Cognitive mechanisms underlying reading and spelling development in five European orthographies

Kristina Moll,[1,2,3] Franck Ramus,[4] Jürgen Bartling,[5] Jennifer Bruder,[5] Sarah Kunze,[5] Nina Neuhoff,[5] Silke Streiftau,[5] Heikki Lyytinen,[6,7] Paavo H. T. Leppänen,[6,7] Kaisa Lohvansuu,[6,7] Dénes Tóth,[8] Ferenc Honbolygó,[8] Valéria Csépe,[8] Caroline Bogliotti,[4,9] Stéphanie Iannuzzi,[10,11,12] Jean-François Démonet,[11,13] Emilie Longeras,[4,14,15] Sylviane Valdois,[14,15] Florence George,[16] Isabelle Soares-Boucaud,[17,18] Marie-France Le Heuzey [19], Catherine Billard [12], Michael O'Donovan,[20] Gary Hill,[20] Julie Williams,[20] Daniel Brandeis,[21,22,23,24] Urs Maurer,[21,24,25,26] Enrico Schulz,[21,24,27] Sanne van der Mark,[24,28] Bertram Müller-Myhsok,[29,30] Gerd Schulte-Körne,[5] & Karin Landerl,[1,2]

[1] Department of Psychology, University of Salzburg, Austria; [2] Department of Psychology, University of Graz, Austria; [3] Department of Psychology, University of York, York, UK; [4] Laboratoire de Sciences Cognitives et Psycholinguistique, Ecole Normale Supérieure, CNRS, EHESS, Paris, France; [5] Department of Child and Adolescent Psychiatry and Psychotherapy, University Hospital Munich, Munich, Germany; [6] Department of Psychology, University of Jyväskylä, Finland; [7] Agora Center, University of Jyväskylä, Finland; [8] Institute for Psychology, Hungarian Academy of Sciences; [9] Université Paris Ouest Nanterre la Défense, MODYCO , CNRS; [10] Unité de Neurologie Pédiatrique, Hôpital des Enfants, Toulouse, France ; [11] Inserm U825, Hôpital Purpan, Toulouse, France; [12] Centre de Référence sur les Troubles des Apprentissages, Hôpital Bicêtre, APHP, Paris, France ; [13] Leenards Memory Center, Centre Hospitalier Universitaire Vaudois, Université de Lausanne; [14] Laboratoire de Psychologie et NeuroCognition UMR 5105 CNRS, Université Pierre Mendès France, Grenoble, France; [15] Centre référent pour le diagnostic des troubles du langage et des apprentissages, Département de pédiatrie, CHU Nord, Grenoble, France ; [16] Centre de Référence des Troubles d'apprentissages, CHU Timone, Marseille, France ; [17] Centre de Référence pour les Troubles des Apprentissages, Hospices Civils de Lyon, Hôpital E. Herriot, Lyon, France ; [18] Centre Hospitalier Le Vinatier, Bron, France; [19] Service de Psychopathologie de l´enfant et de l´adolescent, Hôpital Robert Debré, APHP, Paris, France ; [20] MRC Centre for Neuropsychiatric Genetics and Genomics, Department of Psychological Medicine and Neurology, Cardiff University, Cardiff, UK; [21] Department of Child and Adolescent Psychiatry, University of Zürich, Zürich, Switzerland; [22] Center for Integrative Human Physiology, University of Zürich, Zürich, Switzerland; [23] Department of Child and Adolescent Psychiatry and Psychotherapy, Central Institute of Mental Health, Medical Faculty Mannheim/Heidelberg University, Mannheim, Germany; [24] Neuroscience Center Zurich, University of Zurich and ETH Zurich, Switzerland; [25]Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University, New York, USA; [26] Institute of Psychology, University of Zürich, Zürich, Switzerland; [27] Department of Neurology, Technische Universität München, München, Germany; [28] MR-Center, University Children's Hospital, University of Zürich, Zürich, Switzerland; [29] Max Planck Institute of Psychiatry, Munich, Germany, [30] Munich Cluster for Systems Neurology (SyNergy), Munich, Germany

Address for Correspondence

Kristina Moll, Department of Psychology, University of Graz, Strassoldogasse 10, 8010 Graz, Austria, Tel.: +43 316 380 8480. Email: kristina.moll@gmail.com

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Abstract

This paper addresses the question whether the cognitive underpinnings of reading and spelling are universal or whether there are language/orthography-specific differences. We analysed concurrent predictions of phonological processing (awareness and memory) and rapid automatized naming (RAN) for literacy development in a large (*N* = 1062) European sample of typically developing elementary school children beyond Grade 2 acquiring five different alphabetic orthographies with varying degrees of grapheme-phoneme consistency (English, French, German, Hungarian, Finnish). Findings indicate that (1) phonological processing and RAN constitute two separate factors which both account for significant amounts of unique variance in literacy attainment in all five orthographies. Associations of these proximal predictor measures with reading speed, reading accuracy, and spelling are differential: in general, RAN was the best predictor of reading speed while phonological processing accounted for higher amounts of unique variance in reading accuracy and spelling; (2) the predictive patterns were largely comparable across orthographies, with two exceptions: first the overall predictive power of the cognitive skills on literacy measures was higher in English than in more consistent orthographies and secondly, RAN tended to account for more variance in reading accuracy and spelling in English than in all other orthographies.

Key Words: reading development, cross-linguistic, orthographic consistency, phonological awareness, rapid automatized naming

Cognitive mechanisms underlying reading and spelling development in five European orthographies

1. INTRODUCTION

Recently, considerable research interest has been generated by the question whether the cognitive underpinnings of reading acquisition vary between orthographies or whether they are largely similar. All known orthographic systems represent language, however, there is a large degree of variance in the consistency of the mapping between spoken and written language and consequently in the transparency of these mappings for the young learner. The main principle of all alphabetic orthographies that are used in the Western world is that graphic symbols (letters) represent the sound structure of the spoken word. However, few orthographies closely adhere to this alphabetic principle of simple 1:1 relationships between letters and phonemes (like Finnish), while most alphabets provide the reader with a certain degree of inconsistency or irregularity. The English orthographic system with its many complexities is probably on the most extreme end of this continuum of orthographic consistency. Both, theoretical conceptions (Katz & Frost, 1992; Ziegler & Goswami, 2005) and empirical evidence (see Landerl, 2005 for a review) indicate that the development of decoding skills (i.e., the systematic translation of graphemes into phonemes) takes considerably longer in English than in more consistent orthographies. Thus, the complicated and opaque mapping system of English orthography seems to cause particular problems to the young learner. It is probably no coincidence that the investigation of reading acquisition in English strongly dominates the research field. However, the question then arises, whether the outlier status of English orthographic complexity is reflected in the cognitive mechanisms underpinning the reading process which would seriously limit the relevance of such an “Anglocentric view” (Share, 2008) for other orthographies. This issue is not only of high theoretical interest but has important implications for reading instruction as the relevant cognitive predictors are used to identify children who are at risk for reading failure.

