Orthographic knowledge predicts reading and spelling skills over and above general intelligence and phonological awareness

Jelena Zarić1,2 • Marcus Hasselhorn1,2,3 • Telse Nagler1,2,3

Received: 5 April 2019 / Revised: 18 December 2019 / Accepted: 20 January 2020
Published online: 05 February 2020 © The Author(s) 2020

Abstract

It is widely accepted that general intelligence and phonological awareness contribute to children’s acquisition of reading and spelling skills. A further candidate in this regard is orthographic knowledge (i.e., the knowledge about permissible letter patterns). It consists of two components, word-specific (i.e., the knowledge of the spelling of specific words) and general orthographic knowledge (i.e., the knowledge about legal letter patterns of a writing system). Among German students, previous studies have shown that word-specific orthographic knowledge contributes to both reading and spelling. The results regarding general orthographic knowledge and its contribution to reading and spelling are inconsistent. The major goal of the present study was to determine the incremental predictive value of orthographic knowledge for reading and spelling skills among German elementary-school children (N = 66), over and above the contribution of general intelligence and phonological awareness. The second goal was to examine whether there is a difference between the two subtypes of orthographic knowledge in the amount of their respective contribution to reading and spelling performance. The results show that word-specific as well as general orthographic knowledge contribute to both reading and spelling performance, over and above intelligence and phonological awareness. Furthermore, it reveals that both word-specific and general orthographic knowledge explain more variance of spelling compared to reading. Possible explanations for these results, limitations, and implications of the study are being discussed.

Keywords Orthographic knowledge • General intelligence • Phonological awareness • Reading • Spelling
Introduction

Reading and spelling are essential academic skills necessary for future successful participation in modern societies. Reading includes a variety of processes, which differ in their complexity. At the lowest reading level, basic word-reading processes can be located, including decoding of single words as well as vocabulary knowledge (Klicpera and Gasteiger-Klicpera 1995). Only if the interpretation of the word’s meaning in the given context and the integration of different words is successful, the higher level of understanding the entire sentence can be reached. The highest level of reading includes the understanding of relationships between different sentences, and therefore enabling the processing of texts (Gough and Tunmer 1986; Lenhard and Schneider 2006).

In order to express oneself in written language, verbal information needs to be recoded into letters (i.e., spelling; Preßler et al. 2014). Spelling is considered as a part of the transcription in the writing process (Abbott and Berninger 1993). Spelling skills were shown to have an influence on writing productivity (Kim et al. 2011), writing quality (Kent et al. 2014), and writing fluency (Kim et al. 2015). Moreover, knowledge of the spelling of a word enables its fluent reading, since both build and rely on the same mental representation (Snow et al. 2005). Insufficient reading and spelling skills can negatively affect school career, and future career paths (Valtin 2017).

General intelligence and phonological awareness There is plenty of evidence that various different linguistic and cognitive capabilities contribute to the acquisition of reading and spelling skills (e.g., Preßler et al. 2014; Barron 1986; Coltheart et al. 2001; Siddaiah and Padakannaya 2015; Steinbrink and Lachmann 2014). General intelligence (e.g., Horn and Packard 1985; Stanovich et al. 1984) and phonological awareness (e.g., Caravolas et al. 2001; Castles and Coltheart 2004; Ehri et al. 2001; Kirby et al. 2008; Schulte-Körne 2011; Ziegler and Goswami 2005) are among the most important prerequisites of reading and spelling acquisition. For instance, in a longitudinal study, Ennemoser et al. (2012) showed that general intelligence contributes significantly to reading and spelling performance. Results from another longitudinal study indicate that children with higher intelligence also achieve higher scores in reading and spelling tasks (Zöllner and Roos 2009). A meta-analysis by Pfost (2015) revealed that phonological awareness is a strong predictor of reading and spelling skills.

However, even if considering further capabilities (such as rapid automatized naming, listening comprehension, and letter knowledge) in addition to general intelligence and phonological awareness, there is still substantial unexplained reading and spelling variance left (Furnes and Samuelsson 2009; Jongejan et al. 2007; Landerl and Wimmer 2008; Mutera and Diethelm 2001; Näslund and Schneider 1996; Pae et al. 2010).

Orthographic knowledge Orthographic knowledge is considered as one of the major contributors to word identification, and is hence considered as a further candidate to explain additional reading and spelling variance (Cutting and Denckla 2001; Holland et al. 2004). It is generally agreed that orthographic knowledge is acquired through repeated exposure to print (Barker et al. 1992; Berninger 1994; Fletcher-Flinn and Thompson 2004; Stanovich and West 1989), however, the underlying mechanisms are less clear. It is assumed that orthographic representations of letter combinations and whole word units are stored in the mental lexicon through repeated exposure to printed material. In order to accurately identify a word, it is necessary to know how letters are combined to form a specific word (Apel 2011; Loveall et al.
Fluent reading and/or spelling is hence supported by a sufficient level of orthographic knowledge, enabling the individual to quickly recognize or produce written words with little cognitive effort (e.g., Ehri 2005, 2014). Regarding reading at the higher level (i.e., sentence- and text-level), in the Lexical Quality Hypothesis (LQH; Perfetti and Hart 2002), high-quality orthographic representations are considered to be necessary for higher reading processes, such as reading comprehension. Therefore, it can be assumed that orthographic knowledge supports the automatized single-word recognition, enabling their processing and supporting higher reading processes (i.e., comprehension at sentence- and text-level). However, orthographic processing has been much less examined than phonological processes ones so far (Loveall et al. 2013).

In general, orthographic knowledge refers to the knowledge about permissible letter patterns (Perfetti 1984). However, there are different definitions of orthographic knowledge. For instance, one view of orthographic knowledge defines it as a sensitivity to the written letter patterns (Deacon 2012), or rather to the orthographic structure of the words (Georgiou et al. 2008). Another view considers orthographic knowledge as a knowledge about regularities of visual and orthographic aspects of written language (Roman et al. 2009). In particular, orthographic knowledge includes the knowledge about rules of letter sequences and morphological spelling (Schulte-Körne 2002), which plays a decisive role in automatized word recognition (Venezky and Massaro 1979). Analogous to the stored representations of the spoken words (phonological representations, e.g., Claessen et al. 2009; Foy and Mann 2009), orthographic knowledge contains the specific sequences of graphemes representing written words (mental graphemic representations; Apel 2011). All these different definitions have in common that they consider orthographic knowledge as an understanding of the conventions of a writing system (Conrad et al. 2013). In this paper, orthographic knowledge is referred to as the knowledge about regularities of letter patterns, morphemes, and also higher grammatical and semantic structures of the written language (Schulte-Körne 2002). This ability is considered to deliver a wider understanding on what makes reading and spelling successful, beside general intelligence and phonological awareness.

**Two-dimensional view of orthographic knowledge** There is growing consensus that orthographic knowledge is multi-dimensional consisting of both word-specific and general orthographic knowledge (Conrad et al. 2013; Rothe et al. 2015). This two-level view seems intuitively plausible. If an individual has a sufficient word-specific (lexical) orthographic knowledge to recognize or produce written words, fluent reading or spelling can occur (e.g., Ehri 2014). However, when confronted with a word without a lexical representation, the individual must use his/her general (sublexical) orthographic knowledge as a part of the process of encoding (i.e., spelling) or decoding (i.e., reading) the word (e.g., Apel 2011; Ehri 2014). This two-level view is consistent with several theories of reading and spelling development (e.g., Masterson and Apel 2007; Seymour 1999; Share 2004). For instance, following the assumptions of the Dual-Route-Model, word-specific orthographic knowledge can be considered as useful when using the lexical, more efficient route. It enables quick access to stored mental representations of known words. When unfamiliar words with no stored mental representations occur, the non-lexical, less efficient route is used for translating print into words. In this case, general orthographic knowledge can be considered as useful (e.g., Castles 2006; Grainger and Ziegler 2011; Kirby et al. 2008).
Word-specific orthographic knowledge

Word-specific orthographic knowledge is defined as the knowledge of the spelling of specific words and units within words (Barker et al. 1992). It is usually measured by an orthographic choice task (Olson et al. 1994). Here, participants need to select the correctly spelled word between a real word and a pseudohomophone (i.e., a constructed word with the same pronunciation as an existing word, however, incorrectly spelled, e.g., rain – rane). This task measures orthographic knowledge on the lexical level, because participants need to process both presented possibilities (word and pseudohomophone) and compare them with stored representations in the mental lexicon for solving the task (Deacon et al. 2012). For a correct word recognition, a sufficiently differentiated semantic knowledge and a reliable connection between orthographic information and word meaning in the mental lexicon is required (Hübner 2015).

