The role of orthographic knowledge for reading performance in German elementary school children

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Zusammenfassung (German summary)

Lesen ist unabdingbar, um am gesellschaftlichen Leben erfolgreich teilnehmen zu können. Allerdings zeigen 3-8% (z. B. Moll, Kunze, Neuhoff, Bruder, & Schulte-Körne, 2014) der Kinder im Grundschulalter Leseschwierigkeiten, die zu eingeschränkter Bildung und damit einhergehendem erhöhten Risiko für soziale und finanzielle Nachteile führen können (Valtin, 2017). Um solchen ungünstigen Entwicklungsverläufen entgegenzuwirken ist es wichtig, leserelevante Komponenten zu identifizieren (Tippelt & Schmidt-Hertha, 2018). In diesem Zusammenhang haben sich insbesondere phonologische Bewusstheit (Fähigkeit zu Erkennung und Anwendung von Informationen aus dem Lautsystem einer Sprache) und Benenngeschwindigkeit (Fähigkeit, vertraute Stimuli so schnell wie möglich zu benennen) als wichtige leserelevante Komponenten erwiesen (z. B. Georgiou, Papadopoulos, Fella, & Parrila, 2012; Landerl & Thaler, 2006; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Eine weitere Komponente, die derzeit zunehmend Beachtung in der Forschung bekommt ist das orthographische Wissen. Darunter wird das Wissen über die spezifische Schreibweise bestimmter Wörter (wort-spezifisches orthographisches Wissen) und das Wissen über die zulässigen Buchstabenmuster (generelles orthographisches Wissen) verstanden (Apel, 2011).

Die Rolle des orthographischen Wissens wurde bisher vorrangig für basale Leseprozesse auf Wortebene untersucht (z. B. Conrad, Harris, & Williams, 2013; Rothe, Cornell, Ise, & Schulte-Körne, 2015), die das Erkennen einzelner Wörter und ihrer Bedeutung beinhalten. Der Zusammenhang zwischen orthographischem Wissen und Leseverständnis als übergeordnetem Ziel des Lesens, durch das ein Verständnis der Beziehungen zwischen den Wörtern innerhalb eines Satzes sowie der Kohärenzbildung zwischen den Sätzen ermöglicht wird (Perfetti, Landi, & Oakhill, 2005), war hingegen bisher kaum Forschungsgegenstand. Ein erstes Ziel der vorliegenden Dissertation besteht darin, hier Abhilfe zu schaffen durch die Untersuchung der Rolle des orthographischen Wissens für höhere Leseprozesse auf Satz- und

Textebene. Die wenigen dazu bisher vorgelegten Studien bei Kindern mit Leseschwierigkeiten ergaben kein eindeutiges Befundmuster (siehe z. B. Ise, Arnoldi, & Schulte-Körne, 2014). Daher wird in der vorliegenden Dissertation der Einfluss des orthographischen Wissens auf Wort-, Satz- und Textebene bei Kindern ohne und mit Leseschwierigkeiten untersucht, um diese Forschungslücke zu füllen.

Eine vertiefte Kenntnis der leserelevanten Komponenten ist auch für die Konzeption von Interventionen erforderlich, die auf individuelle Verbesserungen der Lesefähigkeiten abzielen, um dem schulischen Misserfolg entgegenzuwirken. Eine vielversprechende Möglichkeit Kindern zu helfen, ihre Leseschwierigkeiten zu überwinden, stellt das Text-Fading basierte Lesetraining dar, bei dem der zu lesende Text in Leserichtung (im Deutschen von links nach rechts) Buchstabe für Buchstabe ausgeblendet wird (Breznitz & Nevat, 2006). Es wird angenommen, dass das Ausblenden des zu lesenden Trainingsmaterials zu einer höheren Lesegeschwindigkeit und damit einhergehenden Verbesserung des Leseverständnisses führt (z. B. Nagler et al., 2015). Allerdings sind die zugrundeliegenden Mechanismen, die zur verbesserten Leseleistungen führen, bisher noch nicht geklärt. Da bisherige Interventionsstudien gezeigt haben, dass die orthographischen Fähigkeiten Trainingseffekten beeinflussen können (Berninger et al., 1999) und die Wortlesefähigkeit nach einer Leseintervention beeinflussen (Stage, Abbott, Jenkins, & Berninger, 2003), liegt es nahe, das orthographische Wissen bei der Untersuchung von möglichen Trainingseffekten miteinzubeziehen. Daher verfolgt diese Arbeit auch das Ziel, die prädiktive Rolle des orthographischen Wissens für das Leseverständnis während des Text-Fading basierten Lesetrainings zu klären.