1.1. Cognitive predictors of literacy skills

Two cognitive skills that are closely associated with the complex process of reading and spelling acquisition are phonological processing and rapid automatized naming (RAN). Phonological processing refers to the ability to perceive, store and manipulate speech sounds and includes phonological awareness and phonological working memory. In a typical phonological awareness task, a child might be asked to delete a certain sound from a word or nonword pronunciation (e.g., “Say /gulst/ without the /l/”). The child then has to maintain the sound sequence in working memory, identify the /l/-sound in the phoneme string, delete it from the pronunciation, and blend the remaining sound parts. Thus, it is obvious that although such tasks are taken to measure phonological awareness, they usually also require working memory capacity. Phonological awareness enables the child to understand and systematically exploit the mappings between graphic symbols and the sound structure of spoken language. It is crucial whenever the graphemes of words or nonwords are decoded during reading and also when words are segmented into their constituent phonemes during spelling. Thus, phonological awareness plays an important role during early literacy development across alphabetic orthographies (e.g., Byrne, 1998; Wagner & Torgesen, 1987), however, in consistent orthographies competent grapheme-phoneme and phoneme-grapheme translation is typically achieved earlier than in inconsistent orthographies like English (e.g., Seymore, Aro, & Erskine, 2003). Beyond these early phases of literacy development, phonological awareness is supposed to exert its influence on building-up word-specific representations (Ehri, 1992; Perfetti, 1992). According to this theoretical view, an efficient storage of orthographic patterns depends on multiple associations between phonological segments of a spoken word and the corresponding graphemes of its written form. Word specific orthographic representations enable direct word recognition during reading and correct orthographic spelling. Once again, the degree of consistency of grapheme- as well as phoneme-grapheme correspondences can be assumed to play an important role. Coping with the many irregularities and inconsistencies inherent in the English orthographic system may particularly challenge the phonological system of the learner. This would imply that the relevance of phonological processing skills should be lower in consistent than in less consistent orthographies.

Rapid automatized naming (RAN) refers to the speed with which an individual can pronounce the names of a sequentially and repeatedly presented limited set of stimuli like letters, Arabic digits, colour patches, or pictures of familiar objects. Performing RAN-tasks certainly requires phonological skills (accessing the phonological output programs of the required word pronunciations as quickly as possible) and is therefore sometimes seen as a third subcomponent of phonological processing (Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vaessen, Gerretsen, & Blomert, 2009). However, there is now ample evidence that “naming speed is phonological, but not only phonological” (Kirby, Georgiou, Martinussen, & Parrila, 2010, p. 356) and constitutes a second cognitive mechanism underpinning reading development that is largely independent from phonological awareness and memory. First, the correlation between phonological awareness and RAN is typically only low to moderate (.38 in a meta-analysis of 35 studies that were almost exclusively carried out in English; Swanson, Trainin, Necoechea, & Hammill, 2003). Second, although phonological awareness and RAN contribute some amount of shared variance, both components have consistently been shown to make unique contributions to the variance of literacy skills above and beyond the other one. Third and most importantly, these unique contributions seem to be differential: phonological awareness and RAN have been demonstrated to show specific relationships with particular subcomponents of literacy processing. While phonological skills seem to be most strongly related to literacy skills that involve decoding (most importantly nonword reading accuracy), RAN has been found to be most strongly related to the fluency with which different types of reading material (words, nonwords, texts) can be read (Kirby et al., 2010; Swanson et al., 2003).

Although the relationship between RAN and reading is a consistent finding, the mechanisms underlying this association are under debate (see Kirby et al., 2010 for a current review). One theoretical explanation for the RAN-reading relationship, that is currently discussed, is that RAN is a reflection of orthographic processing (Bowers, Golden, Kennedy, & Young, 1994; Bowers & Newby-Clark, 2002; Conrad, & Levy, 2007; Manis, Seidenberg, & Doi, 1999). According to this view, the build-up of an efficient orthographic lexicon depends on the precise integration of visual information about letter sequences in words. When letter identification is slowed down as indexed by poor RAN, representations of orthographic patterns (i.e., whole words) cannot be reliably stored. Following this argument, RAN should be particularly strongly related to orthographic spelling and should be a better predictor of word than of nonword reading as orthographic processes are of relatively low relevance in nonword reading. However, previous studies did not consistently confirm this pattern (e.g., Moll, Fussenegger, Willburger, & Landerl, 2009). Two other explanations for the RAN-literacy relationship that have been put forward are that RAN indicates the efficiency of visual-verbal integration processes (e.g., Moll et al., 2009) or that RAN captures variance in phonological lexical retrieval (Decker, Roberts, & Englund, 2013). Integration of visual and verbal information is relevant in order to fluently read any reading material, including nonwords, which is more in line with the available evidence (Kirby et al., 2010). Predictions of the latter two explanations (fast/efficient mapping and lexical retrieval) for orthographic spelling are less clear, but both accounts predict some contribution of RAN to spelling: First, visual-verbal integration is likely to support the storage of orthographic patterns based on multiple associations between sounds and letters. Secondly, correlations between orthographic and phonological lexical retrieval may explain the RAN-spelling relationship. However, both accounts predict a more important role of RAN during fluent reading than during spelling processes.

It has been suggested that RAN may be a better predictor of reading development in consistent than in inconsistent orthographies (de Jong & van der Leij, 1999; Di Filippo et al., 2005; Georgiou, Parrila, & Papadopoulos, 2008; Landerl & Wimmer, 2000; Mann & Wimmer, 2002; Mayringer et al., 1998; van den Bos et al., 2002). However, this may mostly be due to the fact that reading attainment is usually measured in terms of reading speed in consistent orthographies as accuracy levels are generally high and do not sufficiently differentiate between good and poor readers. Once the same literacy components are considered in orthographies with different degrees of consistency, it is conceivable that the many complexities of the English orthography place higher demands on the cognitive components that are assumed to be measured by RAN than more consistent orthographies. In English, the learner needs to hold a number of letter-sound or sound-letter correspondences active during reading and spelling while in more consistent orthographies the number of orthographic patterns or visual-verbal associations is clearly lower.

1.2. Cross-linguistic studies

Due to the inclusion of different measures it is often problematic to compare findings across studies carried out in different orthographies. A number of studies have attempted to tackle this problem by investigating the cognitive underpinnings of reading development in two or more orthographies within the very same research design. As differences in the predictive patterns are presumably most prominent in the early phases of literacy development, the majority of these cross-linguistic studies examined the cognitive predictors of reading in the first or second school year.

In these early phases of reading development phonological awareness was consistently found to be a reliable concurrent (Caravolas, Volin, & Hulme, 2005; Georgiou et al., 2008; Vaessen et al., 2010; Ziegler et al., 2010) and longitudinal (Caravolas et al., 2012; Furnes & Samuelsson, 2011) predictor of reading skills (accuracy and speed) across different orthographies. However, findings are mixed with respect to the *relative* importance of phoneme awareness as a function of orthographic consistency. While some studies showed that the impact of phonological awareness on reading is stronger in less than in more consistent orthographies (Mann & Wimmer; 2002; Vaessen et al., 2010; Ziegler et al., 2010), others reported an equally strong prediction of phonological awareness in English and in more transparent orthographies (Caravolas et al., 2005, 2012). Differences between orthographies have also been suggested with respect to the impact of phonological awareness on reading over time. It has been argued that in more consistent orthographies the predictive strength of phonological awareness decreases after about one year of reading instruction (Furnes & Samuelsson, 2011; Georgiou et al., 2008; Vaessen et al., 2010), because decoding skills are then already sufficiently acquired. In inconsistent orthographies phonological awareness remains a strong predictor beyond Grade 1, reflecting the fact that the development of decoding skills takes longer in inconsistent compared to consistent orthographies.

Cross-linguistic findings on the predictive pattern of RAN in the early phases of reading development are mixed: Some studies reported that RAN predicts reading in consistent as well as inconsistent orthographies (Caravolas et al., 2012; Furnes & Samuelsson, 2011; Georgiou et al., 2008; Vaessen et al, 2010). In contrast, others found associations between RAN and reading at this age only in consistent orthographies (Mann & Wimmer, 2002) or reported generally weak associations between RAN and reading across orthographies (Ziegler et al., 2010). A plausible explanation for these mixed findings is that RAN has been shown to be specifically linked to fluent word and text reading (see Kirby et al., 2010 for review). Reading fluency is usually assessed by list or text reading paradigms. Especially during the early phases of reading development, such paradigms are of limited validity if young readers´ reading fluency is constrained by problems to read the presented stimuli accurately. Indeed, Vaessen et al (2010) reported an increase of the impact of RAN on reading fluency between Grades 1 and 4. Due to the relatively low reading accuracy, assessing reading fluency in young readers is especially problematic in inconsistent orthographies. This might explain why during the early phases of literacy development RAN was found to be a better predictor in consistent than in inconsistent orthographies.

