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Cognitive Precursors of Reading: A Cross-Linguistic Perspective

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ABSTRACT

In this paper, we survey current evidence on cognitive precursors of reading in different orthographies by reviewing studies with a cross-linguistic research design. Graphic symbol knowledge, phonological awareness, morphological awareness, and rapid automatized naming were found to be associated with reading acquisition in all orthographies investigated. However, apart from rapid naming, this association is mostly interactive, meaning that young children develop their symbol knowledge, and phonological and morphological awareness during reading development. Especially for phonological awareness, cross-linguistic evidence involving phonologically transparent orthographies, both alphabetic and non-alphabetic, suggests that it may be less of a hurdle than in the complex English orthography. Cross-linguistic research designs can be a useful methodological approach to test limits of reading theories that were initially developed for alphabetic orthographies.

Learning to read entails mapping the units of the writing system onto the corresponding spoken language units. In order to read a word or text, a child must be able to decode the graphic units of a particular orthography into spoken language units (e.g., morphemes, syllables, phonemes). During reading acquisition, children not only learn how written words are composed, but also build up orthographic representations of spoken language units (typically words or morphemes). Reading becomes fluent, when (1) decoding is automatized and (2) words can be directly and effortlessly retrieved from the orthographic lexicon (see also Verhoeven & Perfetti, 2021).

By the time children commence formal reading instruction, they have typically already begun to acquire key knowledge and skills that will be associated with their subsequent success in learning. *Cognitive precursors* of reading are skills whose development starts prior to reading and which are functionally related to later reading skills (Marinus & Castles, 2015). In order to decode words, children need to be familiar with the graphic symbols of the writing system (e.g., letters of an alphabet, Chinese characters). They should also become aware of the linguistic units represented by a particular orthography (phonological and morphological awareness). In addition, naming speed, that is the ability to name visual information quickly and effortlessly, is associated with (later) reading fluency. It is important to note that a precursor does not have to be fully established before the onset of reading acquisition. It is also possible that interacting with a writing system induces developmental steps that would not happen without this exposure. However, if these skills cannot be properly developed even in the context of reading exposure, reading difficulties are likely to appear in the long run.

The precursors mentioned above can be assumed to play a role in any orthography. However, orthographies vary widely in how exactly they represent spoken language and, accordingly, cross-linguistic theories of reading development predict that the relevance of, and interplay between, cognitive precursors may also vary. Thus, it is of crucial importance to compare findings across

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orthographies in order to better understand how they are associated with learning to read. For a long time, reading research has focused on alphabetic orthographies (Share, 2014). The dominant theories explaining how individual variability affects reading were developed to explain how variations in spelling-sound correspondences affect reading in alphabetic orthographies, but have been generalized to other orthographies as well. For example, the orthographic depth hypothesis (Frost, Katz, & Bentin, 1987) postulates that some orthographies like English are hard to learn because they are inconsistent at the phonological level, but represent deeper linguistic levels like morphology (Katz & Frost, 1992). Schmalz, Marinus, Coltheart, and Castles (2015) further differentiated the concept of print-to-speech consistency into the complexity of print-to-speech correspondences and the unpredictability of the derivation of word pronunciations on basis of their spelling. Orthographies that represent the phonemic structure in a simple and predictable way make it relatively easy for young children to work out the mappings between graphemes and phonemes. English represents the phoneme level only inconsistently, while more consistent relationships can be found for larger phonological grain sizes like rime units. The psycholinguistic grain-size theory (Ziegler & Goswami, 2005) proposes that identifying and applying these units of variable size and their complex and not always predictable print-to-sound mappings is more demanding than being able to consistently rely on the phonemic level. All theories assume that good access to the phonological structure underlying an orthography is more relevant in phonologically inconsistent than in phonologically consistent orthographies.

In their critique of the generalizations of the "alphabetic" view of reading, Daniels and Share (2018) identified multiple dimensions on which the world's orthographies vary and that can impact reading development, including the visual-spatial characteristics and the sheer number of graphs that need to be learned (e.g., Chinese, Sinhala, Arabic, Latin), the type and size of the spoken language units that are represented (e.g., morphemes in Chinese, syllables in akshara orthographies, and phonemes in alphabetic orthographies), and the distance between the current spoken and the written language. The consistency of the correspondences between spoken and written language units is only one aspect among many that may play a role in learning to read across orthographies. Below we will draw on the orthographic depth hypothesis when discussing alphabetic orthographies but acknowledge its limitations when discussing akshara and morphosyllabic orthographies.

