common for almost all languages. Although Chinese logographic characters represent meaning, the Chinese writing system is not completely free from arbitrariness. This is true especially for simplified characters to the degree that Chinese is not purely logographic. Due to this quality, the term *morphosyllabary* is used to refer to the Chinese writing system. However, what is clear is that Chinese and English have different degrees on the continuum of arbitrariness. Studies that address the different cline of arbitrariness have the potential to contribute to the discussion of script relativity.

Third, the level of graph complexity can be another way to address script relativity. Chang and colleagues (2016) identified the degree to which the visual complexity of an orthography affected the initial stage of grapheme learning, by examining multiple graphemic dimensions of 131 orthographies in five writing systems (i.e., alphabet, abjad, alpha-syllabary, syllabary, and morphosyllabary). As the visual complexity of a script affects the reader's perceptual learning of graphemic forms, the effects of scriptal complexities vary across scripts being read. In addition, the two Chinese scripts (i.e., traditional characters and simplified characters) and the Japanese mixed-scripts also offer a unique opportunity to investigate readers' visuospatial navigation as well as the effect of script complexity on cognitive or nonverbal activities. Chang and Perfetti (2018) noted that reading more complex scripts (i.e., traditional characters that have the higher number of strokes) would require stronger visuo-spatial skills than reading less-complex scripts (i.e., simplified characters). Cross-nation studies of Chinese reading between Taiwanese (traditional characters) and Mainland Chinese (simplified characters) also showed a significant complexity effect on performance on a same-different perceptual judgment task and a pattern recognition task (Chang & Perfetti, 2018). Taiwanese readers showed higher accuracy and faster response times than Chinese readers. This suggests that the more complex the script being read is, the higher visual perceptual skills are required.

In a similar vein, an eye movement study, exploring the impact of character-complexity on Chinese reading and visual search, showed that fixation durations and skipping rates were modulated by character complexity for both English-speaking and Chinese-speaking participants (Li et al., 2019). Reading Japanese Kanji has a similar effect of visual complexity on reading. Tamaoka and Kiyama (2013) examined how visual complexity functioned in Kanji processing using simple (2–6 strokes), medium (8–12 strokes), and complex (14–20 strokes) Kanji words with high and low frequencies. The results of a lexical decision task and a naming task demonstrated that reading low-frequency Kanji words was negatively affected by visual complexity of the stimulus.

Fourth, the presence or absence of a space between words is also a good candidate for testing script relativity, because not all scripts use spaces to demarcate word boundaries. Some Asian scripts, such as Chinese, Japanese, and Thai, use a series of contiguous words in sentence with no interword spacing. This scriptal feature requires readers' efficient lexical parsing within the sentence (compare this sentence for readability with "Thissciptalfeaturerequiresreaders'efficientlexicalparsingwithinthesentence"). The level of difficulty in reading non-space sentences is greater in linear orthographies (e.g., English) than in non-linear orthographies (e.g., Chinese, Japanese, Devanagari). Previous studies have been conducted in reading Chinese (Bai et al., 2008), Japanese (Sainio et al., 2007), Thai (Kasisopa et al., 2013), and English (Juhasz et al., 2005). Comparative studies using different scripts within a study (e.g., Winskel et al., 2009) are needed to test script relativity.

Next, the Japanese multi-scripts offer a unique opportunity for understanding script effects within the writing system, as they use a mixture of scripts consisting of morphosyllabic Kanji (used for content words) and phonosyllabic Kana (used for function words and proper nouns). In Sakuma and colleagues' (1998) study, significant homophone effects were found among adult Japanese readers in reading Kanji words, using a semantic decision task. Results showed that both orthography and phonology played a role in the recognition of Kanji words, but the effect of phonology disappeared when the item was presented only for a brief duration. The results suggest that orthography was a primary source of meaning

extraction for Kanji words. Koyama et al. (2008) found that phonological and orthographic skills played different roles in reading Kana and Kanji for Japanese children. Phonological awareness was a significant predictor of Kana reading skills but not Kanji skills, while orthographic awareness and short-term memory skills were significant predictors of skillful Kana and Kanji reading. These findings suggest that readers can navigate the visuo-spatial features of Kana and Kanji differently in the face of a mixture of Kanji and Kana scripts within the same sentence.