Only a few studies included spelling as a criterion measure and findings indicate that both phonological awareness and RAN predict spelling skills in consistent as well as inconsistent orthographies (Caravolas et al., 2005, 2012; Furnes & Samuelsson, 2011). However, findings are again mixed with respect to the relative importance of RAN and phonological awareness for reading in comparison to spelling skills. While Furnes and Samuelsson (2011) could confirm a differential prediction with RAN being a stronger predictor for reading and phonological awareness being a stronger predictor for spelling, the predictive patterns of these cognitive measures were similar for reading and spelling in the Caravolas et al. study (2012). Up to date, evidence on cross-linguistic differences in the cognitive underpinnings of spelling development is limited to the first two years of formal instruction and studies comparing the predictors of orthographic spelling between orthographies beyond Grade 2 are lacking. On the one hand, larger differences than for reading development could be expected as the correct reproduction of word spellings probably requires a thorough understanding of the function of orthographic markers that are specific to a particular writing system. On the other hand, most alphabetic orthographies are characterised by a good deal of inconsistency in phoneme-grapheme correspondences. In order to spell a word correctly, word specific knowledge is indispensable. Therefore, the spelling process may be more similar across orthographies than the reading process and as a consequence, cognitive underpinnings should be comparable as well.

In summary, during the early phases of literacy development phonological awareness and RAN have been found to predict reading and spelling in a variety of orthographies in cross-sectional as well as longitudinal designs that assessed phonological awareness and RAN before the onset of formal reading instruction. Importantly, Caravolas et al. (2012) showed that the predictive pattern even holds when controlling for the autoregressor (reading or spelling) at the beginning of Grade 1, indicating that phonological awareness and RAN predict growth in reading and spelling. However, findings are mixed with respect to the relative importance of predictors as a function of orthographic consistency and with respect to the relative importance of predictors for reading compared to spelling skills. Phonological memory was assessed in most cross-linguistic studies, but was generally reported to play a rather minor role.

While individual differences in reading accuracy and phonological spelling are probably most prominent in these early years, differences in reading fluency and orthographic spelling dominate later developmental phases when the first hurdles of cracking the alphabetic code are already mastered. To this date, only three cross-linguistic studies have investigated the cognitive underpinnings of reading beyond Grade 2: Patel, Snowling, and de Jong (2004) compared reading skills in 67 English and 40 Dutch speaking children aged 6 to 11 and found a similar pattern for the two orthographies: phonological awareness was a significant predictor in both languages, while RAN did not enter the regression model as a significant predictor. The uncommon finding that RAN did not even predict reading speed may be due to the relatively large age range in association with a relatively small sample size and to the fact that the timed phonological awareness measure included speed variance otherwise picked up by RAN. Vaessen et al., 2010 investigated concurrent predictions of reading fluency cross-sectionally for Grades 1 to 4 and found that the impact of RAN increases with grade level, while the impact of phonological awareness was limited to the lower grades and was weaker in consistent orthographies (esp. Hungarian) than in the more inconsistent ones (French and Portuguese). None of the two studies examined the cognitive underpinnings of orthographic spelling. Finally, in a large European study of developmental dyslexia overlapping with the present one (NEURODYS), the prediction of dyslexia status by phonological awareness and RAN was found to increase with orthographic complexity (Landerl et al., 2012). Phonological memory played a comparatively minor role in the prediction of dyslexia status.

1.3. Aims of the present study

The first analysis of the NEURODYS-sample (Landerl et al., 2012) was limited to rather coarse-grained comparisons of dyslexic vs. typically developing readers in alphabetic European orthographies grouped into three levels of orthographic complexity. In the current paper, we aimed to extend the analysis of the large European NEURODYS sample by providing a more fine-grained analysis of the concurrent predictive mechanisms underlying different literacy components (reading speed, reading accuracy, and spelling) in typically developing readers acquiring five orthographies varying in consistency (English, French, German, Hungarian, and Finnish).

The following research questions will be investigated:

RQ 1: To what extent do phonological processing (phonological awareness and memory) and RAN differentially influence different measures of literacy (reading speed, reading accuracy, and orthographic spelling) beyond Grade 2?

H1.1: Based on previous findings we hypothesize that phonological awareness and RAN constitute two separate factors that independently predict different literacy skills across orthographies.

H1.2: We assume that the predictive patterns for the three literacy measures are differential with RAN being the strongest predictor of reading speed, and phonological processing (i.e. phonological awareness) being the best predictor of reading accuracy. For orthographic spelling predictions are less clear: Phonological awareness should be a strong predictor of orthographic spelling, given its role in building-up orthographic representations. The association between RAN and orthographic spelling should be especially strong if RAN reflects orthographic processing. In contrast, if RAN captures visual-verbal integration or lexical retrieval, it should be less important for spelling than for fluent reading.

RQ2: To what extent does the *absolute* influence of phonological processing and RAN on each literacy measure vary with orthographic complexity beyond Grade 2?

H2.1: We predict that because of the generally higher demands that inconsistent orthographies place on the cognitive processes of the learner, the total amount of variance explained by phonological processing and RAN is higher in inconsistent than in consistent orthographies.

RQ3: To what extent is the *relative* influence (irrespective of the total amount of variance explained) of phonological processing and RAN on each literacy measure determined by orthographic complexity? As the majority of findings in this field are based on English speaking samples, it is of special importance to identify any differences between English and the more consistent orthographies.

H3.1: We assume that the relative predictive pattern is similar across orthographies once the same literacy measures are compared.

2. METHOD

2.1. Rationale

Large-scale cross-linguistic comparisons have to deal with particular methodological problems. First, quantifying the differences between orthographies is extremely difficult and all available attempts have serious methodological limitations (see Protopapas & Vlahou, 2009 for a critical discussion). Although, there is notable agreement on where to place particular writing systems on a continuum of orthographic complexity (e.g., Borgwaldt et al., 2005; Caravolas, 2005; Seymour et al. 2003) the adequate levels of description and their quantification are still under discussion. For instance, Borgwaldt's entropy measure is based on word onsets only and is therefore missing most of the irregularities in many languages. In the current project, we decided to use a more conservative classification by ranking the five orthographies according to their consistency of mappings between graphemes and phonemes (feedforward consistency) and between phonemes and graphemes (feedback consistency).

The five orthographies covered the full continuum of orthographic consistency. The highly complex orthography of English is on the one end of the continuum as it is characterised by high levels of inconsistency in both, the reading and spelling direction[1]. Similar to English, French has complex relationships between phonemes and graphemes (spelling direction), but is in general more rule-based; in the reading direction French vowels are more consistent than English vowels For example, Ziegler, Jacobs, and Stone (1996) reported that 79% of monosyllabic French words are feedback inconsistent, while only 12% are feedforward inconsistent. German has highly consistent grapheme-phoneme correspondences, but less consistent phoneme-grapheme correspondences and represented a medium level of orthographic complexity. Hungarian and Finnish comprised the lowest level of orthographic complexity as both languages are characterised by highly consistent relationships between letters and sounds in both, reading and spelling direction. Especially Finnish represents the extreme other end of orthographic complexity as in addition to simple 1:1 relationships between phonemes and graphemes multi-letter graphemes do not exist and consonant clusters are highly exceptional. Note that our ranking order (English, French, German, Hungarian, and Finnish) is fully consistent with the complexity sequences provided by Seymour et al. (2003), based on reading accuracy at the end of Grade 1, and Borgwaldt et al. (2005) based on word-initial letter-to-phoneme mappings.

Another methodological issue concerns the selection of adequate tasks to measure the relevant cognitive and literacy constructs. Compatibility across languages was relatively easy to achieve for verbal and nonverbal IQ and for phonological memory, as standardized versions of the relevant WISC subtests were available in each language. Naming speed was measured by language specific RAN paradigms requiring children to name as quickly as possible lists of single digits and highly familiar pictured objects that correspond to short, high frequency nouns (e.g., dog, car, fish). Thus, although different stimuli were used across languages, task format and selection criteria for the words that had to be named were matched.