Graphic symbol knowledge

Writing systems use distinct sets of graphs to represent spoken language. Reading obviously requires familiarity with the graphic symbols of the particular writing system, but at the same time, graph knowledge constitutes a reading skill in itself rather than a precursor. How quickly and to what extent a reader masters the graphic symbols of the writing system depends on whether the system is contained or extensive (Nag, 2007), or its "orthographic breadth" (Inoue, Georgiou, Muroya, Maekawa, & Parrila, 2017). Alphabetic orthographies are based on a very limited set of letters that are typically mastered rapidly. The challenges are much higher in other orthographies, for instance, the akshara system of Kannada, which according to Nag (2017) has 347 CV-units and an exponential number of CCV-units, the hybrid Japanese orthography with about 100 Kana and 2000 Kanji characters (e.g., Inoue et al., 2017), or Chinese with some 200 semantic and 800 phonetic radicals that combine to 7000 or so characters (McBride, Pan, & Mohseni, 2021). In these extensive writing systems, learning the graphic units and how they can be combined takes years and is a precursor as well as a foundational component of reading acquisition developed in parallel with word reading and reading comprehension (McBride et al., 2021; Nag, 2007; Wijaythilake & Parrila, 2019).

Theoretically, we would expect that if some of the cognitive resources available for processing the text need to be allocated to identifying the graphs, those resources are not available for word and text level processes. A further plausible cross-linguistic prediction is that as the number of graphs increases, so does their visual complexity (see Verhoeven & Perfetti, 2021, for a systematic analysis of visual complexity) and the demands for visual-spatial skills for learning the graphic symbols. While a few cross-linguistic studies (e.g., Eviatar & Ibrahim, 2004) or cross-orthography learning studies

(Pelli, Burns, Farell, & Moore-Page, 2006) have proposed visual complexity as a possible factor affecting adult readers, studies with children have typically not compared different orthographies (see, however, McBride-Chang & Kail, 2002, for an early exception). Single orthography studies in akshara orthographies and in Chinese tend to show that (contrary to alphabetic orthographies) visual complexity matters for graph learning (Chen & Yuen, 1991; Nag, Snowling, Quinlan, & Hulme, 2014) and that visuo-spatial and visuo-motor skills are associated with individual differences in reading acquisition (e.g., McBride-Chang, Chow, Zhong, Burgess, & Hayward, 2005; see Yang et al., 2013, for a meta-analysis).

Graphic symbol knowledge in early childhood is influenced by educational practices such as at what age children are familiarized with the symbols. In Chinese and English, preschool children are often already familiar with frequently occurring graphs (Kim, Petscher, & Treiman, in press; McBride-Chang & Kail, 2002). In German-speaking countries, some kindergartens are using phonological awareness training schemes that introduce letters, whereas others explicitly refuse to present children with letters because this is considered the responsibility of primary school teachers (Landerl, 2017). These differences are reflected in cross-linguistic studies reporting higher preschool letter-knowledge in English-speaking samples compared to children from other European countries. However, after only a few months of formal reading instruction, those differences disappear and children acquiring alphabetic letter knowledge earlier do not seem to have an advantage in reading development (Caravolas, Lervåg, Defior, Seidlová Málková, & Hulme, 2013; Furnes & Samuelsson, 2010; Mann & Wimmer, 2002; Soodla et al., 2015).

Graphic symbol knowledge appears to be a sine-qua-non of reading acquisition across orthographies, but the challenges differ between writing systems. An additional challenge for research on reading acquisition, especially in alphabetic orthographies, is the tight relation between letter knowledge and phonological awareness (Marinus & Castles, 2015). As discussed in the next section, preschool children who know more letters typically also perform better in phonological awareness tasks.

Phonological awareness

Phonological awareness refers to the ability to consciously access and manipulate sublexical phonological segments, such as syllables, syllable onsets, rimes and phonemes. In a typical phonological awareness task, a child might be instructed to delete a certain sound from a word or nonword pronunciation (e.g., "Say /mift/ without /f/"). The child then has to maintain the sound sequence in working memory, identify the /f/-sound in the phoneme string, delete it from the pronunciation, and blend the remaining sound parts. Thus, although such tasks are taken to measure phonological awareness, they usually also require phonological memory capacity.