Several studies showed that word-specific orthographic knowledge contributes unique variance to reading and spelling proficiency in different languages and different age groups (Greek: Georgiou et al. 2008; Persian: Arab-Moghaddam and Senechal 2001; Dutch: Bekebrede et al. 2009; English: Conrad et al. 2013; Cunningham and Stanovich 1990; Deacon et al. 2012). For English, an opaque language, a similar amount of unique variance in reading (8%) and spelling (5%), was explained by word-specific orthographic knowledge (Arab-Moghaddam and Senechal 2001). For Persian and Dutch, transparent languages, findings suggest that word-specific orthographic knowledge contributes more to spelling (22%) than to reading (9%; Arab-Moghaddam and Senechal 2001; Bekebrede et al. 2009). These differences regarding the amount of unique contribution to reading and spelling may occur due to the use of different materials for measuring word-specific orthographic knowledge, or due to the structure of the examined language (i.e., its orthography, namely the structure of the language and its level of transparency of phoneme-grapheme-correspondences). For the transparent language German, there are only few studies to our knowledge that examined word-specific orthographic knowledge and its relevance to reading and spelling acquisition (e.g., Bergmann and Wimmer 2008; Rothe et al. 2015). For instance, Rothe et al. (2015) showed that word-specific orthographic knowledge contributes a similar amount of unique variance to reading (10%) and spelling (12%) performance across children with and without reading and spelling difficulties. However, the authors reported ceiling effects in the task used for measuring word-specific orthographic knowledge.

General orthographic knowledge

General orthographic knowledge refers to the knowledge about legal letter patterns of a writing system, including structural redundancies (i.e., possible letter combinations in different words), sequential dependencies (i.e., which letters are allowed to follow other letters), and letter position frequencies (i.e., in which position letter combinations occur frequently or rarely; Vellutino et al. 1994). In previous studies, applied orthographic choice tasks consisted of one pseudoword (i.e., pronounceable letter combinations, created by using certain linguistic criteria, e.g., double consonants in different word positions) containing a letter pattern that occurs frequently and in a legal position, whereas the other contains a letter pattern that occurs rarely and in an orthographically illegal position (e.g., yill vs. yihh; Cassar and Treiman 1997; baff vs. bbaf; Cunningham and Stanovich 1993; Treiman 1993). Participants are asked to determine which of the two presented pseudowords looks more like a real word by drawing their knowledge about frequent or legal letter patterns to solve the task. Thus, this task measures the knowledge about permissible letter patterns on the sublexical level, independently of the stored representations of real words in the mental lexicon (Deacon et al. 2012; Hagiliassis et al. 2006; Rothe et al. 2015).
A similar amount of variance contributed by general orthographic knowledge to reading (9%) and to spelling (7%) was identified (e.g., Conrad et al. 2013). For German, mixed results were reported considering the relationship between general orthographic knowledge and reading and spelling proficiency. A study by Ise et al. (2012) has shown a significant correlation between general orthographic knowledge and spelling, but not with reading skills. In contrary, Rothe et al. (2014) have shown that general orthographic knowledge explains a significant amount of unique variance in reading (11%) and spelling skills (7%). Similar results were reported by another study with German elementary-school children (Rothe et al. 2015), showing that general orthographic knowledge contributes a significant amount of unique variance to reading (9%) and spelling (9%) across children with and without reading and spelling difficulties. However, this study has several limitations. Rothe et al. (2015) have used a non-child-oriented data base for item development, and, the same items were used in two tasks for measuring general orthographic knowledge. The analyses revealed ceiling effects in one of the tasks measuring general orthographic knowledge. Using the same items in two different tasks may have led to training effects, thus affecting the results and making them difficult to interpret.

To sum up, most of the previous studies addressing the role of word-specific and general orthographic knowledge in reading and spelling acquisition are from opaque languages like English or French (e.g., Conrad et al. 2013; Cunningham and Stanovich 1990; Deacon et al. 2012; Pacton and Fayol 2004; Pacton et al. 2001). There are only few studies from more transparent languages like Persian or German (e.g., Arab-Moghaddam and Senechal 2001; Rothe et al. 2015) investigating the role of word-specific and general orthographic knowledge in reading and spelling performance simultaneously, over and above general intelligence and phonological awareness. Since the acquisition of reading and spelling skills varies as a function of the orthography and the transparency of the language, the results of former studies should not be generalized over different languages. Studies addressing the role of word-specific and general orthographic knowledge and their contribution to reading and spelling proficiency in German, however, reported mixed results. First, it is still unclear, whether or not word-specific and general orthographic knowledge contribute to both reading (at basic and higher level) and spelling proficiency, over and above general intelligence and phonological awareness in German. And second, if so, it is still questionable whether or not word-specific and general orthographic knowledge do contribute to the same extent to reading and to spelling in German.

The present study

Previous studies stressed the importance of word-specific and general orthographic knowledge for reading and spelling proficiency. Adequate word-specific and general orthographic knowledge support the mastery of these two essential academic skills, thus enhancing a chance to achieve core aims of school education. We are therefore interested to explore to which extent word-specific and general orthographic knowledge contribute to both reading and spelling, in order to identify all of the major components relevant for successful reading and spelling. The major aim of this study was thus to investigate whether or not word-specific and general orthographic knowledge contribute to both reading (at basic and higher level) and spelling proficiency, over and above general intelligence and phonological awareness in a transparent language like German. Furthermore, previous studies exclusively used reading tasks that measure basic reading decoding processes, such as word-reading tasks (e.g., Rothe et al. 2015). However, referring to the LQH (Perfetti and Hart 2002), high-quality orthographic
representations of words are considered to be crucial for higher reading processes, such as reading comprehension. Following this theoretical framework, we use a standardized reading task measuring reading comprehension at basic (i.e., word-reading) and higher level (i.e., sentence- and text-reading) in order to extend our understanding of orthographic knowledge for higher reading processes. In line with previous results (e.g., Rothe et al. 2015), we hypothesize that word-specific and general orthographic knowledge contribute significantly to reading comprehension at word-level, in addition to general intelligence and phonological awareness. Additionally, word-specific and general orthographic knowledge should also contribute to comprehension at higher level (i.e., sentence- and text-level) since sentence- and text-reading includes integrating different words within a sentence or a text passage, and therefore primarily rely on efficient single-word-reading. Thus, we hypothesize that word-specific and general orthographic knowledge also contribute to reading comprehension at higher reading level (i.e., sentence- and text-level), in addition to general intelligence and phonological awareness.

Previous studies reported inconsistent results regarding the amount of contribution to reading and spelling performance explained by word-specific and general orthographic knowledge, especially in transparent languages such as German. Thus, a second aim of the current study was to examine whether there is a difference between the two subtypes of orthographic knowledge (i.e., word-specific vs. general) in their predictive value with regard to reading and spelling. For reading fluency and orthographically correct spelling of words the word-specific representations play a crucial role (e.g., Ehri 2014). Therefore, we hypothesized that the impact of word-specific knowledge is comparable for reading and spelling. For general orthographic knowledge, we assumed that it should play a more important role in spelling than in reading performance, because stored representations of word parts or frequently occurring letter patterns might be especially helpful in producing/spelling (unknown) words. During the reading process, general orthographic knowledge might only be useful for recognizing letter patterns, thus enhancing the automatized reading process, but to a smaller extent compared to its influence in spelling. Hence, contrary to previous findings (e.g., Rothe et al. 2015), we propose that general orthographic knowledge might have a greater impact on spelling than on reading performance.