With respect to phonological awareness we followed the example of earlier cross-linguistic studies (Caravolas et al., 2005; Vaessen et al., 2010; Ziegler et al., 2010) and administered phoneme deletion, thus ensuring reasonable comparability of findings across studies. Phoneme deletion is a standard paradigm which is sufficiently difficult in order to pick up individual differences in higher grades and in samples acquiring consistent orthographies. As the five languages involved differ largely in their linguistic structure, devising one task with exactly the same items for all participants was not viable. Specifying the linguistic structure of presented items across languages might have induced higher typicality in some languages than others (e.g., consonant clusters are atypical in Finnish but very frequent in German, whereas polysyllabic words are frequent in Finnish but less typical in English). Thus, it was decided to leave the language-specific characteristics to individual partners who were advised to select items with typical linguistic structure and to ask children to delete a specified phoneme (e.g., “Say /gulst/ without /l/”).

All partners measured word and nonword reading accuracy as well as speed with language-specific standardized reading tests. Reading speed could be reliably assessed as children had at least two years of reading instruction in the more consistent orthographies (Finnish, Hungarian, and German) and three years in the less consistent orthographies (French and English). Reading accuracy was assessed under speeded conditions in order to avoid error rates at ceiling for consistent orthographies.

In summary, the main advantage of the current joint European research effort is that data collection was parallelized as much as possible across orthographies and that the same constructs were assessed by all partners, so that a major problem of earlier research carried out on the cognitive underpinnings of literacy development could be overcome, namely, the low compatibility of findings from different studies.

2.2. Participants[2]

Participants were native speakers of five different languages and came from seven European countries (English: UK; French: France; German: Germany, Austria, Switzerland; Hungarian: Hungary; Finnish: Finland) Data came from the EU-NEURODYS-study which comprises large samples of dyslexic and typically developing elementary school children across the European Union. The current analysis is mostly regression based and treating two different reading level groups as a homogeneous sample seemed methodologically problematic. It would also have artificially increased the variances within each national sample as the lower end of the distribution of reading skills is clearly overrepresented in the full NEURODYS sample. Thus, it was decided to base the current analysis on the national samples of typically developing readers which were selected by each partner lab based on a standardized language-specific test of word recognition (**Table A1**) with the limitation that performance should not be more than one standard deviation below the age or grade level norm. We are aware that this procedure somewhat reduces the variance of reading skills in our sample and that findings are mostly informative with respect to typical reading, which we consider an interesting perspective with respect to the question of cognitive mechanisms underlying different literacy components across orthographies.

Written informed consent was obtained from parents before testing. Children in less consistent orthographies were slightly older which accounts for the fact that literacy development takes longer in less consistent compared to consistent orthographies (e.g., Seymour et al., 2003) and to ensure that fluent reading and orthographic spelling can be reliably assessed. Data for all relevant measures were available for 1062 children ranging from Grade 2 to Grade 5 for the three consistent orthographies (Finnish, Hungarian and German) and from Grade 3 to Grade 7 for the less consistent orthographies (French and English). The number of children by grade for each country is listed in the Appendix (**Table A2**).

2.3. Tasks

2.3.1. Word and Nonword Reading. In each country reading accuracy and speed for words and nonwords were assessed by presenting language specific material under a speeded instruction ("Read as quickly as possible without making mistakes"). The relevant measures were the total number of items read per minute (reading speed) and the percentage of items read correctly based on the total number of items read (reading accuracy). Grade specific *z*-scores for word and nonword reading speed and accuracy were calculated based on national norms.

2.3.2. Spelling. Language-specific standardized spelling tests were given by each partner. All tests required to spell single words dictated in sentence frames. Grade specific *z*-scores for the percentage of words spelled correctly were calculated based on language-specific norms.

2.3.3. IQ. Verbal and nonverbal IQ were estimated based on the subtests 'Similarities' and 'Block Design' from the Wechsler Intelligence Scale for Children (WISC III-R or IV, depending on availability in each country; Wechsler, 1992, 2003).

2.3.4. Phonological short-term and working memory. WISC digit span (forward and backwards) were given by each partner (Wechsler, 1992, 2003). Scaled scores (M = 10, SD = 3) were calculated based on national norms.

2.3.5. Phonological awareness (PA). In each country, a phoneme deletion task was administered requiring the child to pronounce a sound sequence after deleting a specified sound (e.g. say "/gulst/ without /l/"). Language specific tasks were constructed with comparable difficulty levels in consistent and inconsistent orthographies (see Table 1).

2.3.6. Rapid automatized naming (RAN). Two RAN tasks (digit and picture naming) were administered. Children were asked to name as quickly and accurately as possible a matrix of digits and pictures of simple objects, respectively. The relevant measure was the time to name the lists. Correlations between the two RAN tasks were moderate to high and the component analysis (2.5) revealed that both RAN tasks loaded highly on the same factor. Therefore, a composite RAN score was used for all further analyses.

2.4. Calculation of z-scores

For all variables but the word reading inclusion variable and the WISC subtests (which were already on a standardised scale), raw scores were converted into *z*-scores within each country and each grade level. As expected, some variables in some countries had highly skewed distributions (i.e., reading accuracy in consistent orthographies), thus we further applied the following procedure: Each variable in each country was converted into ranks, then rescaled on a 0-100 interval, then applied the normal distribution function to convert them into grade-specific *z*-scores. This procedure reduced the skew of distributions and made them more comparable between measures and between countries (Landerl et al., 2012).

2.5. Component analysis

Two principal component analyses (Varimax rotation with Kaiser Normalization) were carried out to reduce the number of five outcome measures and four predictor variables to a theoretically meaningful number of factors that could be included in the regression model. The first analysis included the five literacy attainment measures speed and accuracy for word and nonword reading as well as spelling performance. The results indicated a two component solution with clear loadings of word and nonword reading speed on the first component (speed factor: eigenvalue = 2.38; both factor loadings = .90), and word and nonword reading accuracy on the second component (accuracy factor: eigenvalue = 1.10; factor loadings = .76 and .80, respectively). Correlations revealed a notable association between word and nonword reading for all languages (.30 to .61 for accuracy and .46 to 79 for speed). These correlations were higher than the correlations between accuracy and speed within one item category, confirming the two component solution with a speed and an accuracy factor.

The spelling measure loaded higher on the accuracy component than on the speed component (.64 versus .40), but the loadings were not as clear-cut as for the reading measures. Therefore, we decided to analyse spelling separately, resulting in the following three outcome measures: reading speed (composite mean *z*-score for word and nonword reading speed), reading accuracy (composite mean *z*-score for word and nonword reading accuracy), and spelling.

The second analysis included the four predictor variables phonological awareness (phoneme deletion), phonological memory (digit span), RAN digits and RAN pictures. The results showed again a two component solution with phoneme deletion and digit span loading on the first component (phonology factor: eigenvalue = 1.13; factor loadings = .81 and .77, respectively), and the two RAN measures loading on the second component (RAN factor: eigenvalue = 1.64; factor loadings =.87 and .83, respectively). Correlations between the two RAN measures were moderate to high with .47 for the whole sample, ranging from .41 to .72 for the different languages. The correlations between the two phonological tasks were lower than for the two RAN measures (.28 for the whole sample, ranging from .09 to .44). As a consequence a composite score was calculated for the two RAN measures, whereas the two phonology measures were investigated separately in the following analyses.

3. RESULTS

3.1. Descriptives and Correlation Analyses by Language

The descriptive statistics for age, IQ, cognitive measures and literacy skills are presented in **Table 1**. The results show that performance in all measures is similar across languages.