Zur Beantwortung der ersten Forschungsfrage wurden zwei empirischen Arbeiten umgesetzt (siehe Anhang A: Zarić, Hasselhorn, & Nagler, 2020 und Anhang B: Zarić & Nagler, 2021), die die Rolle des orthographischen Wissens für das Lesen auf Wort-, Satz- und Textebene bei deutschen Grundschulkinder ohne und mit Leseschwierigkeiten untersuchen. In

der Arbeit von Zarić et al. (2020) wurde der inkrementelle Zuwachs aufgeklärter Varianz der Leseleistung durch die beiden Komponenten des orthographischen Wissens (wort-spezifisch und generell) gegenüber der durch allgemeine Intelligenz und phonologische Bewussteit aufklärbaren Varianz näher bestimmt. Dafür wurden Daten von 66 deutschen Grundschulkindern der dritten Jahrgangsstufe ohne Leseschwierigkeiten analysiert. Die Korrelations- und multiplen Regressionsanalysen ergaben, dass sowohl das wort-spezifische als auch das generelle orthographische Wissen einen eigenständigen Anteil zur Varianzerklärung des Leseverständnisses auf Wort-, Satz- und Textebene liefern, zusätzlich zur bereits erklärten Varianz durch die allgemeine Intelligenz und phonologische Bewusstheit. Um die Frage zu klären, ob das wort-spezifische und generelle orthographische Wissen auch bei Kindern mit Leseschwierigkeiten zusätzlich zu den etablierten Prädiktoren phonologische Bewusstheit und Benenngeschwindigkeit Lesevarianz erklären, wurden in einer weiteren Studie Daten von 103 leseschwachen deutschen Grundschuldkindern der dritten Jahrgangsstufe analysiert (Zarić & Nagler, 2021). Die Ergebnisse sprechen dafür, dass sowohl das wort-spezifische als auch das generelle orthographische Wissen zusätzlich Varianzanteile auf Wort- und Satzebene erklären. Auf Textebene konnte durch die beiden Komponenten des orthographischen Wissens keine zusätzliche eigenständige Varianz erklärt werden. Hier erwies sich die phonologische Bewusstheit als einziger signifikanter Prädiktor für die Erklärung der Varianz auf Textebene. Diese Ergebnisse deuten darauf hin, dass das Wissen über die Schreibweise spezifischer Wörter (wort-spezifisches orthographisches Wissen) und das Wissen über die legalen Buchstabenmuster (generelles orthographisches Wissen) für das Verständnis auf Wortebene von Bedeutung sind. Folgt man beispielsweise der Annahmen der Lexical Quality Hypothesis (Perfetti & Hart, 2002), sind qualitativ hochwertige orthographische Repräsentationen im mentalen Lexikon für höhere Leseprozesse, wie das Leseverständnis, zentral. Es kann daher davon ausgegangen werden, dass das wort-spezifische und generelle orthographische Wissen die automatisierte Erkennung

und das Lesen einzelner Wörter unterstützen, wodurch sie schnell verarbeitet werden und dadurch kognitive Ressourcen frei setzen, die für das Leseverständnis (auf Satz- und Textebene) genutzt werden können. Bei Kindern mit Leseschwierigkeiten scheint allerdings für die Leseprozesse auf Textebene das orthographische Wissen keine signifikante Rolle zu spielen. Dies könnte damit zusammenhängen, dass Kinder mit Leseschwierigkeiten für das Lesen auf Textebene vermehrt auf phonologische Prozesse zurückgreifen (Constantinidou & Stainthorp, 2009). Diese Annahme passt zu dem vorliegenden Ergebnis, dass bei diesen Kindern nur die phonologische Bewusstheit sich als signifikanter Prädiktor für das Lesen auf Textebene erwiesen hat (Zarić & Nagler, 2021).

Um die zweite Forschungsfrage zu beantworten, wurde in einer weiteren Studie die prädiktive Rolle des orthographischen Wissens und der Benenngeschwindigkeit für das Leseverständnis während eines auf Text-Fading-Methode basierten Lesetrainings untersucht (siehe Anhang C: Nagler, Zarić, Kachisi, Lindberg, & Ehm, 2021). Dafür wurden 120 deutsche Grundschulkindern der dritten Jahrgangsstufe mit Leseschwierigkeiten untersucht. Die Strukturgleichungsanalysen ergaben, dass das orthographische Wissen signifikant zur Varianzaufklärung der Leseverständnisleistung während des Text-Fading basierten Lesetrainings nur dann beiträgt, wenn das Trainingsmaterial in eigener Geschwindigkeit gelesen werden durfte (Kontrollgruppen-Bedingung). Für die Experimentalgruppe, die die Text-Fading-Methode erhielt, erwies sich nur die Benenngeschwindigkeit als signifikanter Prädiktor. Diese Ergebnisse legen nahe, dass das orthographische Wissen die automatisierte Erkennung und das Lesen einzelner Wörter erleichtert und ihre Verarbeitung unterstützt (Ehri, 2014), wodurch der Inhalt der Sätze während des Lesens in eigener Geschwindigkeit besser verstanden werden kann. Wenn aber das Lesen schneller erfolgen soll, wie beim Text-Fading-Training durch das Ausblenden des Textes evoziert, spielt der automatisierte und schnelle Abruf von orthographischen Repräsentationen (gespiegelt in den Benenngeschwindigkeit) eine wichtigere Rolle als die orthographischen Repräsentationen selbst.