Method

Participants

Participants were recruited from one public elementary school in Frankfurt/Main in Germany. Teachers and parents of third graders were contacted and informed about the study via mail and information brochures. Initially, 81 children whose parents gave informed consent to participate were included in the study.

Children with very low or very high levels of non-verbal intelligence (IQ ≤ 85 or IQ ≥ 130) as assessed by a standardized test (Zahlen-Verbindungs-Test – ZVT; Oswald and Roth 1987) were excluded from further analyses. The final sample consisted of 66 children (29 girls, 37 boys, mean age = 9.25 years, SD = 0.43, 31 children spoke one or more other languages besides German) with an average IQ (mean = 107, SD = 12.30). All children received the typical amount of reading and writing instructions according to the regular school curriculum. The information about their reading and spelling proficiency are presented in Table 1. The study was approved by a research ethics commission.
Measures

Reading

Reading performance was assessed using the paper-pencil version of a standardized German reading test (Ein Leseverständnistest für Erst- bis Sechstklässler – ELFE 1-6; [A reading comprehension test for first till sixth grade]; Lenhard and Schneider 2006). ELFE 1-6 measures reading comprehension at word-, sentence-, and text-level with time limitation. To assess reading comprehension at word level, 72 items are presented, each composed of a picture accompanied by four word alternatives. Participants are instructed to decide which of the four word alternatives corresponds to the picture. For measurement of reading comprehension at sentence level, participants have to complete 28 sentences by choosing one of five possible word alternatives. Reading comprehension at text level is derived from participant’s multiple choice answers of 20 items, each comprising a connected text and a corresponding multiple choice question. Reported internal consistency of the three subtest varies between $\alpha = .92$ und $\alpha = .97$. For further statistical analyses, we used reading standardized T-scores at word-, sentence-, and text-level.

Spelling

Spelling skill was assessed using the spelling subtest of the standardized German reading and spelling test (Salzburger Lese- und Rechtschreibtest II – SLRT II; [Salzburg reading and spelling test II]; Moll and Landerl 2010). In this test, participants are asked to accomplish a cloze task with 48 words. The words are read aloud as instructed in the manual by the investigator in consideration of German spelling rules. Reported retest-reliability for second-fourth grades varies between $r_{tt} = .80$ und $r_{tt} = .97$. For further statistical analyses, we used the number of correctly spelled words.

General (non-verbal) intelligence

Children’s non-verbal intelligence was assessed using a standardized test (ZVT; Oswald and Roth 1987). The test consists of four matrices with different configurations of digits ranging from 1 to 90. Within a time limit of 30 s per matrix, participants are asked to connect the digits

| Table 1 | Means and standard deviations of all measures |
|---------|------------------------------------------|
|         | Mean          | Standard deviation |
| Age (years/months) | 9.25          | 0.43              |
| General intelligence (IQ) | 107.32       | 12.84             |
| Phonological awareness | 27.83         | 2.84              |
| Reading at basic level (word)$^a$ | 41.82         | 7.59              |
| Reading at higher level (sentence)$^a$ | 43.11         | 8.61              |
| Reading at higher level (text)$^a$ | 46.42         | 10.10             |
| Spelling$^b$ | 30.59         | 10.35             |
| Word-specific orthographic knowledge$^c$ | 8.41          | 1.75              |
| General orthographic knowledge$^d$ | 21.21         | 4.16              |

$^a$ Standard T-score, $^b$ raw score (maximum 48), $^c$ raw score (maximum 11), $^d$ raw score (maximum 28), $IQ$, intelligence quotient
in the counting order as fast as possible for all four matrices. This test measures cognitive speed processing components and has been considered as a basic (general) intelligence quotient (IQ) measurement. Reported retest-reliability varies between $r_{tt} = .84$ und $r_{tt} = .97$. Correlations between ZVT and other IQ-tests (e.g., I-S-T, Amthauer 1970; CFT-3, Weiß 1971) vary between $r = .40$–.83. For further statistical analyses, we used the IQ-scores provided by the manual.

**Phonological awareness**

Phonological awareness was assessed using the subtest of a standardized German sound differentiation test (Heidelberger Lautdifferenzierungstest – H-LAD; [Heidelberg sound differentiation test]; Brunner et al. 1999). Participants have to decide for each of the 32 items (9 syllable-pairs and 23 word-pairs) whether they hear two different or two same words/syllables. The internal consistency reported by the authors varies between Cronbach’s $\alpha = .88$ and Cronbach’s $\alpha = .86$. The number of correctly answered items was calculated and used for further analyses.

**Orthographic knowledge**

For the present study, we developed new item sets according to the construction principle of previous studies (e.g., Rothe et al. 2015) to measure orthographic knowledge for German elementary-school children on the word-specific and general level.¹ For item development and selection, information given by the child-oriented childLex database was used (Schroeder et al. 2015). Both subtypes of orthographic knowledge were applied using two orthographic choice tasks programmed in *Psychology software in Python* (PsychoPy; Peirce 2008) and presented on a laptop with 14.1-in. monitor on a black screen with white letters in font size 35. Participants are asked to decide which of the two presented alternatives closest resembles a real German word by pressing the corresponding button on a computer keyboard.

**Word-specific orthographic knowledge** The task consisted of 20 self-developed randomly presented test items and one practice item (see Appendix Table 5). All selected words were low frequent.² This procedure was chosen to reduce the possibility of ceiling effects found in other German studies (e.g., Rothe et al. 2015). Pseudohomophones were developed by manipulating real words (i.e., by alternating single letters; e.g., /e/ and /a/: *reich - raich*), which were similarly pronounceable as the real words. Thus, a single item consisted of a presented word and a pseudohomophone.

**General orthographic knowledge** The task consisted of 40 self-developed randomly presented test items and two practice items (see Appendix Tables 6 and 7). Each item consisted of two pronounceable pseudowords with six letters. Twenty items addressed the knowledge about

---

¹ The results of an explorative factor analysis (see Appendix, Table 8) indicate that data reduction resulting in two factors explains more variance (19.95%) than the one-factor solution (13.23%). Thus, the two-factor data reduction (i.e., word-specific factor and general factor) can be considered as a more suitable solution than the one-factor solution.

² Type frequency of the selected words was ≤ 500 times per million continuous words in the corpus, and could be therefore classified as low frequent in comparison to other words.
frequency of double consonants. Therefore, one pseudoword in each pair contained a frequent double consonant (e.g., /ll/), whereas the other contained a low frequent double consonant in German (e.g., /dd/). Pseudowords of 10 test items contained a double consonant in the middle (e.g., bellab – beggab) and in other 10 items at the end (e.g., dihett – dihegg). Bigram\(^3\) and trigram\(^4\) frequencies were controlled for all test items and were comparable for pseudowords containing frequent and pseudowords containing low frequent double consonants (see Appendix Table 6). Other 20 items addressed the knowledge about the legal positions of double consonants. One pseudoword in each pair contained a double consonant in a legal position (central: e.g., tammit, or end position: e.g., narell), while the other contained a double consonant in an illegal position in German (e.g., nnisum). Bigram\(^5\) and trigram frequencies\(^6\) were controlled for all test items and were comparable for pseudowords containing double consonants in a legal position and pseudowords containing double consonants in an illegal position (see Appendix Table 7).

**Procedure**

Participants were tested on two days (ca. 45 min each) in small groups during regular school times in the morning. On the first day, children were first asked to complete the trail-making-test (ZVT; Oswald and Roth 1987), and then the standardized reading test (ELFE 1-6; Lenhard and Schneider 2006). After completing the reading test, children conducted the standardized spelling test (SLRT-II; Moll and Landerl 2010). On the second day of investigation, children were first asked to complete the standardized phonological awareness task (H-LAD; Brunner et al. 1999). After that, children completed the two orthographic choice tasks.

