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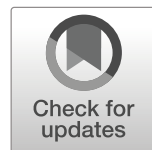


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Orthographic knowledge predicts reading and spelling skills over and above general intelligence and phonological awareness

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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

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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; Muter 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.

2013). 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 both word-specific and general orthographic knowledge provide an unique contribution to both reading and spelling proficiency, over and above the contribution of 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 ($IQ \leq 85$ or $IQ \geq 130$) as assessed by a standardized test (Zahlen-Verbindungs-Test – ZVT; [A trail making test]; 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.

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

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 $\alpha = .92$ and $\alpha = .97$. 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 $r_{tt} = .80$ and $r_{tt} = .97$. 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

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*). Bigram³ and trigram⁴ 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*). Bigram⁵ and trigram frequencies⁶ 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 ($\leq .11$) and difficulty ($\leq .40$ and $\geq .95$) 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

Table 2 Intercorrelations among general intelligence, phonological awareness, word-specific orthographic knowledge, general orthographic knowledge, reading, and spelling skills

	1	2	3	4	5	6	7	8
1 General intelligence (IQ)	–							
2 Phonological awareness	.08	–						
3 Reading at word- level	.28*	.22*	–					
4 Reading at sentence-level	.35**	.23*	.83**	–				
5 Reading at text-level	.27*	.28*	.73**	.76**	–			
6 Spelling	.28*	.20	.67**	.67**	.61**	–		
7 Word-specific orth. know.	–.01	.08	.39**	.33** ^a	.28*	.44**	–	
8 General orth. know.	.07	.18	.38**	.25 ^a	.24 ^a	.39**	.37**	–

* $p \leq .05$, *orth. know.* orthographic knowledge, ^a Comparison of the correlations coefficients via Fischer z-transformation test shows no significant difference between the correlations coefficients (z -value = .40, $p = .34$), *IQ*, intelligence quotient

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		
			β	R^2	ΔR^2	β	R^2	ΔR^2	β	R^2	ΔR^2
1	1	IQ	.35*	.16		.43**	.23		.24*	.12	
		PA	.18								
	2	IQ	.36*	.33	.17**	.43**	.38	.15**	.25*	.20	.08*
		PA	.12								
		Word-specific orth. know.	.42**								
		General orth. know.	.32*								
2	1	IQ	.35*	.16		.43**	.23		.24*	.12	
		PA	.18								
	2	IQ	.35*	.25	.09*	.42**	.31	.08*	.24*	.17	.05*
		PA	.18								
		Word-specific orth. know.	.32*								
		General orth. know.	.32*								
3	1	IQ	.35*	.16		.43**	.23		.24*	.12	
		PA	.18								
	2	IQ	.35*	.36	.20**	.42**	.40	.17**	.24*	.21	.09*
		PA	.18								
		Word-specific orth. know.	.35*								
		General orth. know.	.19*								

* $p \leq .05$, ** $p \leq .01$, *IQ*, intelligence quotient (i.e., general intelligence); *PA*, phonological awareness; *orth. know.*, orthographic knowledge

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 4 Results from hierarchical multiple regression analyses for spelling performance (dependent variable: raw score in the spelling task—SLRT-II)

Model	Step	Predictor	β	R^2	ΔR^2
1	1	General intelligence (IQ)	.26*	.10*	
		Phonological awareness	.19		
	2	General intelligence (IQ)	.26*	.38**	
		Phonological awareness	.12		
		Word-specific orthographic knowledge	.53**		
2	1	General intelligence (IQ)	.26*	.10*	
		Phonological awareness	.19		
	2	General intelligence (IQ)	.24*	.23**	
		Phonological awareness	.08		
		General orthographic knowledge	.37**		
3	1	General intelligence (IQ)	.26*	.10*	
		Phonological awareness	.19		
	2	General intelligence (IQ)	.25*	.41**	
		Phonological awareness	.07		
		Word-specific orthographic knowledge	.46**		
		General orthographic knowledge	.21*		.31**

* $p \leq .05$, ** $p \leq .01$, *IQ*, intelligence quotient

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 minimize 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).

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Appendix

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

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

^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

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

Frequently occurring			Rarely occurring		
Stimuli	Bigramfreq.	Trigramfreq.	Stimuli	Bigramfreq.	Trigramfreq.
Sittor ^a	630,328	38,239	Siddor ^a	471,866	10,524
Bellab	804,082	56,918	Beggab	579,106	19,018
Bettab*	658,065	8278	Beddab*	728,860	8506
Dihett*	790,950	2455	Dihegg*	729,714	2012
Dallan*	919,441	31,511	Dahhan*	838,610	7960
Getemm*	1,576,248	48,822	Getekk*	1,459,920	45,863
Gettie*	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
Kebebm*	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	912,505	25,471
Liramm	586,021	5192	Lirabb	599,570	7801
Mellig*	726,245	21,588	Mehhig*	520,578	19,191
Mizull	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
Ritemm*	1,322,411	45,606	Ritekk*	1,206,083	62,647
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

Legal			Illegal		
Stimuli	Bigramfreq.	Trigramfreq.	Stimuli	Bigramfreq.	Trigramfreq.
Lodenn ^a	2,147,677	258,604	Lloden ^a	2,152,641	212,635
Fahopp*	209,152	9611	Ffahop*	218,147	7322
Fosupp*	118,094	4964	Ffosup*	127,089	1044
Fuppat*	232,213	5276	Ffupat*	241,208	876
Lannag*	927,832	112,628	Llanag*	932,796	39,967
Leminn*	1,412,114	29,622	Llemin*	905,998	97,451
Linnur*	1,244,304	54,952	Llinur*	1,249,268	56,678
Matell	1,526,302	86,744	Mmatel	1,441,786	45,866
Misett	1,475,675	196,837	Mmiset	1,441,786	45,208
Mugott*	873,142	46,826	Mmugot*	839,253	30,426
Narell*	1,038,418	64,317	Nnarel*	1,033,454	24,932
Nellus*	996,278	57,524	Nnelus*	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	Ppafab*	233,948	1177
Pasaff*	508,841	12,790	Ppasaf*	499,846	7644
Pateff*	1,111,250	18,167	Ppatef*	1,102,255	16,520
Puffan*	608,541	11,744	Ppufan*	599,546	9418
Tammit*	610,325	98,796	Ttमित*	644,214	93,110
Timmac*	531,645	84,176	Ttimac*	565,534	41,395
Tokamm*	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

	1 factor	2 factors
Explained variance	13.23%	19.95%

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Current themes of research:

Acquisition of reading and spelling. Orthographic knowledge. Early childhood education.

Most relevant publications in the field of Psychology of Education:

No previous publications

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Current themes of research:

Acquisition of reading, spelling, and arithmetics. Learning disabilities. Early education.

Most relevant publications in the field of Psychology of Education:

- Ehm, J.-H., Lonnemann, J., Brandenburg, J., Huschka, S., Hasselhorn, M., & Lervåg, A.O. (2019). Exploring factors underlying children's acquisition and retrieval of sound-symbol association skills. *Journal of Experimental Child Psychology*, 177, 86–99. [doi.org/https://doi.org/10.1016/j.jecp.2018.07.006](https://doi.org/10.1016/j.jecp.2018.07.006)
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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.
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