Last, scripts that have extralinguistic diacritics appearing to the right, left, above, below, within, or surrounding a base letter, including Semitic abjads (Arabic, Hebrew), abugidas (alphasyllabaries of South Asia), some European alphabets (e.g., German umlaut, the French acute accent, the Czech hacek, etc.) are useful resources to test script relativity due to their distinct scriptal features and characteristics. Due to the unique script characteristics of being both a phonologically well-specified shallow orthography with pointed Hebrew and a deep orthography with unpointed Hebrew that requires readers to unitize words and morphemes via consonantals, Share and Bar-On (2017) propose a triplex model of Hebrew reading development, including (1) lower-order, phonological (sublexical) sequential spelling-to-sound translation, (2) higher-order, string-level (lexical), lexico-morpho-orthographic processing, and (3) a supralexical contextual processing of pervasive homography of unpointed Hebrew. This proposal may be Hebrew-specific or specific to reading abjads, and it warrants further research on the applicability to other scripts.

Share (2021) laments that the science of reading has long shown Anglocentirc bias by focusing on English, which is a writing system outlier because of its extreme inconsistency in spelling-sound correspondence. Share (2021) lists 10 dimensions of orthography complexity as follows: spoken-written linguistic distance; multilinearity and nonlinearity; visual confusability and visual complexity; historical change: retention of historical spellings despite pronunciation change; spelling uniformity despite morphophonemic alternation; omission of phonological elements; allography; dual-purpose letters; ligaturing; and inventory size (see Share, 2021 for details). By addressing the script features discussed above in reading research and in testing script relativity, we can overcome obstacles, such as *Anglocentrism* and *alphabetism,* that impede optimal progress in the science of reading. Research on such scripts' within-language and between-language effects on readers' cognition and problem-solving strategies facilitates our understanding of scriptal effects in terms of script-universality and script-specificity because their psychological implications for the script-to-cognition link are still unknown.

Necessary conditions for the script relativity hypothesis

Given that the *script relativity hypothesis* has to do with unidirectional relations, certain criteria need to be met in order to pass the necessary conditions for unidirectionality, which is similar to causal relations. According to Hill (1965), there are nine criteria for causality: strength, consistency, specificity, temporality, biological gradient, plausibility, coherence, experimental evidence, and analogy. The first criterion *strength* has to do with an effect size or a sample-based estimate of relationships between variables, which can be gauged by the magnitude of experimental effects. The second one *consistency* can be characterized by reproducibility or repeated observations of the same phenomenon. *Specificity* indicates a single effect with no spurious variables involved in the strength and direction of a relationship. *Temporality* shows that the cause precedes the effect in time sequence, which means that a reverse time order is unacceptable. *Biological gradient* refers to an exposure–response relationship (a.k.a., a dose–response curve) in which the magnitude of the response is determined as a function of exposure to a stimulus. *Plausibility* shows a reasonable relation. *Coherence* indicates a systematic and logical connection, which means that a cause-effect interpretation is not in conflict with natural principles. Next, *experimental evidence* needs to be empirically obtained by conducting experiments including intervention and prevention programs. Finally, *analogy* represents similarities between the observed relationship and any other relationships. An additional criterion of *conditionality* (i.e., if the cause is removed from the equation, the effect should not be observed) can also be added to the criteria.

These criteria may be saddled with exceptions in the determination of causation. However, they are useful to make reasonable inference based on observations or research findings. Of these standards, an essential condition is *temporality* (i.e., the cause precedes the effect in time) for a verdict on causation. This condition is a useful basis for the discussion of script relativity. When this is applied to script relativity, reading is a temporal antecedent to the effect such as the rewired reading brain (Dehaene et al., 2015), bilingual mind (Cook et al., 2006), or cognitive changes. In other words, the *cause* is habitual reading in a particular script, while the *effect* is a particular mode of operation in attention, perception, and thinking that is displayed as a result of reading by a group of readers who share the script of a written language. This causal relationship from script to cognition is tenable as previous research has implicitly shown (as reviewed above), whereas the reverse directionality is implausible. Another way to look at this association is whether the mode of operation in attention, perception, and thinking can be restructured by reading or whether reading can be restructured by the mode of operation. Again, the former is tenable, while the latter is not. Although it is difficult to test script relativity, systematic research is needed.