**Data preparation**

For further statistical analyses, item-analyses were done for the scales of word-specific and general orthographic knowledge.\(^7\) Items with a poor degree of selectivity (≤.11) and difficulty (≤.40 and ≥.95) were excluded from further analyses. Hence, the number of correct answers of the remaining 11 out of 20 items of the task measuring word-specific orthographic knowledge represents its raw score (see Appendix Table 5). Still, this task revealed to have less than satisfactory consistency (Cronbach’s \(\alpha\) = .57). The number of correct answers of the remaining 28 out of 40 items of the task measuring general orthographic knowledge represents its raw score (see Appendix Tables 6 and 7) with a sufficient internal consistency (Cronbach’s \(\alpha\) = .75).

---

\(^3\) \(U = 155.00, p = .22\); no significant difference between bigram frequencies of the pseudowords containing frequent double consonants vs. pseudowords containing low frequent double consonants

\(^4\) \(U = 140.50, p = .11\); no significant difference between trigram frequencies of the pseudowords containing frequent double consonants vs. pseudowords containing low frequent double consonants

\(^5\) \(U = 196.00, p = .91\); no significant difference between bigram frequencies of the pseudowords containing double consonants in the legal vs. pseudowords containing double consonants in illegal position

\(^6\) \(U = 145.00, p = .14\); no significant difference between trigram frequencies of the pseudowords containing double consonants in the legal vs. pseudowords containing double consonants in illegal position

\(^7\) In Appendix, Table 8, we report results of an explorative factor analysis in order to provide a support for our two sub-types view (word-specific and general) of orthographic knowledge
Results

Table 1 presents means and standard deviations for all measures used in the current study for the entire sample included.

Relationship between word-specific and general orthographic knowledge, general intelligence, phonological awareness, reading and spelling skills

Correlations between word-specific and general orthographic knowledge, general intelligence, and phonological awareness, as well as reading and spelling, are shown in Table 2. Because of violation of normal distribution, we report Spearman’s Rho $r_s$ correlation coefficients. Word-specific and general orthographic knowledge significantly correlated with reading and spelling skills, but not with general intelligence and phonological awareness. Phonological awareness did not correlate with general intelligence, whereas reading and spelling correlated significantly.

Prediction of reading and spelling by word-specific and general orthographic knowledge

To explore the predictive value of word-specific and general orthographic knowledge for reading and spelling, we conducted multiple hierarchical regression analyses. We calculated separate regression models for word-specific (model 1) and general orthographic knowledge (model 2), and also included both components (model 3), separately for reading (Table 3) and spelling (Table 4). In all models, general intelligence and phonological awareness were entered in step 1. In step 2, word-specific, or general orthographic knowledge, or both word-specific and general orthographic knowledge, were entered to the respective models.

Basic-level reading

General intelligence explained 16% of the variance of reading at basic level (i.e., word-level), whereas phonological awareness turned out not to be a significant predictor. Even if entering word-specific and/or general orthographic knowledge into the regression model, general intelligence revealed to be a significant predictor. In addition, both word-specific and general orthographic knowledge were significant predictors for basic-level
reading. Word-specific orthographic knowledge explained an additional amount of 17% of variance of reading (Table 3, model 1, basic-level column), whereas general orthographic knowledge explained another 9% (Table 3, model 2, basic-level column). Together, the two components of orthographic knowledge explained an additional amount of 20% of basic-level reading variance (Table 3, model 3, basic-level column); however, only word-specific orthographic knowledge remained a significant predictor here.

**Higher-level reading** General intelligence and phonological awareness explained 23% of variance of reading at sentence-level, and 12% of variance of reading at text-level. After entering word-specific and/or general orthographic knowledge into the regression model, phonological awareness proved to be a significant predictor only at text-level, but not at sentence-level. General intelligence remained a significant predictor at sentence - and text-level. Word-specific orthographic knowledge explained an additional amount of 15% of variance of reading at sentence-level (Table 3, model 1, higher-reading column), whereas general orthographic knowledge explained another 8% (Table 3, model 2, higher-reading column). After entering both components of orthographic knowledge for reading at sentence-level, only word-specific knowledge remained a significant predictor. Regarding reading at text-level, word-specific orthographic knowledge explained an additional amount of 8% (Table 3, model 1, higher-reading column), whereas general orthographic knowledge

---

**Table 3** Results from hierarchical multiple regression analyses for reading at basic and higher level (dependent variable: overall reading standardized T-score ELFE 1-6)

| Model | Step | Predictor | Basic level | Higher level |  |
|-------|------|-----------|-------------|--------------|---|
|       |      |           | Word level  | Sentence level | Text level |
|       |      |           | \( \beta \) | \( R^2 \) | \( \Delta R^2 \) | \( \beta \) | \( R^2 \) | \( \Delta R^2 \) | \( \beta \) | \( R^2 \) | \( \Delta R^2 \) |
| 1     | 1    | IQ        | .35*        | .43**        | .24*        | .35*        | .43**        | .24*        | .35*        | .43**        | .24*        |
|       |      | PA        | .18         | .21*         | .25*        | .18         | .21*         | .25*        | .18         | .21*         | .25*        |
| 2     | 2    | IQ        | .36*        | .38 .15**    | .20 .08*    | .36*        | .38 .15**    | .20 .08*    | .36*        | .38 .15**    | .20 .08*    |
|       |      | PA        | .12         | .16          | .21*        | .12         | .16          | .21*        | .12         | .16          | .21*        |
|       |      | Word-specific orth. know. | .42** | .39** | .28* | .42** | .39** | .28* |
| 3     | 1    | IQ        | .35*        | .43**        | .24*        | .35*        | .43**        | .24*        | .35*        | .43**        | .24*        |
|       |      | PA        | .18         | .21*         | .25*        | .18         | .21*         | .25*        | .18         | .21*         | .25*        |
| 2     | 2    | IQ        | .35*        | .42**        | .24*        | .35*        | .42**        | .24*        | .35*        | .42**        | .24*        |
|       |      | PA        | .18         | .13          | .18         | .18         | .13          | .18         | .18         | .13          | .18         |
|       |      | General orth. know. | .32* | .29** | .22* | .32* | .29** | .22* |
| 3     | 3    | IQ        | .35*        | .43**        | .24*        | .35*        | .43**        | .24*        | .35*        | .43**        | .24*        |
|       |      | PA        | .18         | .21*         | .25*        | .18         | .21*         | .25*        | .18         | .21*         | .25*        |
|       |      | Word-specific orth. know. | .36* | .40 .17** | .21 .09* | .36* | .40 .17** | .21 .09* |
|       |      | General orth. know. | .19* | .17 | .14 | .19* | .17 | .14 |

* \( p \leq .05, ** p \leq .01, \) IQ, intelligence quotient (i.e., general intelligence); PA, phonological awareness; orth. know., orthographic knowledge
explained additional amount of 5% (Table 3, model 2, higher-reading column). After entering both components into the regression model for reading at text-level, only word-specific orthographic knowledge remained a significant predictor.

**Spelling** General intelligence contributed significantly to spelling performance, explaining 10% of the variance, whereas phonological awareness revealed not to be a significant predictor for spelling. After entering word-specific and/or general orthographic knowledge into the regression model, general intelligence still remained a significant predictor for spelling. In addition, both word-specific and general orthographic knowledge contributed significantly to spelling. Word-specific orthographic knowledge explained an additional amount of 28% of the spelling variance (Table 4, model 1), whereas general orthographic knowledge an additional amount of 13% (Table 4, model 2). Together, these two components of orthographic knowledge explained an additional amount of 31% of spelling variance (Table 4, model 3), over and above general intelligence and phonological awareness.