Orthographies represent the phonological structure of the corresponding language in varying ways. Alphabetic orthographies represent phonemes and the more complex and unpredictable the relationships with corresponding graphemes, the higher are the demands on children´s phonological competencies in order to work them out. In alphabetic orthographies, most children acquire explicit knowledge about the sound structure of their language in the context of learning about letters and learning to read (Castles & Coltheart, 2004; Wimmer, Landerl, Linortner, & Hummer, 1991). Phonological awareness has thus consistently been found to be closely associated with children's reading development, explaining unique variance in reading skills above and beyond general factors like age and nonverbal IQ (Melby-Lervåg, Lyster, & Hulme, 2012). Early training of phonological awareness can improve reading outcomes (Melby-Lervåg et al., 2012; Suggate, 2016), but note that training is clearly more efficient when children are at the same time introduced to the letters representing the trained sounds (Hatcher, Hulme, & Ellis, 1994; Schneider, Roth, & Ennemoser, 2000).

Even though most of the research has been carried out in the context of Western alphabetic orthographies, relationships between phonological awareness and reading have been demonstrated for the abjad systems Arabic (Tibi & Kirby, 2018) and Hebrew (Share & Levin, 1999), Korean Hangul

(Cho & McBride-Chang, 2005) or the complex akshara-system of Kannada (Nag & Snowling, 2012). Moderate correlations of phonological awareness with reading accuracy and fluency were also reported in a meta-analysis of 35 studies in Chinese (Song, Georgiou, Su, & Shu, 2016), and for Japanese Kanji (Inoue et al., 2017), arguably very inconsistent orthographies in terms of spelling-to-sound correspondences. Note, however, that when age and nonverbal IQ are controlled, phonological awareness may no longer predict Kanji reading (Inoue et al., 2017; Koyama, Hansen, & Stein, 2008). Further, the nature of the phonological unit of importance may also vary: While the phoneme is clearly the most relevant phonological unit in Latin-based orthographies, this is not always the case in other orthographies (Nakamura, Joshi, & Ji, 2017; Perfetti & Verhoeven, 2017; Wijaythilake, Parrila, Inoue, & Nag, 2019). For example, syllable awareness – but not always phoneme awareness – is consistently correlated with akshara knowledge and reading in akshara orthographies (see e.g., Nakamura et al., 2017).

A number of large European projects comparing the *concurrent association* of phonological awareness with reading development across alphabetic orthographies with children beyond the early stages of reading development have provided correlational evidence that the relevance of phonological awareness increases with the inconsistency of the spelling-sound correspondences (Landerl et al., 2013; Moll et al., 2014; Vaessen et al., 2010; Ziegler et al., 2010). However, a cross-sectional study with Chinese and English-speaking kindergarten-children (McBride-Chang & Kail, 2002) did not find much evidence for differences between the two language groups in the relation of phonological awareness with letter/character knowledge and reading. This may seem surprising given that Chinese represents words at the morpheme level while English uses an alphabetic orthography. However, the Chinese-speaking participants in this study also received instruction in English, which may have affected the results. Naturally, cross-sectional study designs can only be the starting point of research that investigates the exact nature of cross-linguistic differences in the association between phonological awareness and reading.

Longitudinal association studies investigating whether there is an association of preschool phonological awareness with later reading are only informative if they also report potential concurrent associations of early reading skills at the earlier time point. This is important because an observed association between early phonological awareness and later reading may be caused by only few precocious children who already have basic letter knowledge or reading skills at the first assessment (Castles & Coltheart, 2004). Powell and Atkinson (2020) recently reported an interesting longitudinal study with English-speaking children who were first assessed as early as age 3;11 years. Even at that early point in development, some children could already read simple words and were explicitly excluded from analysis. As typical for this young age group, phonological awareness was mostly assessed on the syllable and rhyme level, and only the hardest items required children to pronounce the final phoneme of a presented word. Phonological awareness assessed at 3;11 years predicted word reading 18 months later, at the end of the first year of formal reading instruction. Note that even at T1, when children were still nonreaders, their phonological awareness showed a significant correlation of .53 with letter knowledge, reflecting the tight association between those constructs.