Die vorgelegten Ergebnisse unterstreichen die Rolle des orthographischen Wissens für basale Leseprozesse und erweitern die bisherigen Befunde (z. B. Rothe et al., 2015) auf höhere Leseprozesse bei deutschen Grundschulkindern mit und ohne Leseschwierigkeiten. Besonders interessant ist hierbei der Befund, dass das orthographische Wissen insbesondere das Leseverständnis zu beeinflussen scheint, wenn in eigenem Tempo gelesen wird. Dies ist bei der Weiterentwicklung des Text-Fading-Lesetrainings zu berücksichtigen. Zusammenfassend kann festgehalten werden, dass die Erfassung des orthographischen Wissens Potenzial für die Diagnostik und Förderung von Kindern mit Leseschwierigkeiten zu haben scheint. Insbesondere könnten dadurch Kinder mit erhöhtem Risiko für Leseschwierigkeiten frühzeitig erkannt und entsprechend gefördert werden.

Summary

Reading is crucial for successful participation in the modern world. However, 3-8% (e.g., Moll et al., 2014) of children in elementary school age show reading difficulties, which can lead to limited education and enhance risks of social and financial disadvantages (Valtin, 2017). Therefore, it is important to identify reading relevant components (Tippelt & Schmidt-Hertha, 2018). In this context, especially phonological awareness (i.e., awareness of the sound structure of the language) and naming speed (i.e., fast and automatized retrieval of information) were identified as significant components for reading skills (e.g., Georgiou et al., 2012; Landerl & Thaler, 2006; Vellutino, Fletcher, Snowling, & Scanlon, 2004). One further component, which is of growing interest to the recent research, is orthographic knowledge. It comprises the knowledge about the spelling of specific words (word-specific orthographic knowledge) and about legal letter patterns (general orthographic knowledge; Apel, 2011).

Previous research focused predominantly on examining the role of orthographic knowledge on basic reading level, including word identification and word meaning (Conrad et al., 2013; Rothe et al., 2015). The relationship between orthographic knowledge and reading comprehension as the core objective of reading, including understanding of the relationship between words within a sentence as well as building a coherence between sentences (Perfetti et al., 2005), was on the contrary scarcely the object of research. The first goal of this dissertation is, therefore, to provide a remedy by investigating the role of orthographic knowledge on higher reading processes (sentence- and text-level). The scarce body of research investigating children with reading difficulties provide a mixed result pattern (e.g., Ise et al., 2014). Therefore, this dissertation aims at clarifying the influence of orthographic knowledge on word-, sentence-, and text-level in children without and with reading difficulties.

A thorough understanding of reading relevant components is also important for conception of interventions aiming at individual reading performance improvements in order to prevent school failure. One promising approach to help children to overcome their reading difficulties is a text-fading based reading training. During this procedure, reading material is faded out letter by letter in reading direction (i.e., in German from left to right; Breznitz & Nevat, 2006). The aim of this manipulation is to prompt the individual to read faster than usual, resulting in reading rate and comprehension improvements (e.g., Nagler et al., 2015). However, the underlying mechanisms leading to improvements of reading performance are still unclear. Considering previous findings showing orthographic skills to influence training outcomes (Berninger et al., 1999), and also word reading performance after a reading intervention (Stage et al., 2003), it seems plausible to include orthographic knowledge when investigating potential training effects. Therefore, this dissertation aims at investigating the predictive value of orthographic knowledge for comprehension performance during the text-fading based reading training.