Insert Table 1 about here

Table 2 presents the simple correlations (based on grade-specific scores) between all predictor and literacy measures separately for each language. Reading speed showed higher associations with RAN than with the two phonological measures in all orthographies apart from Finnish where the associations with the three predictor components were roughly equal. For reading accuracy however, the correlations were highest for phonological awareness followed by phonological memory and were not significant for RAN. The only exception was the English sample where RAN correlated moderately with reading accuracy. A similar pattern was observed for spelling with higher correlations for phonological awareness and memory than for RAN. Again, the English sample showed different associations between the predictor variables and spelling with comparable correlations for the three predictors.

Insert Table 2 about here

3.2. Prediction of literacy skills separately for each language

The concurrent predictions of phonological processing (memory and awareness) and RAN[3] with the three dependent literacy measures (reading speed, reading accuracy, and spelling) were examined separately for each language in a series of stepwise regression analyses. In all analyses step 1 controlled for differences in age and IQ (verbal and nonverbal). In Step 2 the three theoretically interesting proximal factors (phonological memory, phonological awareness and RAN) were entered simultaneously. For each factor we calculated the percentage of variance in the dependent variable explained by a specific predictor variable, above and beyond the other predictors. These regression analyses allowed investigating whether the predictive patterns for the three literacy measures are differential (question 1) and to assess the absolute influence of predictors on each literacy measure separately for each language (question 2).

All regression models reported in this section were calculated for a composite RAN score as well as separately for RAN digits and RAN pictures. In general, the predictive pattern for both RAN measures was similar to the pattern reported for the composite RAN score, therefore, only the models for the composite score will be reported.

3.2.1. Reading speed

Table 3 shows an impressively consistent pattern of prediction of reading speed across languages. RAN explained clearly higher amounts of unique variance in reading speed than the two phonological predictor measures in English, French, German, and Hungarian (16.7 to 22.8%). Only in Finnish the contribution of all proximal factors was largely equal and low compared to the other orthographies (4.3 and 3.1% for phonological measures and 3.5% for

RAN). Phonological processing made unique but comparably small contributions to reading speed in English (phonological awareness and memory) and German (phonological awareness only), but explained hardly any unique variance in French and Hungarian.

Insert Table 3 about here

3.2.2. Reading accuracy

Table 4 shows that overall the proximal predictors phonological processing and RAN could account for higher amounts of variance in reading accuracy in English (39 %) than in all other orthographies (11.3 to 14.7%). The variance explained by phonological memory was comparably small (0.4 to 6.9 %) and not always significant. While RAN was found the best unique predictor of reading speed, phonological awareness accounted for more variance in reading accuracy (5.2 to 17.6 %). The only orthography in which RAN could account for a substantial amount of variance above and beyond phonological processing was English (14.2 %).

Insert Table 4 about here

3.2.3. Spelling

As it was found for reading accuracy, **Table 5** shows that the proximal predictors (phonological awareness, memory and RAN) accounted for clearly higher amounts of variance in English (34.7 %) than in all other orthographies (8.9 to 16.2 %). Phonological memory seems to be somewhat more important for spelling than for the reading measures, as it could account for significant amounts of variance in Finnish, French, and Hungarian. Phonological awareness accounted for significant amounts of variance in all orthographies (4.1 to 8.9%) apart from French (2.2 %). Interestingly, English was once again the only orthography where RAN could make a significant – and indeed the highest – contribution to variance in spelling.

Insert Table 5 about here

3.3. Prediction of literacy skills across orthographies

In order to identify any differences in the cognitive mechanisms associated with literacy skills between orthographies (question 3) we resorted to multi-level analyses using the R-package lme4 (lme4_0.999999-0: http://CRAN.R-project.org/package=lme4). We nested children within the variable language (model M1) and allowed for fixed (model M2) and both fixed and random effects (effectively allowing the predictor to vary by level of the nesting variable) for each of the three predictors (models M3). In addition IQ and age were included as covariates in each model. Thus, three models were specified for each predictor based on the whole sample of 1062 children. These models were run for the three dependent measures (reading speed, reading accuracy, and spelling).

To test the fixed effect we compared the likelihood ratio between models M1 and M2. The distributional property of the test statistic was verified using a sample of 10,000 permutations of the dependent measure for each of the nine predictor-literacy combinations. In each case the fit of the distribution was found to adhere very well to theoretical expectations, hence *p*-values derived on asymptotic theory are provided.

The test for heterogeneity between languages in the estimates (again by means of a likelihood ratio test, this time between models M2 and M3) showed severe deviation from the expected distribution of test statistics, again tested by means of a permutation of the nesting variable language. The test was very severely conservative; therefore we tested the heterogeneity of random effect estimates by means of permutations (n = 10,000 for each combination). The test statistic used was the sum of the Euclidean distances between the random effect estimates for each of the languages. In those cases where the test for heterogeneity of the random effect estimates for a predictor reached significance, pair-wise comparisons between the languages were tested to identify the source of the heterogeneity, again using the permutations performed. Estimates and confidence intervals from these analyses are provided in Tables 6 to 8, with estimates being obtained from model M3.

In sum, the results of the multilevel analyses support our third prediction, that the predictive pattern is to a great extent similar across orthographies once the same literacy skills are compared, with the following exceptions:

(1) For *reading speed,* phonological awareness showed some evidence for heterogeneity between languages ($p = .021$); however differences between consistent and inconsistent languages were not clear-cut which might to some extent reflect that the impact of phonological awareness for reading speed was generally low (3.2.1.).

(2) For *reading accuracy,* RAN showed clear evidence for heterogeneity between languages ($p = .008$), reflecting that RAN is more important in English than in the other languages. Pair-wise comparisons revealed that this difference was significant for all four languages.

(3) For *spelling,* there was a tendency for a higher contribution of RAN in the English sample compared to more consistent orthographies (see regression analysis separately for each language (3.2.3). However, this difference was not significant in the direct language comparison based on the multi-level analysis.

Insert Tables 6 to 8 about here

4. DISCUSSION

The current paper compares the associations of phonological processing (awareness and memory) and RAN with reading (speed and accuracy) and spelling in five alphabetic orthographies covering the full range of orthographic consistency. Obviously, the presented concurrent analyses do not allow strong conclusions on the directions of causality, nevertheless, the findings add to the cross-linguistic literature as this is the first analysis of cognitive mechanisms underlying reading as well as orthographic spelling beyond the initial stages of literacy development.

First, we asked to what extent phonological processing and RAN differentially influence different measures of literacy (RQ1). In line with our predictions (H1.1), our analyses indicate that phonological processing and RAN constitute two separate factors which both account for significant amounts of unique variance in literacy attainment in all five orthographies. In contrast to other studies (Kirby et al., 2010), we did not find a clear difference between alphanumeric and non-alphanumeric RAN (digits vs. pictures), both conditions showed similar predictive patterns. As we had predicted (H1.2), the associations of the predictor measures with reading speed, reading accuracy, and spelling were differential: In general, RAN was the best predictor of reading speed while phonological processing (phonological awareness and memory) accounted for higher amounts of unique variance in reading accuracy and spelling.

Next we asked to what extent the absolute (RQ2) and relative (RQ3) influence of phonological processing and RAN on each literacy measure varies with orthographic complexity. A central question was whether the outlier orthography of English (Share, 2008) behaves in any crucial aspects differently from more regular and consistent orthographies. Such an orthographic difference would seriously limit the generalizability of the rich English research literature to other orthographies. In summary, our findings confirm the assumption (H3.1) that the predictive pattern is similar across orthographies once the same literacy components are compared. English behaves like more consistent alphabetic orthographies to a large extent, but with two notable differences: (1) As assumed (H2.1) the overall predictive power of the cognitive skills of interest on literacy measures was higher in English (25-39%) than in more consistent orthographies (9-26%). (2) The association between RAN and reading accuracy as well as between RAN and spelling was negligible in more consistent orthographies (0-2%), whereas in English RAN turned out to be a significant predictor for reading accuracy and spelling (14 and 16 % respectively).