In a longitudinal association study following a cross-linguistic sample including English and the more consistent alphabetic orthographies Spanish, Czech, and Slovak, Caravolas et al. (2012, 2013, 2019) did not observe marked differences in the prediction of phoneme isolation and blending assessed at five to six years for reading one year later. Phoneme awareness predicted later reading accuracy even when early letter knowledge and basic reading skills were controlled. This study confirmed earlier findings that reading development progresses more slowly in English than in more consistent orthographies (e.g., Frith, Wimmer, & Landerl, 1998; Seymour, Aro, & Erskine, 2003), but prediction of phoneme awareness for reading growth was similar across orthographies. In a more recent analysis of the prediction of reading comprehension in Grade 2, Caravolas et al. (2019) reported the models separately for each language. Based on a confirmatory factor analysis, phoneme awareness and letter knowledge were combined into one and the same latent factor, which in turn was highly collinear with early word reading in all four languages. This evidence once more

impressively illustrates the difficulties in clearly distinguishing early phonological awareness from early reading as these two constructs are closely intertwined. In summary, it appears that until formal reading instruction kicks in, early phonological awareness skills are tied to early knowledge of graphic symbols across orthographies, and this combined skill is associated with current and later reading abilities.

An important criterion in concurrent as well as longitudinal association studies is the dependent reading measure. Phonological awareness is assumed to help children understand the sublexical units that are represented in an orthography. It should thus be most relevant for the development of accurate decoding procedures. However, in phonologically transparent orthographies, reading accuracy often shows ceiling effects quite early in development. Georgiou, Torppa, Manolitsis, Lyytinen, and Parrila (2012), for instance, found a longitudinal association of syllable and phoneme blending assessed at five and a half years for nonword reading accuracy in Grade 2 in English, but not in the more transparent orthographies of Greek and Finnish, where many children performed at or close to ceiling.

Another set of studies explicitly investigated the *interaction* of phonological awareness and reading during development by repeatedly assessing both constructs. Landerl et al. (2019) assessed phoneme deletion and word and nonword reading fluency three times (beginning and end of Grade 1 and end of Grade 2) in English, French, German, Dutch, and Greek. Quite surprisingly, the development of phonological awareness and reading turned out to be largely parallel but independent across Grade 1 in all orthographies except French, where cross-lagged relations between the two constructs were observed. From 2nd to 3rd assessment, such an interactive relation was evident for English, French, and German, whereas the prediction was unidirectional from reading to phonological awareness in Dutch and Greek. Overall, there was not much evidence that earlier phonological awareness predicts later reading. It should, however, be noted that the study started relatively late, at the onset of formal reading instruction.

A comprehensive cross-linguistic longitudinal assessment based on the International Longitudinal Twin Sample contrasted reading acquisition in English with two more consistent Scandinavian alphabetic orthographies (Swedish and Norwegian). In early reports of that project (Furnes & Samuelsson, 2010, 2011), preschool phonological awareness predicted reading in the consistent orthographies only in Grade 1, while it continued to be a predictor for the English language sample in Grade 2. In spite of these early differences, Peterson et al. (2017) reported a language-universal model of cross-lagged relations between phonological awareness, RAN and reading at pre-kindergarten (age 5), kindergarten (age 6), Grade 1 and Grade 4 (where only children from US and Sweden still participated). Similar to Landerl et al. (2019), the cross-lagged correlations revealed an interactive relation of phonological awareness and reading throughout the study period, with relatively low coefficients from phonological awareness to the reading assessments in Grades 1 and 4.

In summary, the cross-linguistic evidence on the association of phonological awareness with reading is currently diverse and inconsistent. Among alphabetic orthographies, cross-sectional studies point toward a stronger association in more complex orthographic systems. Longitudinally, the pattern looks more similar across orthographic systems: Until formal reading instruction kicks in, early phonological awareness skills are tied to early letter knowledge across orthographies, and this combined skill is associated with current and later reading abilities. Cross-lagged study designs reveal the longitudinal interactions between phonological awareness and reading: The general pattern seems to be that whether or not children have explicit access to relevant phonological units before they start learning to read may be less crucial than whether or not they can develop this access during their reading acquisition. If interacting with written language does not induce adequate levels of phonological awareness, risk for reading failure increases and intervention is called for. The exact pattern of this interaction depends on a multitude of factors that vary across orthographies and cultures,

including educational and home literacy practices and the characteristics of the particular language and orthography. Such factors are likely to contribute to inconsistencies in empirical findings across studies.