Of particular interest are the separate and unique contributions of word-specific and general orthographic knowledge to reading and spelling skills. A descriptive comparison revealed that word-specific orthographic knowledge contributes a higher amount of unique variance for spelling (28%) than for reading (word-level 17%, sentence-level 15%, and text-level 8%), contrary to our expectations (see Tables 3 and 4). In line with our hypothesis, the descriptive analyses underlined that general orthographic knowledge contributes a higher amount of unique spelling variance (13%) as compared to reading (word level 9%, sentence level 8%, and text level 5%; see Tables 3 and 4).
Discussion

The major goal of this study was to determine the incremental predictive value of word-specific and general orthographic knowledge for reading and spelling among German elementary-school children, over and above the contribution of general intelligence and phonological awareness. In line with our expectations, the results show that word-specific and general orthographic knowledge contribute to reading at basic-level (i.e., word-level) as well as at higher-level (i.e., sentence- and text-level). However, considering the results of the model with both word-specific and general orthographic knowledge, it seems that word-specific representations stored in the mental lexicon play a more important role than the knowledge about legal patterns at higher reading level (i.e., sentence- and text-level). The analyses also show that both word-specific and general orthographic knowledge are significant predictors for spelling performance. These results support and extend previous reports (e.g., Arab-Moghaddam and Sénéchal 2001; Conrad et al. 2013; Rothe et al. 2015), indicating that orthographic representations stored in the mental lexicon and knowledge about legal patterns are crucial for reading as well as for spelling.

As proposed by Conrad et al. (2013), it is possible that both sub-components of orthographic knowledge provide unique contributions to reading at basic and higher level as well as to spelling because they both have different function. Word-specific orthographic knowledge supports the direct recognition of familiar words, which are read automatically as a single unit, thus, enabling their quick processing and enhancing comprehension at sentence- and text-level (i.e., higher reading level). In addition, word-specific orthographic knowledge enables spelling directly from word-specific representation stored in mental lexicon (Ehri 2005). Word-specific orthographic knowledge can also be useful in reading and spelling of unfamiliar words through analogy to words stored in memory (Conrad et al. 2013).

General orthographic knowledge may contribute to reading and spelling in two ways, as suggested by Conrad et al. (2013). First, word representations are established in memory through the linking of a word’s spelling with its pronunciation and meaning (Ehri 2005). These connections are also influenced and formed through the growing knowledge of recurring spelling patterns, regularities, and consistencies in different words. By learning these recurring spelling patterns, readers can use larger units to form connections to memorize specific words. Hence, general orthographic knowledge may play an important role in the connection forming processes necessary to establish word-specific representations in memory (Conrad et al. 2013), thus supporting basic-reading (i.e., word-level). Regarding higher-level reading (i.e., sentence- and text-level), more complex processes, related to the extraction of semantic meaning and the activation of background knowledge, are assumed to have a large impact (Klicpera et al. 2017). Thus, the contribution of general orthographic knowledge, when considered simultaneously with word-specific orthographic knowledge, might not be as relevant as the influence of word-specific representations for higher-level reading. Second, general orthographic knowledge might also contribute to reading and spelling more directly. The knowledge about recurring letter patterns can provide information about how any written word may be read and how any pronounced word might be spelled, and therefore, it is useful for reading and spelling, especially of unknown words (Ehri 2005).

Contrary to our expectations and previous findings (e.g., Arab-Moghaddam and Senechal 2001; Rothe et al. 2015), our analyses revealed that word-specific orthographic knowledge contributed a higher amount of unique variance for spelling (28%) than for reading (word-level 17%, sentence-level 15%, and text-level 8%). This might indicate that, at least in German, word-specific representations stored in the mental lexicon may play a more important role in retrieving and producing words for spelling than in retrieving words while reading.
Furthermore, in line with our expectations, although contrary to previous results (Rothe et al. 2015), analyses showed that general orthographic knowledge contributed a higher amount of unique variance for spelling (13%) than for reading (word-level 9%, sentence-level 8%, and text-level 5%). These results, however, indicate that general orthographic knowledge, at least in German, plays a more important role in producing words during spelling by activating the knowledge about legal letter patterns than in the reading process.

Reading and spelling requirements in German A possible explanation for these results might be the reading and spelling requirements in German. Considering the reading process in the Dual-Route-Model (e.g., Castles 2006), a more efficient way of reading a (known) word is using the lexical route by activating its orthographic representation and retrieving it from the mental lexicon. When an unknown word occurs, the non-lexical, less efficient route is used to recode the word. Similar processes account for spelling performance, however, the knowledge about orthographically correct spelling of a specific word is therefore necessary. While during the reading process it is crucial to know the sound structure of a word or grapheme combinations in order to pronounce it/them correctly, for a correct spelling of a word or grapheme combinations the knowledge about the correct orthography and its rules is mandatory. According to the integration of multiple patterns model (IMP; Treiman and Kessler 2014), experienced spellers have stored information about the spelling of specific words (which we refer to as word-specific orthographic knowledge) and about patterns that apply across words (which we refer to as general orthographic knowledge). When spelling, people use their knowledge about these patterns in order to spell known, novel, and also irregular words. Therefore, since the grapheme-to-phoneme-correspondences in reading are more regular than phoneme-to-grapheme-correspondences in spelling for German, word-specific and general orthographic representations might play a more important role in spelling than in reading. These results indicate that in order to teach children to read and spell correctly, at least in German, differences between phonemes and graphemes for reading and spelling should be addressed early during the acquisition process, accompanied by imparting explicit orthographic rules.

Items for measuring orthographic knowledge Regarding word-specific orthographic knowledge, different items used in previous research and in the present study for measuring word-specific orthographic knowledge might be accountable for the discrepancies found in the amounts of unique explained variance for reading and spelling. In the present study, infrequent words and the corresponding pseudohomophones differed in only one letter from correctly spelled words. Therefore, there was a minimal visual difference between the two presented alternatives. In order to solve the task correctly, participants had to retrieve the correct spelling of a specific word from the mental lexicon and compare it to the two presented alternatives, rather than using the method of elimination. The method of elimination might be used when, for instance, there is a big optical difference between the two presented alternatives. As a consequence, no ceiling effects could be found like in previous studies (e.g., Rothe et al. 2015). Regarding general orthographic knowledge, it is also possible that the use of different items measuring general orthographic knowledge in previous studies (e.g., Rothe et al. 2015) and in the present study had an influence on the reported amounts of unique explained variance. In the present study, the general orthographic knowledge was assessed by pseudoword choice of items, consisting of frequent/low frequent double consonants in legal/illegal positions. In comparison, Rothe et al. (2015) used a time-speeded task consisting of items with double consonants in legal/illegal position. It might be that the knowledge about
legal letter positions and letter frequencies combined contribute more to spelling than to reading than the knowledge about legal position of the letters alone.

**Reading measure** Previous studies used measures of basic reading decoding processes, such as word-reading tasks (e.g., Rothe et al. 2015). We consider the use of a score for measuring reading comprehension at basic- (i.e., word-level) and higher-level (i.e., sentence- and text-level) as one of the strengths of our study. As reported above, our results show that word-specific and general orthographic knowledge predict reading at word-, sentence-, and text-level. More specifically, our results support the LQH (Perfetti and Hart 2002) and its assumption that high-quality orthographic representations of words are crucial for higher-level reading, such as sentence- and text-comprehension. However, it is possible that the connection between orthographic knowledge and these higher reading processes is not as strong compared to the basic decoding processes examined in previous studies. Thus, the amount of unique variance contributed by orthographic knowledge for higher reading processes is not as high as for basic reading processes. Future studies should simultaneously use the tasks for measuring basic decoding as well as higher reading processes for a better understanding of the predictive patterns of orthographic knowledge for reading performance.

**Limitations** Despite promising results, this study has some limitations. First, in contrary to previous findings (e.g., Rothe et al. 2015; Vellutino et al. 2004), we were neither able to replicate a significant impact of phonological awareness on basic-level reading (i.e., word-level) and spelling, nor the correlations between phonological awareness and word-specific and general orthographic knowledge. A possible reason for this discrepancy might be the task used for measuring phonological awareness in this study. As described above, we used a standardized sound differentiation task, which was possibly not adequate for prediction of reading at basic-level and spelling. In addition, this aspect of phonological awareness might not have a strong connection to orthographic knowledge, thus, no significant correlations could be found. Other substantial tasks (e.g., analysis of words, syllables or rhymes) might have been more suitable for examining the relationship patterns among these capabilities.