In order to answer the first research question, two empirical papers are implemented (see Appendix A: Zarić et al., 2020 and Appendix B: Zarić & Nagler, 2021), which investigate the role of orthographic knowledge for reading at word-, sentence-, and text-level in German school children without and with reading difficulties. The study by Zarić et al. (2020) examines the incremental predictive value for explained reading variance of both word-specific and general orthographic knowledge in relation to variance amount explained by general intelligence and phonological awareness. For this purpose, data from 66 German third-graders without reading difficulties were analyzed. Correlation and multiple regression analyses have shown that word-specific and general orthographic knowledge contribute a unique significant amount to the variance of reading comprehension on word-, sentence-, and text-level, over and above the explained variance by general intelligence and phonological awareness. In order to answer the question whether word-specific and general orthographic

knowledge also explain variance in children with poor reading proficiency, in addition to established predictors phonological awareness and naming speed, the data from 103 German third-graders with reading difficulties were analyzed in a second study (Zarić & Nagler, 2021). The analyses revealed that word-specific and general orthographic knowledge explain a unique significant amount of the variance of reading on word- and sentence-level. On text-level, these two components did not explain a significant amount of unique variance. Here, only phonological awareness was shown to be a significant predictor. The results indicate that the knowledge about the spelling of specific words (word-specific orthographic knowledge) and the knowledge about legal letter patterns (general orthographic knowledge) contribute to reading comprehension on word-level. Following the assumptions, for instance, of the Lexical Quality Hypothesis (Perfetti & Hart, 2002) high-quality orthographic representations are considered to be important for higher reading processes, such as comprehension. It can be assumed that word-specific and general orthographic knowledge support the automatized identification and reading of single words, thus, enabling their quick processing, which in turn frees up cognitive resources necessary for (sentence- and text-) comprehension. However, in children with reading difficulties orthographic knowledge does not seem to play an important role for reading at text-level. These might occur due to an increased use of phonological skills on text-level in children with poor reading proficiency (Constantinidou & Stainthorp, 2009). This is in line with the result showing that in a sample of children with reading difficulties, only phonological awareness was identifyed as a significant predictor for reading comprehension on text-level (Zarić & Nagler, 2021).

In order to answer the second research question, the predictive role of orthographic knowledge for reading comprehension performance during a text-fading based reading training was investigated in a further study (see Appendix C: Nagler, Zarić, Kachisi, Lindberg, & Ehm, 2021). For this purpose, 120 German third-graders with reading difficulties were investigated. Structural equation model analyses revealed that orthographic knowledge

is only a significant predictor for reading comprehension when the training material is read in own pace (control group). For the experimental group, who received the text-fading manipulation, only naming speed was identified as a significant predictor. These results indicate that orthographic knowledge supports the automatized identification and reading of single words, enabling their processing (e.g., Ehri, 2014) as well as comprehension of the content of the sentences only while reading in own pace. However, when reading under time constraint, as evoked in the text-fading condition, the ability to quickly and accurately retrieve the stored orthographic representations from the mental lexicon seems to play a more important role than the mere quality of these orthographic representations.

The results of this dissertation underline the role of orthographic knowledge for basic reading processes and extend previous results (e.g., Rothe et al., 2015) for higher reading processes in German elementary school children with and without reading difficulties. Especially interesting is the finding showing orthographic knowledge to particularly influence reading comprehension when reading in own pace. This should be considered for further development of the text-fading based reading interventions. To sum up, orthographic knowledge assessment seems to have potential in diagnostic processes as well as in fostering children with reading difficulties. This is especially of great importance when identifying children at risk for developing reading difficulties as well as when implementing a prompt and appropriate intervention.

1. Reading: Processes and challenges

Reading is one of the essential academic skills crucial for future successful participation in modern societies. In their everyday life, people are often confronted with information presented in written form. These information need to be decoded through the complex processes of reading in order to be comprehensible. However, some individuals struggle to reach sufficient reading proficiency level during and after elementary school education. Between 3-8% of the children show difficulties in acquiring adequate reading skills (e.g., (Landerl & Moll, 2010; Moll et al., 2014). Problems in reading can not only lead to limited education, and enhance the chances of financial and economic disadvantages (Valtin, 2017; Vellutino et al., 1996), but can also facilitate development of emotional and psychological problems, such as depression or phobia (e.g., Carroll, Maughan, Goodman, & Meltzer, 2005; Willcutt & Pennington, 2000). In order to counter such disadvantageous development, identifying reading relevant factors as well as development and improvement of instruments for recognizing children at risk are vital (Castles, Rastle, & Nation, 2018; Tippelt & Schmidt-Hertha, 2018). Moreover, adequate intervention approaches fostering children with poor reading skills should be applied as early as possible in order to achieve and preserve training attributable improvements (Brassel & Rasinski, 2008; Potocki, Magnan, & Ecalle, 2015).