Morphological awareness

Morphological awareness is defined as the "ability to reflect upon and manipulate morphemes and employ word formation rules in one´s language" (Kuo & Anderson, 2006, p. 161). In the Reading Systems Framework (Perfetti, Landi, & Oakhill, 2005; Perfetti & Stafura, 2014), the contribution of morphology to reading is twofold: As part of the word lexicon it contributes to word reading, and it further contributes to reading comprehension indirectly through word reading and also more directly through morphology as part of a general linguistic system (e.g., Deacon, Kieffer, & Laroche, 2014).

It has been hypothesized that morphological awareness should be more relevant in orthographies that represent phonology in a rather nontransparent way (like English or Chinese) such that morphology is needed to work out word pronunciations (Ruan, Georgiou, Song, Li, & Shu, 2018). Most alphabetic and akshara orthographies prioritize phonological transparency over morphological transparency when such compromise is necessary. Again, English is an exception and many inconsistencies and irregularities on the letter-sound level have morphological bases (Rastle, 2019; Venezky, 1970). The consonantal writing systems of Semitic languages specifically represent the root morphemes, whereas the Chinese writing system represents morphology in terms of semantic radicals within a character (see Verhoeven & Perfetti, 2017, for descriptions of these orthographies).

Morphological awareness has been found to be concurrently as well as longitudinally associated to word reading and reading comprehension (as well as spelling) in a large number of different languages. However, study designs, criterion measures, and tasks used to asses morphological awareness vary greatly between those studies. In their categorization of morphological awareness tasks, Deacon, Parrila, and Kirby (2008) identified a number of critical dimensions, including the explicitness of morphological information to be processed (e.g., decisions on relatedness of two words versus explicit manipulation of word forms), task format (oral versus written), and the type of morphological processes involved (e.g., inflectional, derivational, compounding). The issue of type of morphological segment and process assessed is particularly relevant when comparing studies in different languages as morphological characteristics and complexity can be very different. Cross-linguistic studies investigating more than one language have the advantage that designs are parallelized. However, Desrochers, Manolitsis, Gaudreau, and Georgiou (2018) made the important point that equating morphological features across languages may result in sampling a relatively narrow range of features from the morphologically more complex languages. Simply translating standard paradigms used in the dominant English research literature is unlikely to tell us much about the morphological processes that are relevant in other languages. Comparing the relevance of morphological processes that are available in many languages (e.g., combining words into compounds) may be a feasible starting point, but even lexical compounding is more productive in some languages than others. In the long run, it will be important to identify and investigate language-specific morphological characteristics in order to better understand the relevance of morphology in written language processing.

Cross-linguistic studies on morphological awareness are as yet rare, perhaps due to the methodological challenges mentioned above. In a *concurrent association* study, McBride-Chang et al. (2005) investigated 2nd-grade samples learning to read in the Chinese morphosyllabary (in Cantonese or Mandarin), the Korean alphasyllabary Hangul, and alphabetic (but phonologically often opaque) English. Tasks were created to mirror the structure of the languages involved. This meant that the morphological task required lexical compounding in all languages, while in English, items assessing inflection (like plural formation) were also included. The assessment of phonological awareness was based on syllable and onset deletion in Chinese and Korean, and included phoneme-based items in English only. In Chinese, morphological awareness accounted for a larger amount of unique variance in word reading accuracy than phonological awareness, while in Korean it was the other way round. In

the English-speaking sample, the morphological task was not correlated with word reading, which may be due to the task chosen, the alphabetic orthography, or (quite likely) both. The pattern of findings was largely confirmed in a meta-analysis comparing studies in English and Chinese (Ruan et al., 2018). There was not much evidence for differences in correlations of morphological awareness with reading accuracy, fluency and comprehension when differences in phonological awareness were controlled, but note that the number of studies that include measures of fluency and comprehension is still small. However, the authors suggested that the "division of labor" between phonological and morphological processes may be different between English and Chinese: While in English studies the contribution of morphological awareness was generally smaller compared to phonological awareness for reading accuracy and fluency (with no difference for comprehension), morphological awareness seemed to play a bigger role than phonological awareness for reading accuracy and comprehension (with no difference for fluency) in Chinese.