A second limitation is the less than satisfying internal consistency of the orthographic choice task in this study. This indicates that further item improvement and development are necessary in order to more reliably measure word-specific orthographic knowledge. Nonetheless, the task was able to explain a high additional amount of variance for reading and spelling.

As a third limitation, we did not include an assessment of other skills relevant for reading at the basic level, such as RAN (e.g., Rothe et al. 2015; Siddaiah and Padakannaya 2015), or for reading at the higher level, such as listening comprehension (e.g., Verhoeven and van Leeuwe 2012) in the present study. Future also longitudinal research is necessary to examine the predictive patterns of word-specific and general orthographic knowledge combined with RAN, listening comprehension, general intelligence and phonological awareness for reading and spelling skills concurrently in order to better understand the relationship between these capabilities and their role in reading and spelling.

To sum up, the results of this study add to the understanding of the role of both word-specific and general orthographic knowledge in reading and spelling, beside the well-established predictors, general intelligence and phonological awareness. The tasks and items used to measure word-specific and general orthographic knowledge in this study seem to be promising, however further development (especially) of the items is necessary. Moreover, longitudinal studies investigating the role of orthographic knowledge during the scriptural competence development are necessary.
in order to better understand the reciprocal relationship between these capabilities. As a desirable prospect, the development of a standardized test for measuring word-specific and general orthographic knowledge for different languages could reduce methodological discrepancies and enhance the comparability of results. Such a potential standardized test could furthermore be a very important and useful tool for researchers as well as for teachers to reliably identify students with difficulties in these components. By accessing student’s level of word-specific and general orthographic knowledge, it could be possible to identify students at risk for developing reading and spelling difficulties and promptly intervene. Following this aim, it is potentially possible to consider the development of a suitable orthographic knowledge training, which could be implemented in the regular school curriculum, and might be helpful for the acquisition of specific word spellings and orthographic rules. By identifying children at risk as early as possible, and fostering them adequately, it is possible to minimalize their chance of developing reading and spelling difficulties (Valtin et al. 2016).

The results of an explorative factor analysis show that reducing the data structure of the orthographic knowledge measurements into one factor explains 13.23% of the variance. In contrast, when reducing the data structure into two factors, these two factors explain 19.95%. These results indicate that the two-factor data reduction represents the data better than the one-factor solution. These two factors could be considered as the stated two subtypes of orthographic knowledge (word-specific and general).

Acknowledgements Open Access funding provided by Projekt DEAL.

Appendix

Table 5 Items of task measuring word-specific orthographic knowledge—words and pseudohomophones

| Word                      | Frequencya | Pseudohomophone |
|---------------------------|------------|-----------------|
| Fünf [five]b             | 1330       | Fünvb           |
| Aal [eel]                 | 11         | Ahl             |
| Bärtig [bearded]*        | 1          | Bertig*a        |
| Besenstiel [broomstick]* | 114        | Besenstihl*a    |
| Br ei [porridge]         | 102        | Brai            |
| Eilig [urgent]*          | 453        | Allig*a         |
| Fest [tight]*            | 298        | Fäst*a          |
| Fettig [greasy]          | 9          | Fättig          |
| Fleisch [meat]           | 325        | Flaisch         |
| Gelb [yellow]b           | 9          | Gälbb           |
| Getreide [grain]*        | 158        | Getraide        |
| Hässlich [ugly]          | 72         | Hesslich        |
| Jagd [hunting]*          | 34         | Yugd*a          |
| Jacke [jacket]           | 72         | Jakke           |
| Lahm [lame]*             | 214        | Laam*b          |
| Lecker [delicious]       | 462        | Läcker          |
| Märchen [fairy tale]*    | 51         | Merchen*a       |
| Reich [rich]             | 132        | Raich           |
| Saal [hall]*             | 305        | Sahl*a          |
| Specht [woodpecker]      | 177        | Spächt          |
| Zärtlich [fond]*         | 263        | Zärtlich*a      |

a Word-frequency per million words from the corpus in childLex; b practice item * word-pseudohomophone-pairs used to calculate the score in the task measuring word-specific orthographic knowledge after item-analysis
Orthographic knowledge predicts reading and spelling skills over and...

### Table 6 Items of task measuring general orthographic knowledge—knowledge of frequent double consonants

| Stimuli   | Bigramfreq. | Trigramfreq. | Stimuli   | Bigramfreq. | Trigramfreq. |
|-----------|--------------|---------------|-----------|--------------|---------------|
| Sittora   | 630,328      | 38.239        | Siddor*   | 471,866      | 10,524        |
| Bellarb*  | 804,082      | 56,918        | Beggarb*  | 579,106      | 19,018        |
| Bettarb*  | 658,065      | 8278          | Beddab*   | 728,860      | 8506          |
| Dihett*   | 790,950      | 2455          | Dihegg*   | 729,714      | 2012          |
| Dallan*   | 919,441      | 31.511        | Dahliab*  | 838,610      | 7960          |
| Getemm*   | 1,576,248    | 48,822        | Getekk*   | 1,459,920    | 45,863        |
| Gette*    | 1,366,786    | 19,271        | Geggie*   | 1,245,649    | 19,408        |
| Hassic    | 1,222,851    | 110,064       | Haddic    | 930,323      | 14,759        |
| Henemm*   | 2,098,605    | 178,496       | Henekk*   | 1,982,277    | 148,098       |
| Kebemm*   | 648,118      | 35,442        | Kebekk*   | 531,790      | 41,776        |
| Kemman    | 736,851      | 29,294        | Kekkan    | 569,485      | 21,588        |
| Lammei    | 1,064,939    | 34,623        | Lakkei    | 912,666      | 25,471        |
| Lummm*    | 586,021      | 4792          | Lirabb    | 599,570      | 7801          |
| Mellie*   | 726,245      | 21,588        | Mehlig*   | 520,578      | 19,191        |
| Mizullah* | 337,837      | 1562          | Mizudd*   | 316,233      | 948           |
| Nelles*   | 1,168,607    | 24,568        | Nehhes    | 1,112,866    | 9952          |
| Nedutt*   | 603,388      | 1994          | Nedugg*   | 559,565      | 1597          |
| Rissau    | 784,698      | 12,062        | Riddau    | 734,196      | 6212          |
| Ritemb*   | 1,322,411    | 45,606        | Ritekk*   | 1,206,083    | 42,647        |
| Walann    | 865,323      | 34,870        | Walabb    | 590,743      | 4206          |
| Wisamm*   | 551,105      | 33,806        | Wisabb*   | 564,654      | 16,940        |

*pseudoword-pairs used to calculate the score in the task measuring general orthographic knowledge after item-analysis; a practice item; Bigramfreq., bigram-frequency; Trigramfreq., trigram-frequency; Bigram-frequency and trigram-frequency show the mean cumulated percentage of occurrence per million continuous words in the corpus within childLex database