4.1 Predictive pattern for reading speed

The predictive pattern for reading speed was highly similar in consistent and less consistent alphabetic orthographies with RAN being a strong and consistent predictor in all five orthographies, a finding that is very much in line with Vaessen et al.´s (2010) recent cross-linguistic analysis of the cognitive mechanisms underpinning reading fluency in Portuguese, Dutch, and Hungarian. Interestingly, it was not English but Finnish, which is located on the extreme other end of the continuum of orthographic complexity that turned out to behave like an outlier orthography in the current study. Although the relative influence of RAN on reading speed did not differ between languages, the absolute contribution of RAN in explaining individual differences in reading fluency in the Finnish samplewas relatively small and not larger than that of the two phonological predictors. Ziegler et al. (2010) recently also found a relatively minor impact of RAN on Finnish children´s reading attainment, suggesting that in this highly transparent orthographic system reading skills may be more strongly dependent on other factors like reading experience than on RAN. This effect may be limited to typically developing readers as a number of earlier studies on Finnish including poor or dyslexic readers consistently reported RAN to be the strongest predictor of reading speed (Holopainen, Ahonen, & Lyytinen, , 2001; Lepola, Poskiparta, Laakkonen, & Niemi, 2005; Puolakanaho et al., 2007; Torppa, Lyytinen, Erskine, Eklund, & Lyytinen, 2010). One important conclusion that can be drawn based on the similarity of the predictive pattern for reading speed is that the consistent inclusion of reading speed measures in English studies is highly desirable and would help to increase the comparability of findings across orthographies.

4.2 Predictive pattern for reading accuracy

Currently, the central measure of reading attainment in English studies is usually reading accuracy, in especially number of items (words or nonwords) read correctly. This measure is not always useful in more consistent orthographies due to reduced variance in accuracy scores. In the current study, reading accuracy was measured under speeded conditions ("Read as fast as possible") which helped to induce reasonably distributed numbers of incorrect readings in all languages. As language specific tests were used and scores were *z*-

standardized separately for each subsample, a direct comparison of reading accuracy across orthographies is not feasible in the current design. Instead of analysing absolute performance scores, we compared the relative importance of predictors between languages. The overall variance in accuracy accounted for by phonological processing and RAN tended to be larger in English than in the other orthographies which may at least partly be due to the greater variance of the reading accuracy measure in the English sample. The most obvious difference, however, was that English was the only orthography where RAN could account for a significant amount of variance in reading accuracy above and beyond phonological processing.

4.3 Predictive pattern for spelling

This is the first study that investigated the cognitive underpinnings of spelling development in different orthographies beyond Grade 2. As predicted (H3.1), no significant interactions between predictors and orthographic structure were observed. However, as it was found for reading accuracy, the predictive pattern was only partly consistent across orthographies. Once again, a higher amount of variance could be explained in English than in the other orthographies (H2.1). Phonological processing was the better proximal predictor of spelling in all orthographies except English, where RAN accounted for more variance than phonological awareness. Within the two phonology measures, memory was somewhat more important for spelling than for reading speed and accuracy. This finding probably reflects that in most orthographies letter-sound correspondences are less consistent in the spelling than in the reading direction. As a consequence storing word specific knowledge in memory is crucial in order to produce orthographically correct spellings. However, in general this subcomponent played a rather minor role, a finding that is in line with most earlier studies (Caravolas et al., 2012; Vaessen et al., 2010; Ziegler et al., 2010).

In summary, the current large-scale analysis of the associations of phonological processing and RAN with reading and spelling in different alphabetic orthographies allows the conclusion that the commonalities of cognitive underpinnings of literacy development between these orthographies are obviously prevailing. Previous studies (e.g., Caravolas et al., 2012) reported similar predictive patterns across orthographies in the very early phases of literacy development. The current study complements these findings by showing that similarities between languages can also be observed later on in primary school. Still, there are also a number of fine-grained differences that warrant further investigation in more detailed research designs.

4.4 Educational implications

Our findings have a number of practical implications concerning the assessment of literacy skills:

(1) Literacy skills do not represent a single construct, as the underlying cognitive mechanisms vary depending on the literacy component (reading speed, reading accuracy, or spelling) that is assessed. Comprehensive assessment batteries need to differentiate between these literacy components.

(2) Most assessment batteries that include cognitive measures associated with literacy skills focus on phonological processing, whereas performance in RAN is not always assessed. While phonological processing is a reliable predictor of individual differences in spelling, it is a less useful predictor of reading skills, especially in more consistent orthographies where reading speed (not accuracy) is the relevant measure to differentiate between good and poor readers. Assessment tools should therefore include both, phonological processing and RAN, given that both cognitive skills are significant and unique predictors of literacy performance across orthographies.

(3) In line with a number of other studies (Landerl et al., 2012, Vaessen et al., 2010; Ziegler et al., 2010) our findings indicate that phonological processing and RAN are generally less powerful in explaining performance in reading and spelling in consistent (i.e. in Finnish) compared to inconsistent orthographies. This implies that children with low performance in

phonological processing or RAN have a better chance to develop adequate literacy skills in consistent than in inconsistent orthographies.

4.5 Limitations and implications for future research

The reader should be aware that although the integrated European research initiative NEURODYS enabled the systematic direct comparison of predictive patterns for an unprecedented number of alphabetic orthographies and literacy measures, there are certain methodological limitations that result from this approach. First, some measures required normalisation in order to allow the intended cross-linguistic comparisons. The predictive patterns reported here are based on rank ordered data and may therefore not be directly comparable with earlier studies based on raw or standard scores. Second, the samples sizes for the five languages differed considerably. The German sample was especially large due to the fact that three German speaking countries were involved in this European network. In comparison with the German sample the English and French samples were rather small, but still of reasonable size. In order to reduce the effect of sample size on the results, predictive patterns rather than absolute performances were compared between language groups.

It should also be noted that variance was reduced in the current analysis as the sample did not include children whose reading level was more than one standard deviation below the age norm. Differences in predictive patterns between orthographies might overall be larger across the whole range of literacy skills. The advantage of this approach, however, is that the current analysis is informative with respect to cognitive underpinnings of reading and spelling development in standard classrooms (see 4.4) and therefore goes beyond group comparisons between dyslexic and control readers. Note that Landerl et al.´s (2012) finding that based on phonological processing and RAN more participants were correctly classified as dyslexic or typical reader in complex than in less complex orthographies indicates that the predictive pattern reported here does extend to the whole range of reading skills.

Finally, the aim of the NEURODYS research initiative was to investigate concurrent predictions, and longitudinal patterns of prediction may differ. This may be less of a problem for the RAN-reading relationship which seems to be mostly unidirectional: RAN predicts growth in reading, while reading development does not seem to have a relevant impact on RAN performance (Lervåg & Hulme, 2009). For phonological memory, a recent analysis (Nation & Hulme, 2011) even suggests that it is reading development that drives improvement in nonword repetition while nonword repetition cannot predict growth in reading skills. The picture is most complex for phonological awareness which obviously develops in close interaction with the acquisition of an alphabetic orthography. The apparently largely consistent phonological awareness-literacy relationship that we found across orthographies may largely reflect this close interaction. Longitudinal studies in consistent orthographies repeatedly found that the prediction of preschool phonological awareness is mostly limited to the early stages of reading development (de Jong & van der Leij, 1999; Landerl & Wimmer, 2008). The longitudinal studies comparing the early prediction of phonological awareness and RAN in a consistent orthography with English corroborate this evidence (Furnes & Samuelsson, 2011; Georgiou et al., 2008; BUT see also Caravolas et al, 2012 for no differential pattern across orthographies in the first 10 months of literacy instruction). Further research applying more fine-grained research designs and following children beyond Grade 2 will be necessary to finally settle this question.