In a *longitudinal association* study, Desrochers et al. (2018) investigated the prediction of morphological awareness at the beginning of Grade 2 for reading at the end of Grade 2 in the three alphabetic orthographies of English, French, and Greek. While minor differences in language-specific models were observed (morphological awareness predicted reading comprehension in all orthographies, reading fluency in English and French, and reading accuracy in English only), no significant differences were found in the contribution of morphological awareness to literacy outcomes in multigroup analyses including all languages.

In a detailed longitudinal investigation of the *interactive associations* between morphological awareness in English and Greek from Grades 1 to 3, Manolitsis, Georgiou, Inoue, and Parrila (2019) ran cross-lagged analyses across four assessment points. Whereas morphological awareness predicted reading comprehension (and spelling) at the next assessment point in both languages, reading fluency was only predicted in English. In turn, reading fluency (as well as spelling) also predicted morphological awareness at the next assessment point, but again only in English and not in Greek.

In sum, there is as yet only tentative evidence that morphological awareness may be more relevant in morphosyllabic Chinese than in alphabetic English and again more relevant in opaque English than in more transparent orthographies. Longitudinal *precursor studies* showing that morphological skills assessed before the onset of reading acquisition impact on later reading exist for single languages (e.g., Lyster, 2002; Manolitsis, Grigorakis, & Georgiou, 2017). Studies matching designs and tasks across languages are as yet lacking, so that we do not know to what extent the relevance of morphological awareness as a precursor is similar or different. An aspect that may be of particular relevance for studies with beginning readers is that the morphology of a language impacts word length. Especially at the beginning of reading acquisition, English children read dominantly monosyllabic and often monomorphemic words, while in many other inflectional or agglutinative languages, this word type is highly exceptional and even beginning readers have to cope with long and morphologically complex words. The majority of studies on the association between morphological awareness and literacy skills have focused on one particular language and cross-linguistic study designs are still rather exceptional. In particular, there is a lack of knowledge about early development. Thus, while there is convincing evidence that morphological awareness is a unique predictor of reading, there is less evidence to suggest that it is an early precursor across orthographies.

Naming speed

The efficiency with which verbal information can be accessed from visual targets is usually assessed by rapid automatized naming (RAN) tasks measuring the speed of pronouncing sequentially presented letters or digits (alphanumeric RAN) or color patches or pictured objects (non-alphanumeric RAN). Alphanumeric RAN, particularly letter naming, is considered to be more closely associated with reading than non-alphanumeric RAN, as it requires fluent naming of the graphic symbols necessary for reading itself. As letter RAN measures a subcomponent of reading, its interpretation as a precursor of reading is problematic. In general, RAN requires phonological skills

(quickly accessing the phonological output programs of the required word pronunciations) and is therefore sometimes seen as a subcomponent of phonological processing (Savage, Pillay, & Melidona, 2007; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vaessen, Gerretsen, & Blomert, 2009). However, there is ample evidence that "naming speed is phonological, but not only phonological" (Kirby et al., 2010, p. 356) and constitutes a separate precursor of reading development (Parrila, Kirby, & McQuarrie, 2004; Wolf & Bowers, 1999). The mechanisms underlying the RAN-reading relationship are still a subject of debate (Jones, Snowling, & Moll, 2016; Lervåg & Hulme, 2009; Poulsen, Juul, & Elbro, 2015; Protopapas, Altani, & Georgiou, 2013). The different perspectives largely converge in assuming that sequential naming mimics the timely integration of visual and verbal skills required during efficient word recognition and allows simultaneous processing of multiple stimuli presented serially, which explains why RAN exerts its strongest effects on reading fluency (Kirby et al., 2010).