### Table 7 Items of task measuring general orthographic knowledge—knowledge of legal positions of double consonants

| Stimuli   | Bigramfreq. | Trigramfreq. | Stimuli   | Bigramfreq. | Trigramfreq. |
|-----------|--------------|---------------|-----------|--------------|---------------|
| Lodenna   | 2,147,677    | 258,604       | Lloden*   | 2,152,641    | 212,635       |
| Fahopp*   | 209,152      | 9611          | Ffahop*   | 218,147      | 7322          |
| Fosupp*   | 118,094      | 4964          | Ffosp*    | 127,089      | 1044          |
| Fuppat*   | 232,213      | 5276          | Ffupat*   | 241,208      | 876           |
| Leminn*   | 1,412,114    | 29,622        | Llemin*   | 905,998      | 97,451        |
| Linnr*    | 1,244,304    | 54,952        | Linur*    | 1,249,268    | 56,678        |
| Matell    | 1,526,302    | 86,744        | Mmatel    | 1,441,786    | 45,866        |
| Misett*   | 1,475,675    | 196,837       | Mmisett*  | 1,441,786    | 45,208        |
| Mugott*   | 873,142      | 46,826        | Mmugot*   | 839,253      | 30,426        |
| Narel*    | 1,038,418    | 64,317        | Narel*    | 1,033,454    | 24,932        |
| Nellus*   | 996,278      | 57,524        | Nelnus*   | 991,314      | 51,863        |
| Nillau*   | 900,006      | 54,367        | Nnilau*   | 895,042      | 30,282        |
| Nomell    | 706,712      | 63,128        | Nnomel    | 701,748      | 20,619        |
| Paffab*   | 242,943      | 6116          | Ppaffab*  | 233,948      | 1177          |
| Passaf*   | 508,841      | 12,790        | Ppasaf*   | 499,846      | 7644          |
| Patef*    | 1,112,250    | 18,167        | Ppatef*   | 1,102,255    | 16,520        |
| Puffan*   | 608,541      | 11,744        | Ppuffan*  | 599,546      | 9418          |
| Tammit*   | 610,325      | 98,796        | Ttammit*  | 644,214      | 93,110        |
| Timmac*   | 531,645      | 84,176        | Ttimmac*  | 565,534      | 41,395        |
| Tokam*    | 289,750      | 31,979        | Ttokam*   | 323,639      | 15,464        |

*pseudoword-pairs used to calculate the score in the task measuring general orthographic knowledge after item-analysis; a practice item; Bigramfreq., bigram-frequency; Trigramfreq., trigram-frequency; Bigram-frequency and trigram-frequency show the mean cumulated percentage of occurrence per million continuous words in the corpus within childLex database
Table 8: Results of the explorative factor analysis

|                | Explained variance |
|----------------|--------------------|
| 1 factor       | 13.23%             |
| 2 factors      | 19.95%             |

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Abbott, R. D., & Berninger, V. W. (1993). Structural equation modeling of relationships among developmental skills and writing skills in primary- and intermediate-grade writers. *Journal of Educational Psychology*, 85(3), 478–508.

Amthauer, R. (1970). *Intelligenz-Struktur-Test 70*. Göttingen: Hogrefe.

Apel, K. (2011). What is orthographic knowledge? *Language, Speech, and Hearing Services in Schools*, 42(4), 592–603.

Arab-Moghaddam, N., & Senechal, M. (2001). Orthographic and phonological processing skills in reading and spelling in Persian/English bilinguals. *International Journal of Behavioral Development*, 25(2), 140–147.

Barker, T. A., Torgesen, J. K., & Wagner, R. K. (1992). The role of orthographic processing skills on five different reading tasks. *Reading Research Quarterly*, 27(4), 334.

Barron, R. W. (1986). Word recognition in early reading: a review of the direct and indirect access hypotheses. *Cognition*, 24(1–2), 93–119.

Bekebrede, J., van der Leij, A., & Share, D. L. (2009). Dutch dyslexic adolescents: Phonological-core variable-orthographic differences. *Reading and Writing*, 22(2), 133–165.

Bergmann, J., & Wimmer, H. (2008). A dual-route perspective on poor reading in a regular orthography: Evidence from phonological and orthographic lexical decisions. *Cognitive Neuropsychology*, 25(5), 653–676.

Berninger, V. W. (1994). Introduction to the varieties of orthographic knowledge I: Theoretical and developmental issues. In V. W. Berninger (Ed.), *The varieties of orthographic knowledge I. Theoretical and developmental issues* (pp. 1–25). Dodrecht: Kluwer Academic Publishers.

Brunner, M., Seibert, A., Dierks, A., & Körkel, B. (1999). *Heidelberger Lautdifferenzierungstest H-LAD. Prüfung der auditiv-kinästhetischen Wahrnehmung zur Differenzierung der Ursachen bei Lese- und Rechtschreibschwäche*. Heidelberg: Westra.

Caravolas, M., Hulme, C., & Snowling, M. J. (2001). The foundations of spelling ability: Evidence from a 3-year longitudinal study. *Journal of Memory and Language*, 45(4), 751–774.

Cassar, M., & Treiman, R. (1997). The beginnings of orthographic knowledge: Children’s knowledge of double letters in words. *Journal of Educational Psychology*, 89(4), 631–644.

Castles, A. (2006). The dual route model and the developmental dyslexias. *London Review of Education*, 4(1), 49–61.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition*, 91(1), 77–111.

Claessen, M., Heath, S., Fletcher, J., Hogben, J., & Leitão, S. (2009). Quality of phonological representations: A window into the lexicon? *International Journal of Language & Communication Disorders*, 44(2), 121–144.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108(1), 204–256.

Conrad, N. J., Harris, N., & Williams, J. (2013). Individual differences in children’s literacy development: The contribution of orthographic knowledge. *Reading and Writing*, 26(8), 1223–1239.

Cunningham, A. E., & Stanovich, K. E. (1990). Assessing print exposure and orthographic processing skill in children: A quick measure of reading experience. *Journal of Educational Psychology*, 82(4), 733–740.

Cunningham, A. E., & Stanovich, K. E. (1993). Children’s literacy environments and early word recognition subskills. *Reading and Writing*, 5(2), 193–204.
Orthographic knowledge predicts reading and spelling skills over and...
Loveall, S. J., Channell, M. M., Phillips, B. A., & Conners, F. A. (2013). Phonological recoding, rapid automatized naming, and orthographic knowledge. *Journal of Experimental Child Psychology, 116*(3), 738–746.

Masterson, J., & Apel, K. (2007). Spelling and word-level reading: A multilingual approach. In A. Kamhi, J. Masterson, & K. Apel (Eds.), *Clinical decision making in developmental language disorders* (pp. 249–266). Baltimore: Paul H. Brookes Pub. Co.

Moll, K., & Landerl, K. (2010). *Lese- und Rechtschreibtest (SLRT II).* Weiterentwicklung des Salzburger Lese- und Rechtschreibtests (SLRT). Bern: Verlag Hans Huber.

Muter, V., & Diethelm, K. (2001). The contribution of phonological skills and letter knowledge to early reading development in a multilingual population. *Language Learning, 51*(2), 187–219.

Näslund, J. C., & Schneider, W. (1996). Kindergarten letter knowledge, phonological skills, and memory processes: Relative effects on early literacy. *Journal of Experimental Child Psychology, 62*(1), 30–59.

Olson, R., Forsberg, H., Wise, B., & Rack, J. (1994). Measurement of word recognition, orthographic, and phonological skills. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: new views on measurement issues* (pp. 243–277). Baltimore: Brookes Publishing.

Oswald, W. D., & Roth, E. (1987). *Der Zahlen-Verbindungs-Test (ZVT).* Ein sprachfreier Intelligenztest zur Messung der kognitiven Leistungsgeschwindigkeit (2. überarb.). Göttingen: Hogrefe.

Pacton, S., & Fayol, M. (2004). Learning to spell in a deep orthography: The case of French. In R. Berman (Ed.), *Language development across childhood and adolescence* (pp. 163–167). Amsterdam: Benjamin.

Pacton, S., Perruchet, P., Fayol, M., & Cleeremans, A. (2001). Implicit learning out of the lab: The case of orthographic regularities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(3), 401–426.

Pae, H. K., Sevcik, R. A., & Morris, R. D. (2010). Cross-language correlates in phonological awareness and naming speed: Evidence from deep and shallow orthographies. *Journal of Research in Reading, 34*(4), 374–391.

Peirce, J. W. (2008). Generating stimuli for neuroscience using PsychoPy. *Frontiers in Neuroinformatics, 2*(10), 1–8.

Perfetti, C. A., & Hart, L. (2004). *Precursors of Functional Literacy.* Oxford, Mass: Oxford Univ. Press.