Broader impact of script relativity

As the *reading systems framework* (Perfetti & Stafura, 2014) underscores the processes of word-to-text integration, quality processes at the word level positively contribute to text comprehension. At the stage of lexical processing, diverse graphophonic representations across scripts (e.g., alphabets, abjads, alphasyllabaries, syllabaries, or morphosyllabaries) are likely to yield the different modes of sound-symbol mapping, visual exploration, and integration. The mode of processing can diverge into script-universal and script-specific processes engaged in reading. Script-universal processing involves the nature of orthographic-phonological conversions, while script-specific processing concerns orthographic units that a particular script shows.

Lucy (1997) asserts that linguistic relativity not only relates to semiotic-level characteristics of the language (a micro-level relation between language and thought), but also to discourse-level characteristics (how patterns of language use in cultural context can affect thought at a macro-level of relations). Beyond what has been discussed so far at the micro level of script effects, script relativity extends to the macro level as well. Figure 2 depicts the flow of script effects on both micro and macro levels. Unraveling the patterns of information processing upon reading and cognitive functions engaged in reading is one way to better understand scriptal effects on our thinking and to advance the sciences of reading, psycholinguistics, comparative linguistics, education, and second language studies.

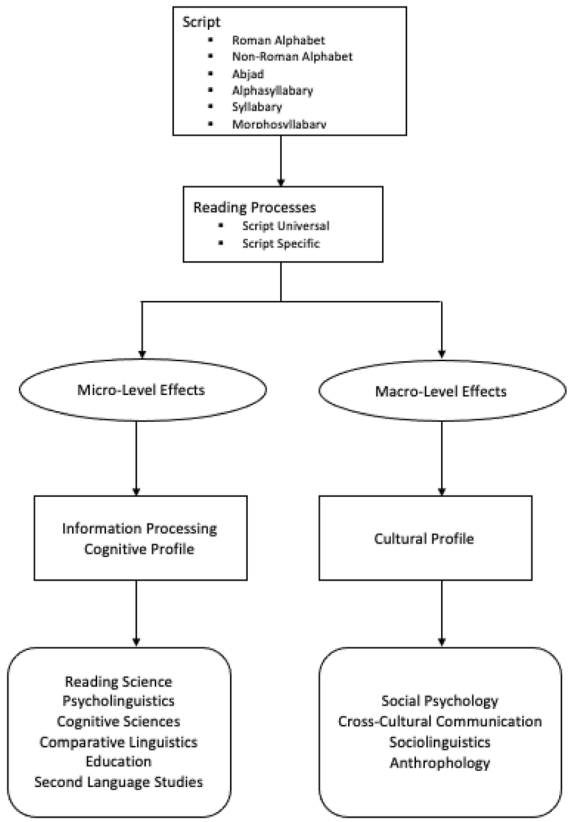

Fig. 2 The Micro and Macro Influences of Script and Advances in Sciences

Although it is possible to tease out the impact of script on comprehension using advanced methods (e.g., fMRI, well-designed masked priming tasks, eye movement studies) and analyses (e.g., ANCOVA, mediation analyses, path analyses, cross-classified modeling), reading comprehension is too broad to disentangle the *true* effects of script. Many componential skills, such as prior knowledge, vocabulary,

syntactic knowledge, working memory, reasoning, inference, and self-monitoring, along with individual differences, can inadvertently function as spurious factors. The componential skills are also involved as direct and indirect contributors to comprehension. It would be better to start with a manageable bottom-up approach. Therefore, the macro-level effects of script in relation to discourse, rhetorical patterns, and culture are beyond the scope of the present article. It is still an open question how script impacts macro-level functions, which calls for systematic research in the near future. The macro-level effect of script can shed light on the understanding of language users' or learners' profiles in the disciplines of social psychology, trans-cultural communication, sociolinguistics, and anthropology. Bernstein's (1971) notion of *elaborated code* and *restricted code* can be addressed at the macro level. The elaborated code applies to situations where no shared understanding or knowledge is available among members of a social group. The restricted code works well for insiders who share prior knowledge and mutual understanding of a given topic.