As the mechanisms underlying the RAN-reading association are as yet under debate, cross-linguistic predictions are also not very clear. Proficient integration of visual and verbal processes is relevant for fluent reading in all orthographies, so similar predictive patterns might be expected. It has been proposed that RAN might be more relevant in transparent orthographies where reading accuracy is often at ceiling early on and reading fluency tasks are used to capture individual differences in reading (Kirby et al., 2010; Mann & Wimmer, 2002). However, reading fluency is important in English as well, although it has not always been assessed in earlier studies. On the other hand, it has been argued that RAN might be particularly relevant in the morphosyllabic Chinese orthography, because Chinese reading requires fast and efficient naming of characters and reading acquisition entails rote learning of symbol-sound correspondences (Hanley, 2005; Song et al., 2016).

The question of orthographic differences has been explicitly addressed in meta-analyses. Based on 137 studies with almost 29 000 participants, Araújo, Reis, Petersson, and Faísca (2015) reported associations with word, text and nonword reading as well as comprehension. Associations with reading fluency were not moderated by age or reading level, while the association with reading accuracy increased from kindergarten to 1st and 2nd grade, and after that decreased with increasing grade level. This age difference may be related to the fact that reading accuracy gets close to ceiling with increasing reading experience, especially in more transparent orthographies, so that effect sizes for older students were actually almost exclusively based on English samples. Another potential explanation is that RAN tasks in kindergarten and early primary school may measure different skills than later on, as naming, especially of letters and digits, may not as yet be fully automatized, and may be influenced by variance in familiarity with alphanumeric symbols.

Araújo et al. (2015) also reported a stronger association between RAN and reading in opaque orthographies (e.g., English, r = .57) than in transparent orthographies (e.g., Finnish or Greek, r = .48). This finding confirms evidence from a European *concurrent association* study which reported a stronger association in English compared to other orthographies (French, German, Dutch, Hungarian, Finnish) in typical (Moll et al., 2014) as well as dyslexic readers (Landerl et al., 2013). In a second meta-analysis focusing on dyslexia, Araújo and Faísca (2019) found no significant difference in effect sizes between opaque (d = 1.26), medium (d = 1.08) and transparent (d = 1.16) orthographies. These mixed findings on dyslexia may be caused by different selection criteria and study designs that are pooled in a meta-analysis, while these features are matched as much as possible in cross-linguistic designs.

Even more important than investigating probably minor differences between alphabetic orthographies is to what extent RAN predicts reading in non-alphabetic orthographies. A meta-analysis based on 35 studies with almost 7000 Chinese children (Song et al., 2016) confirmed RAN as a significant correlate of reading accuracy and fluency with coefficients that are comparable to what has been reported for alphabetic orthographies. Araújo and colleagues (Araújo & Faísca, 2019; Araújo et al., 2015) did not find evidence for significant differences in the RAN-reading relationship between alphabetic and non-alphabetic orthographies. Cross-linguistic study designs directly comparing the

concurrent RAN-reading relation in Chinese with English as well as Korean (Altani et al., 2017) and Finnish (Georgiou, Aro, Liao, & Parrila, 2015; Georgiou, Parrila, & Papadopoulos, 2008) also found no remarkable differences between orthographies, but note that sample size in these studies was relatively small. Japanese is interesting because the precursors of syllabic Hiragana and morphographic Kanji can be directly compared. There is tentative evidence that digit RAN assessed at the beginning of Grade 1 may be more strongly related to fluency in Kanji than in Hiragana reading at the end of Grade 1 (Inoue et al., 2017).

Findings summarized so far are predominantly based on cross-sectional data. Longitudinal *precursor studies* with cross-linguistic designs that assessed RAN before the onset of schooling and investigated its impact on later reading skills also confirm RAN as a universal precursor of word and nonword reading that is not modulated by orthographic transparency (Caravolas et al., 2013, 2012; Furnes & Samuelsson, 2011; Georgiou et al., 2012). Whereas the relation between reading and phonological awareness is interactive, the RAN reading relationship has mostly been found to be unidirectional: Longitudinal studies with cross-lagged designs across several assessment points have found consistent prediction of RAN for later assessments of reading, while prediction from reading to RAN is exceptional (Landerl et al., 2019; Lervåg & Hulme, 2009). Peterson et al. (2017) recently reported for their cross-linguistic analysis of reading development in English versus Scandinavian orthographies that a measure of print knowledge (including letter knowledge) at the age of about five years predicted RAN one and a half years later in kindergarten, above and beyond RAN at the first assessment. Note that the pre-kindergarten RAN assessment was based on color and object naming, while in kindergarten, color-, letter-, and digit-RAN were used. Especially early letter naming speed is likely to be influenced by familiarity with letters as measured in the early print knowledge construct. In line with this interpretation, Clayton, West, Sears, Hulme, and Lervåg (2020) observed a negative prediction of early reading skills for later RAN digits performance. The authors suggested that children with the weakest reading skills in preschool may also have had insecure knowledge of digit names and strengthening that knowledge resulted in faster growth in RAN compared to better initial readers.