Pfost, M. (2015). Children’s phonological awareness as a predictor of reading and spelling: A systematic review of longitudinal research in German-speaking countries. *Zeitschrift für Entwicklungspychologie und pädagogische Psychologie, 47*(3), 123–138.

Preßler, A.-L., König, T., Hasselhorn, M., & Krajewski, K. (2014) Cognitive preconditions of early reading and spelling acquisition: A latent-variable approach with longitudinal data. *Reading and Writing, 27*(2), 383-406.

Roman, A. A., Kirby, J. R., Parrila, R. K., Wade-Woolley, L., & Deacon, S. H. (2009). Toward a comprehensive view of the skills involved in word reading in grades 4, 6, and 8. *Journal of Experimental Child Psychology, 102*(1), 96–113.

Rothe, J., Cornell, S., Ise, E., & Schulte-Körne, G. (2015). A comparison of orthographic processing in children with and without reading and spelling disorder in a regular orthography. *Reading and Writing, 28*(9), 1307–1332.

Rothe, J., Schulte-Körne, G., & Ise, E. (2014). Does sensitivity to orthographic regularities influence reading and spelling acquisition? A 1-year prospective study. *Reading and Writing, 27*(7), 1141–1161.

Schoerder, S., Würzner, K.-M., Heister, J., Geyken, A., & Kliegl, R. (2015). childLex: A lexical database of German read by children. *Behavior Research Methods, 47*(4), 1085–1094.

Schulte-Körne, G. (2011). *Lese- und Rechtschreibstörung im Schulalter - neuropsychologische Aspekte.* Zeitschrift für Psychiatrie, Psychologie und Psychotherapie, 59(1), 47–55.

Seymour, P. H. K. (1999). Cognitive architecture of early reading. In I. Lundberg, F. E. Tønnessen, & I. Austad (Eds.), *Dystexia: Advances in theory and practice. Neuropsychology and cognition* (16th ed.). Dodrecht: Springer.

Share, D. L. (2004). Orthographic learning at a glance: On the time course and developmental onset of self-teaching. *Journal of Experimental Child Psychology, 87*(4), 267–298.

Sididdah, A., & Padakannaya, P. (2015). Rapid automatized naming and reading: A review. *Psychological Studies, 60*(1), 70–76.

Snow, C. E., Griffin, P., & Burns, M. S. (2005). Knowledge to support the teaching of reading: Preparing teachers for a changing world. San Francisco: John Wiley & Sons.

Stanovich, K. E., Cunningham, A. E., & Feeman, D. J. (1984). Intelligence, cognitive skills, and early reading progress. *Reading Research Quarterly, 19*(3), 278.

Stanovich, K. E., & West, R. F. (1989). Exposure to print and orthographic processing. *Reading Research Quarterly, 24*(4), 402.

Steinbrink, C., & Lachmann, T. (2014). *Lese- Rechtschreibstörung. Grundlagen, Diagnostik, Intervention.* Berlin: Springer.

Treiman, R. (1993). *Beginning to spell: A study of first-grade children.* Oxford, Mass: Oxford Univ. Press.
Orthographic knowledge predicts reading and spelling skills over and...
Brod, G., Hasselhorn, M., & Bunge, S. A. (2018). When generating a prediction boosts learning: The element of surprise. Learning and Instruction, 55, 22–31.

Klesczewski, J., Brandenburg, J., Fischbach, A., Schuchardt, K., Grube, D., Hasselhorn, M. & Büttner, G. (2018). Development of working memory from grade 3 to 5: Differences between children with and without mathematical learning difficulties. International Journal of Disability, Development, and Education, 1–17. doi: https://doi.org/10.1080/1034912X.2017.1419555

Bar-Kochva, I., & Hasselhorn, M. (2017). The training of morphological decomposition in word processing and its effects on literacy skills. Frontiers in Psychology, 8:1583. doi:https://doi.org/10.3389/fpsyg.2017.01583

Brandenburg, J., Klesczewski, J., Schuchardt, K., Fischbach, A., Büttner, G., & Hasselhorn, M. (2017). Phonological processing in children with specific reading disorder versus typical learners: Factor structure and measurement invariance in a transparent orthography. Journal of Educational Psychology, 109, 709–726. doi:https://doi.org/10.1037/edu0000162

Nagler, T., Lindberg, S., & Hasselhorn, M. (2017). The training of morphological decomposition in word processing and its effects on literacy skills. Lernen und Lernstörungen, 1–12. doi:https://doi.org/10.1024/2235-0977/a000185

Vidmar, M., Niklas, F., Schneider, W., & Hasselhorn, M. (2017). On-entry assessment of school competencies and academic achievement: A comparison between Slovenia and Germany. European Journal of Psychology of Education, 32, 311–331. doi:https://doi.org/10.1007/s10122-016-0294-9

Brandenburg, J., Fischbach, A., Labuhn, A.S., Rietz, C.S., Schmid, J., & Hasselhorn, M. (2016). Overidentification of learning disorders among language-minority students: Implications for the standardization of school achievement tests. Journal of Educational Research Online, 8 (1), 42–65.

Ehm, J.-H., Kernler auch Koerner, J., Gawrilow, C., Hasselhorn, M., & Schmiedek, F. (2016). The association of ADHD symptoms and reading acquisition during elementary school years. Developmental Psychology, 52 (9), 1445–1456. doi: https://doi.org/10.1037/dev000186

Bar-Kochva, I., & Hasselhorn, M. (2015). In search of methods enhancing fluency in reading: An examination of the relations between time constraints and processes of reading in readers of German. Journal of Experimental Child Psychology, 140, 140–157. https://doi.org/10.1016/j.jecp.2015.06.012

Brandenburg, J., Klesczewski, J., Fischbach, A., Schuchardt, K., Büttner, G., & Hasselhorn, M. (2015). Working memory in children with learning disabilities in reading versus spelling: Searching for overlapping and specific cognitive factors. Journal of Learning Disabilities. 48, 622–634. doi:https://doi.org/10.1177 /0022219414521665

Hasselhorn, M., Andresen, S., Becker, B., Betz, T., Leuzinger-Bohleber, M., & Schmid, J. (2015). Children at risk of poor educational outcomes: In search of a transdisciplinary theoretical framework. Child Indicators Research, 8, 425–438. doi:https://doi.org/10.1007/s12187-014-9263-5

Linkersdörfer, J., Jurcoane, A., Lindberg, S., Kaiser, J., Hasselhorn, M., Fiebach, C. J., & Lonnemann, J. (2015). The association between gray matter volume and reading proficiency - A longitudinal study of beginning readers. Journal of Cognitive Neuroscience, 27, 308–318. doi:https://doi.org/10.1162/jocn_a_00710

Nagler, T., Korinth, S., Linkersdörfer, J., Lonnemann, J., Rump, B., Hasselhorn, M., & Lindberg, S. (2015). Text-fading based training leads to transfer effects on children’s sentence reading fluency. Frontiers in Psychology, 6 (119). doi:https://doi.org/10.3389/fpsyg.2015.00119

Telse Nagler. Leibniz Institute for Research and Information in Education (DIPF), Rostocker Straße 6 60323 Frankfurt am Main, Germany. E-mail: nagler@dipf.de

Current themes of research:

Early childhood education. Acquisition of reading. Text-fading reading training.

Most relevant publications in the field of Psychology of Education:

Nagler, T., Lindberg, S. & Hasselhorn, M. (2018). Leseentwicklung in der Kindheit: Einflussfaktoren und Fördermöglichkeiten. Kindheit und Entwicklung, 27, 5–13.

Nagler, T., Lindberg, S. & Hasselhorn, M. (2018). Leseentwicklung im Grundschulalter. Kognitive Grundlagen und Risikofaktoren. Lernen und Lernstörungen, 7, 33–44.

Nagler, T., Linkersdörfer, J., Lonnemann, J., Hasselhorn, M. & Lindberg, S. (2016). The impact of text fading on reading in children with reading difficulties. Journal of Educational Research Online, 8, 26–41.
Orthographic knowledge predicts reading and spelling skills over and...