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Footnotes

[1] Note, that most alphabetic orthographies show an asymmetry in orthographic consistency with higher consistency in the reading direction (grapheme-phoneme correspondences) compared to the spelling direction (phoneme-grapheme correspondences). The only exception is Finnish which is highly consistent in both directions.

[2] The present dataset overlaps with the data reported by Landerl et al. (2012) (954 participants in common), which focused on predictors of dyslexia across groups of dyslexic and control children, but did not analyse literacy skills. There is a further overlap of 44 Hungarian participants with Ziegler et al (2010) and of 178 Hungarian children with Vaessen et al. (2010).

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Table 1

Gender ratios and Means (SD) for age, IQ, cognitive predictors and literacy skills for the five languages

	English	French	German	Hungarian	Finnish
N	60	86	473	195	248
Gender [% boys)	71.7	44.2	51.2	51.8	50.8
Age [months]	129.7 (17.1)	120.1 (12.3)	114.4 (10.8)	113.2 (10.0)	111.4 (6.4)
PIQ *	10.5 (2.4)	11.2 (2.4)	11.0 (2.6)	11.9 (2.6)	10.4 (2.6)
VIQ *	12.0 (2.9)	13.1 (2.8)	12.8 (2.8)	12.4 (2.8)	11.5 (3.4)
Digit span *	9.8 (3.7)	9.6 (2.7)	10.2 (2.5)	10.9 (2.5)	9.2 (2.6)
PA [% correct]	88.2 (10.8)	91.6 (11.7)	78.3 (16.4)	81.1 (15.2)	89.0 (14.1)
RAN composite [items/min.]	99.0 (21.1)	96.9 (17.9)	94.3 (17.9)	96.3 (14.3)	67.5 (12.7)
Reading speed [z-score]	-0.02 (0.86)	0.02 (0.91)	-0.03 (0.96)	-0.00 (0.95)	-0.16 (0.92)
Reading accuracy [% correct]	77.3 (13.8)	86.5 (9.8)	96.5 (3.9)	96.0 (3.7)	90.7 (9.3)
Spelling accuracy [% correct]	70.9 (15.3)	73.6 (20.2)	78.3 (16.4)	67.4 (17.4)	65.4 (21.8)

* standardized scaled score (Mean = 10, SD = 3)

Table 2

Correlations (based on grade specific z-scores) between predictor variables and outcome measures for the five languages

	READ Speed	READ Acc	SPELL	Digit-span	PA	RAN Digit	RAN picture	RAN comp
								ENGLISH
READ Speed		.298*	.185	.196	-.126	.370**	.378**	.426**
READ Acc	.330**		.576***	.221	.483***	.383**	.330*	.401**
SPELL	.356**	.612***		.297*	.403**	.517***	.255	.432**
Phon. Mem.	.096	.317**	.295**		.308*	.088	.093	.103
PA	.153	.343**	.214*	0.094		.092	.084	.100
RAN digit	.452***	-.080	.048	.263*	.041		.543***	.878***
RAN picture	.366**	-.074	-.071	.080	.049	.717***		.879***
RAN comp	.442***	-.083	-.012	.185	.049	.927***	.926***	
	FRENCH							

	READ Speed	READ Acc	SPELL	Digit-span	PA	RAN Digit	RAN picture	RAN comp
								GERMAN
READ Speed		.272***	.516***	.108*	.306***	.465***	.309***	.458***
READ Acc	.166*		.404***	.170***	.376***	.044	.081	.074
SPELL	.254***	.366***		.190***	.375***	.120**	.205***	.192***
Phon. Mem.	.097	.270***	.446***		.268***	.014	.124**	.081
PA	.152*	.360***	.496***	.440***		.073	.209***	.166***
RAN digit	.440***	.001	.143*	.081	.140		.430***	.847***
RAN picture	.442***	.120	.296***	.133	.284***	.489***		.844***
RAN comp	.511***	.070	.254***	.124	.246**	.863***	.862***	
	HUNGARIAN							

	READ Speed	READ Acc	SPELL	Digit-span	PA	RAN digit	RAN picture	RAN comp
								FINNISH
READ Speed		.371***	.329***	.338***	.286***	.178**	.291***	.279***
READ Acc			.467***	.216**	.378***	-.013	.085	.043
SPELL				.228***	.293***	.101	.132*	.138*
Phon. Mem.					.247**	.039	.155*	.116
PA						.133*	.192**	.194**
RAN digit							.412***	.839***
RAN picture								.842***
RAN comp								

Table 3

Regression analyses for the five languages with reading speed as dependent variable

		READING SPEED			
ENGLISH	*N* = 60	R^2-Change %	*p*	*B*	*SE B*
step 1	Age/IQ	9.2	.143		
step2	Unique Phon. Memory	5.8	.036	.238	.111
	Unique PA	4.4	.066	-.212	.113
	Unique RAN	17.2	.000	.440	.118
	Variance step 2	24.9	.001		
	Total variance	34.0			
FRENCH	*N* = 86				
step 1	Age/IQ	5.4	.204		
step2	Unique Phon. Memory	0.2	.674	-.041	.097
	Unique PA	0.5	.451	.070	.092
	Unique RAN	19.1	.000	.442	.098
	Variance step 2	20.4	.000		
	Total variance	25.8			
GERMAN	*N* = 473				
step 1	Age/IQ	1.0	.189		
step2	Unique Phon. Memory	0.0	.761	.012	.040
	Unique PA	4.8	.000	.219	.040
	Unique RAN	16.7	.000	.467	.045
	Variance step 2	25.5	.000		
	Total variance	26.5			
HUNGARIAN *N* = 195					
step 1	Age/IQ	3.4	.085		
step2	Unique Phon. Memory	0.0	.745	.022	.068
	Unique PA	0.0	.896	-.009	.071
	Unique RAN	22.8	.000	.545	.071
	Variance step 2	23.7	.000		
	Total variance	27.1			
FINNISH	*N* = 247				
step 1	Age/IQ	9.0	.000		
step2	Unique Phon. Memory	4.3	.000	.208	.056
	Unique PA	3.1	.002	.162	.052
	Unique RAN	3.5	.001	.208	.063
	Variance step 2	15.1	.000		
	Total variance	24.1			

Table 4

Regression analyses for the five languages with reading accuracy as dependent variable

		READING ACCURACY			
ENGLISH	*N* = 59	R^2-Change %	*p*	*B*	*SE B*
step 1	Age/IQ	0.2	.989		
step2	Unique Phon. Memory	0.7	.440	.087	.112
	Unique PA	17.6	.000	.445	.115
	Unique RAN	14.2	.001	.425	.122
	Variance step 2	39.0	.000		
	Total variance	39.2			
FRENCH	*N* = 86				
step 1	Age/IQ	11.5	.018		
step2	Unique Phon. Memory	6.9	.008	.236	.087
	Unique PA	7.1	.007	.227	.083
	Unique RAN	2.1	.139	-.131	.088
	Variance step 2	14.7	.002		
	Total variance	26.2			
GERMAN	*N* = 473				
step 1	Age/IQ	1.5	.063		
step2	Unique Phon. Memory	0.4	.129	.055	.036
	Unique PA	11.2	.000	.284	.036
	Unique RAN	0.0	.865	.007	.041
	Variance step 2	13.7	.000		
	Total variance	15.2			
HUNGARIAN	*N* = 195				
step 1	Age/IQ	8.6	.001		
step2	Unique Phon. Memory	2.3	.022	.139	.061
	Unique PA	5.2	.001	.222	.063
	Unique RAN	0.1	.573	-.036	.064
	Variance step 2	11.3	.000		
	Total variance	19.9			
FINNISH	*N* = 247				
step 1	Age/IQ	4.4	.012		
step2	Unique Phon. Memory	0.8	.137	.084	.056
	Unique PA	10.9	.000	.292	.052
	Unique RAN	0.3	.349	-.059	.063
	Variance step 2	13.5	.000		
	Total variance	17.9			