In summary, RAN appears to be a universal and unidirectional precursor of reading, with at the most minor differences between orthographies. It most likely indicates the speed with which an individual can automatically and efficiently access the verbal units represented by sequences of visual symbols, a skill that is needed in all orthographies.

Conclusions and cross-language issues

The evidence reviewed in this paper confirms that graphic symbol knowledge, explicit understanding of phonological and morphological units and naming speed are concurrently and longitudinally associated with reading in all orthographies investigated. Most children develop graph knowledge and an understanding of the linguistic units that they represent in the context of learning to read, and not necessarily beforehand. Thus, the relations between these cognitive precursors and reading are interactive and reciprocal: In order to crack the code of their orthography, children need to acquire incremental knowledge of graphs and how they are mapping onto relevant linguistic units. Reading experience in turn triggers further developments in these precursor constructs. The relation with reading seems to be different for RAN, which predicts changes in reading skills, while it is not itself influenced by reading development beyond learning the named graphs in alphabetic RAN. Conceptually, RAN is not necessary to understand how an orthography represents its language. It indicates the efficiency with which visual-verbal associations can be built and retrieved.

Most of the evidence on cognitive precursors of reading are based on English and other alphabetic orthographies (Share, 2008, 2014) and we are only starting to understand differences in the interplay of these precursors among each other and with reading. It appears that learning of graphic symbols is unduly simple in Western alphabets and the relative relevance of phonological versus morphological units seems to vary in relation to the linguistic structure of the particular language. The important

contribution of cross-linguistic studies is that design, constructs, and samples are deliberately parallelized as much as possible. A major issue in cross-linguistic studies is the extent to which tasks designed in different languages tap similar cognitive processes and represent similar levels of difficulty (i.e. no ceiling or floor effects in one, but not the other language).

A methodological approach that has so far not been exploited in this research domain is computational modeling. This approach allows for testing specific hypotheses with tight control of assessed constructs. Specific parameters that are typically confounded in real world languages (like morphological structure and word length or the priority of phonological versus morphological level in word spellings) could be systematically varied and the impact on subcomponents of written language processing (e.g., decoding, reading fluency, comprehension) could be investigated. Obviously, this approach would also nicely control for confounding influences of cultural differences in (pre)school education or home literacy practices.

To date, cross-linguistic studies are dominantly carried out in the context of Western alphabetic orthographies. Even if non-Western writing systems such as Arabic or Chinese are the subject of investigation, the research often attempts to confirm the validity of precursors of reading identified for English. It will be important to identify cognitive skills that may be more relevant in languages other than English. One reason why research is often limited to phonology and RAN is perhaps that these tasks are easier to match across orthographies than other constructs involving morphological or orthographic processing, which may be realized by very distinct parameters in different languages. In sum, research on the world language of English and its complex orthography has made tremendous contributions to our understanding of reading and its development, but it has also confined our view to characteristics that may be more relevant in English than in other orthographies (Share, 2008, 2014).

An important contribution of research across orthographies is that it explicitly tests the limits of reading theories that were developed for Western alphabets based on empirical evidence from other orthographies, which so far have received less attention. In the future, it will also be promising to devise alternative models that might better explain reading in other orthographies. We expect that such models will also change our perspective of learning to read in alphabetic orthographies and will lead to new and exciting research questions. Reading development depends not only on the cognitive profile of children and their socio-cultural background, but also on the characteristics of the writing system. Continuing research efforts on reading development in different orthographies will be crucial to improving our understanding of the mechanisms underlying reading and its development.

Disclosure statement

All studies summarized in this review paper conform to recognized ethics standards, as for example: Declaration of Helsinki or US Federal Policy for the Protection of Human Subjects. Participants of the reviewed studies (or their legal guardians) gave their informed consent and children gave their assent prior to their inclusion in the study. No potential conflict of interest was reported by the author(s).

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