Conclusion and future directions

In this paper, the linguistic relativity hypothesis has been extended to a *script relativity hypothesis,* and focused research areas are recommended to specifically test this proposal. As Casasanto (2008) encouraged researchers to continue to conduct investigation into linguistic relativity in order to explain trans-linguistic cognitive differences and the boundaries of human biological and cultural diversity, it is also suggested that researchers tackle script relativity in data-driven research by controlling for confounding variables in the course of causation. Linguistic relativity can have profound implications for the study of mental representations because crosslinguistic cognitive differences provide useful information about how thinking works in our minds and brains (Casasanto, 2008). This is directly applicable to script relativity. There has been a lack of research that is specifically designed to test script relativity in the body of literature, although there is a wealth of studies that have investigated the relationship between literacy and cognitive processes. Empirical evidence gleaned from previous studies points toward the notion that script relativity rises above and beyond being subsidiary to linguistic relativity because script influences go beyond linguistic influences on thinking.

The quantity, quality, and range of research paradigms on linguistic relativity have significantly increased and broadened over time, which has resulted in refined explanations of language-specific effects on cognition (Lucy, 2016). Bylund and Athanasopoulos (2014) also emphasized the usefulness of studies of linguistic relativity, as in "the fields of SLA and relativity research have a tremendous potential for cross-fertilization" (p. 978). The heterogeneity and dynamic nature of nonnative speakers' learning can be better explained in trans-linguistic studies. The same goes for script relativity as well. Drawing upon the studies of linguistic relativity, it is time to recognize script effects on our thinking and cognition beyond linguistic relativity and to consolidate previous studies through the lens of script relativity. Research on trans-scriptal influences would be a way to initiate a systematic exploration of cognitive mechanisms behind L2 reading and script-dependent reading specificity.

Given that script relativity is a proposal that explains the script-to-cognition connection, this hypothesis can guide the formation of novel theories and models for the cognitive dynamics of reading. This is particularly feasible considering that the word identification system requires high-quality scriptal and linguistic information for efficient word-to-text integration and is the basis of bottom-up input for building a meaningful comprehension system (Perfetti & Stafura, 2014). Recently, Winskel (2022) has joined the discussion of script relativity through a critical review of the literature in light of scripts' spatial layouts and varied lexical tones and also called for further systematic research.

The script relativity hypothesis has the potential to address the aforementioned necessary criteria for causation with advanced methodologies (e.g., fMR that shows brain activation upon certain script processing, eye tracking techniques that allow for tracking attention shifts with script manipulations, masked priming paradigms, and Stroop tasks) and

analysis techniques (e.g., path analyses, mediation and/or moderation analyses, cross-classified modeling) in cognitive sciences, applied linguistics, and psychology. It is particularly encouraging to test script relativity in the writing systems of abjads (Arabic and Hebrew) and abugidas (alphasyllabaries of South Asia; Kannada, Telugu, Thai, Tibetan) because these writing systems offer unique opportunities for elucidating scriptal effects on our verbal and nonverbal performance. The focus on non-European scripts also aligns with the notion of overcoming the Western, educated, industrialized, rich, and democratic (WEIRD) Anglophone science of reading (Share, 2021).

In addition, studies of sign languages and braille literacy will expand the horizon of script relativity. This line of research has great potential to provide unique insights into a better understanding of the consequences of literacy on the brain, attention, perception, and thinking in the science of reading. This effort also has a broader impact on democracy, as in Morais' (2018) argument of dynamic reciprocity between literacy and democracy, which impacts the individual's mind and brain as well as the levels of global and human history.

Funding The author appreciates an Open Educational Resources Grant provided by the University of Cincinnati Press and CLIPS.

Declarations

Conflict of interests The author declares that there is no conflict of interest associated with this article.

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