Table 5

Regression analyses for the five languages with spelling as dependent variable

		SPELLING			
ENGLISH	*N* = 58	R^2-Change %	*p*	*B*	*SE B*
step 1	Age/IQ	4.3	.492		
step2	Unique Phon. Memory	2.5	.154	.164	.113
	Unique PA	8.9	.009	.300	.110
	Unique RAN	16.7	.000	.436	.116
	Variance step 2	34.7	.000		
	Total variance	39.0			
FRENCH	*N* = 86				
step 1	Age/IQ	6.8	.122		
step2	Unique Phon. Memory	6.6	.015	.284	.114
	Unique PA	2.2	.157	.155	.108
	Unique RAN	0.5	.502	-.078	.115
	Variance step 2	8.9	.046		
	Total variance	15.7			
GERMAN	*N* = 463				
step 1	Age/IQ	3.5	.001		
step2	Unique Phon. Memory	0.5	.107	.074	.045
	Unique PA	8.5	.000	.311	.045
	Unique RAN	1.6	.003	.153	.051
	Variance step 2	13.8	.000		
	Total variance	17.2			
HUNGARIAN	*N* = 195				
step 1	Age/IQ	23.0	.000		
step2	Unique Phon. Memory	4.8	.000	.250	.065
	Unique PA	4.1	.000	.241	.068
	Unique RAN	1.0	.073	.123	.068
	Variance step 2	16.2	.000		
	Total variance	39.3			
FINNISH	*N* = 246				
step 1	Age/IQ	3.5	.036		
step2	Unique Phon. Memory	1.4	.050	.133	.068
	Unique PA	5.1	.000	.232	.062
	Unique RAN	0.4	.325	.074	.075
	Variance step 2	9.3	.000		
	Total variance	12.7			

Table 6

Multilevel analyses for the three predictors (a-c) for reading speed

READING SPEED			
	Estimates	95%CI	p-value
(a) Phon. Memory			
Fixed effect estimates for Phon. Memory			
	0.127	[0.070 - 0.188]	<.001
Random effect estimates Phon. Memory by Language			
English	0.005	[-0.072 - 0.085]	
French	-0.024	[-0.142 - 0.048]	
German	-0.032	[-0.111 - 0.031]	
Hungarian	-0.039	[-0.148 - 0.035]	
Finnish	0.089	[0.005 - 0.228]	
Global heterogeneity of random effects			.127
(b) PA			
Fixed effect estimates for PA			
	0.152	[0.068 - 0.220]	<.001
Random effect estimates PA by Language			
English	-0.102	[-0.320 - -0.002]	
French	-0.020	[-0.146 - 0.115]	
German	0.093	[0.003 - 0.206]	
Hungarian	-0.041	[-0.131 - 0.047]	
Finnish	0.071	[-0.013 - 0.194]	
Global heterogeneity of random effects			.021
(c) RAN			
Fixed effect estimates for RAN			
	0.439	[0.372 - 0.512]	<.001
Random effect estimates RAN by Language			
English	-0.004	[-0.105 - 0.108]	
French	-0.001	[-0.109 - 0.126]	
German	0.053	[-0.027 - 0.146]	
Hungarian	0.059	[-0.018 - 0.172]	
Finnish	-0.107	[-0.243 - -0.015]	
Global heterogeneity of random effects			.086

Table 7

Multilevel analyses for the three predictors (a-c) for reading accuracy

READING ACCURACY			
	Estimates	95%CI	p-value
(a) Phon. Memory			
Fixed effect estimates for Phon. Memory			
	0.155	[0.109 - 0.231]	<.001
Random effect estimates Phon. Memory by Language			
English	0.000	[-0.138 - 0.137]	
French	0.000	[-0.031 - 0.139]	
German	0.000	[-0.110 - 0.022]	
Hungarian	0.000	[-0.050 - 0.082]	
Finnish	0.000	[-0.076 - 0.070]	
Global heterogeneity of random effects			1.0
(b) PA			
Fixed effect estimates for PA			
	0.297	[0.249 - 0.366]	<.001
Random effect estimates PA by Language			
English	0.000	[-0.014 - 0.245]	
French	0.000	[-0.142 - 0.062]	
German	0.000	[-0.089 - 0.034]	
Hungarian	0.000	[-0.124 - 0.030]	
Finnish	0.000	[-0.084 - 0.067]	
Global heterogeneity of random effects			1.0
(c) RAN			
Fixed effect estimates for RAN			
	0.084	[0.009 - 0.156]	.081
Random effect estimates RAN by Language			
English	0.214	[0.000 - 0.464]	
French	-0.075	[-0.246 - 0.024]	
German	-0.029	[-0.110 - 0.056]	
Hungarian	-0.041	[-0.142 - 0.055]	
Finnish	-0.069	[-0.177 - 0.032]	
Global heterogeneity of random effects			.008

Table 8

Multilevel analyses for the three predictors (a-c) for spelling

SPELLING			
	Estimates	95%CI	p-value
(a) Phon. Memory			
Fixed effect estimates for Phon. Memory			
	0.237	[0.175 - 0.313]	<.001
Random effect estimates Phon. Memory by Language			
English	-0.009	[-0.122 - 0.105]	
French	0.008	[-0.104 - 0.142]	
German	-0.057	[-0.153 - 0.017]	
Hungarian	0.093	[0.000 - 0.210]	
Finnish	-0.034	[-0.152 - 0.039]	
Global heterogeneity of random effects			.082
(b) PA			
Fixed effect estimates for PA			
	0.325	[0.262 - 0.386]	<.001
Random effect estimates PA by Language			
English	0.007	[-0.047 - 0.121]	
French	-0.027	[-0.207 - 0.013]	
German	0.009	[-0.050 - 0.088]	
Hungarian	0.036	[-0.002 - 0.179]	
Finnish	-0.025	[-0.124 - 0.024]	
Global heterogeneity of random effects			.268
(c) RAN			
Fixed effect estimates for RAN			
	0.185	[0.109 - 0.271]	<.001
Random effect estimates RAN by Language			
English	0.013	[-0.018 - 0.300]	
French	-0.019	[-0.302 - 0.028]	
German	0.009	[-0.070 - 0.111]	
Hungarian	0.011	[-0.051 - 0.155]	
Finnish	-0.015	[-0.179 - 0.054]	
Global heterogeneity of random effects			.435

APPENDIX

Table A1

Standardized reading tests applied in the five languages for sample selection

Language	Reading Test
English	Elliot, C., Smith, P., & McCulloch, K. (1997). *British Ability Scales II*. Windsor: NFERNelson.
French	Jacquier-Roux, M., Valdois, S., & Zorman, M. (2005). *Odédys: Outil de dépistage des dyslexiques (version 2)*. Grenoble: Laboratoire Cognisciences.
German	Moll, K. & Landerl, K. (2010). *SLRT-II – Verfahren zur Differentialdiagnose von Störungen der Teilkomponenten des Lesens und Schreibens*. Bern: Huber.
Hungarian	Tóth, D., Csépe, V., Vaessen, A., Blomert, L. (in press). *3DM-H: A diszlexia differenciáldiagnózisa. Az olvasás és helyesírás kognitív elemzése*. Nyíregyháza: Kogentum.
Finnish	Häyrinen, T., Serenius-Sirve, S., & Korkman, M. (1999). *Lukilasse*. Helsinki: Psykologien Kustannus Oy.

Table A2

Number of participants by Grade and country

Language	Country	Grade	N
English	United Kingdom	3	7
		4	11
		5	12
		6	15
		7	15
		Total	60
French	France	3	23
		4	26
		5	22
		6	15
		Total	86
German	Germany	3	124
		4	96
		Total	220
	Switzerland	2	8
		3	10
		4	2
		5	25
		Total	45
	Austria	2	59
		3	88
		4	61
		Total	208
Hungarian	Hungary	2	75
		3	63
		4	57
		Total	195
Finnish	Finland	2	87
		3	160
		4	1

Total	248