1.1 The interplay between basic and higher reading processes

The goal of reading is comprehension, which includes accessing and constructing meaning from written text and coordinating different language level and cognitive components (Johnston, Barnes, & Desrochers, 2008). It includes different processes, which differ in their complexity and interact on word-, sentence, and text-level (Gruhn, Segers, Keuning, & Verhoeven, 2020; Ouden, Keuning, & Eggen, 2019). Written words need to be identified first, before sentences can be comprehended and coherences between sentences can be established

(Perfetti et al., 2005; Vellutino et al., 2004). The word level, therefore, represents the basic level of reading. It includes decoding of single words as well as understanding of their meaning (Karageorgos, Müller, & Richter, 2019). Single word reading requires mostly lower level processing skills, such as efficient orthographic and phonological processing (Wolf & Katzir-Cohen, 2001). Word decoding is assumed to play a crucial role for reading and its development (Verhoeven & Perfetti, 2008).

Successful identification of the words, interpretation of their meaning in the given context, and their integration enable reading comprehension at higher level (i.e., sentence-level; Lenhard & Schneider, 2006). Semantic and syntactic elements are assumed to be processed parallel in order to comprehend the content of the sentence (Lenhard & Schneider, 2006; Taraban & McClelland, 1990). Sentence structure and word meanings are both used to develop a hypothesis about the meaning of the sentence (Verhoeven & Perfetti, 2008).

To reach text-level comprehension, the reader must understand the relationship between different sentences, and combine the meaning of each sentence, which enables processing of texts (Gough & Tunmer, 1986; Lenhard & Schneider, 2006; Verhoeven & Perfetti, 2008). In order to comprehend a text, information extraction, establishment of cross-reference (anaphoric) connection, and inference conclusion (i.e., "reading between the lines") are necessary (Lenhard & Schneider, 2006). In addition, for comprehending connected text, higher-level reading processes, such as language processing and comprehension skills are also important (Jenkins, Fuchs, van den Broek, Espin, & Deno, 2003).

To sum up, efficient word-level reading, fostered by practice and exposure to print frees up cognitive resources which can be used for sentence- and text-level comprehension (Bowers & Wolf, 1993; Joshi & Aaron, 2002). Thus, decoding accuracy is important but not sufficient for proficient reading, because a certain level of automaticity is necessary (Hudson, Isakson, Richman, Lane, & Arriaza-Allen, 2011). Considering the interplay of basic and higher-level reading processes and their interdependency (e.g., Daugaard, Cain, & Elbro,

2017), it is essential to look more closely at relevant reading related components, because they influence reading comprehension and vary among individuals with different reading comprehension abilities (e.g., Elleman, 2017).

1.2 Reading relevant components

There is plenty of evidence showing that various different linguistic and cognitive capabilities contribute to reading skills (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Preßler, Könen, Hasselhorn, & Krajewski, 2014; Steinbrink & Lachmann, 2014). In this regard, especially phonological awareness (i.e., awareness of the sound structure of the language; Castles & Coltheart, 2004; Schulte-Körne, 2011; Ziegler & Goswami, 2005) and naming speed (i.e., fast and automatized retrieval of information; Denckla & Rudel, 1976) are among the most important prerequisites of reading skills. Deficits in these components might lead to dysfunctional reading acquisition (e.g., Georgiou et al., 2012; Landerl & Thaler, 2006; Vellutino et al., 2004; Wimmer, 1993).

1.2.1 Phonological awareness

Phonological awareness is considered as a prerequisite of early decoding development, influencing later reading comprehension (Vellutino, Tunmer, Jaccard, & Chen, 2007). A large body of research supports the role of phonological awareness for the acquisition of reading skills (e.g., Ennemoser, Marx, Weber, & Schneider, 2012; Moll, Fussenegger, Willburger, & Landerl, 2009). In a meta-analysis (Pfost, 2015), phonological awareness was shown to be of predictive value for reading accuracy, speed, and comprehension. It is assumed that deficits in phonological awareness lead to difficulties in building and storing phonological and orthographic representations in the mental lexicon, resulting in difficulties in reading acquisition (Landerl & Thaler, 2006; Scheerer-Neumann, 2015). In line with this assumption, it was shown that children with reading difficulties also show deficits in different aspects of

phonological awareness, such as phoneme deletion and segmentation tasks (e.g., pronouncing words without specific letters, such as “mouth” without /m/; Melby-Lervåg, Lyster, & Hulme, 2012; Paulesu et al., 2001).

1.2.2 Naming speed

Naming speed is a basic cognitive process which has an impact on reading speed development (Moll, Wallner, & Landerl, 2012). It is usually operationalized through rapid automatized naming (RAN) tasks requiring the speeded naming of lists of familiar stimuli, such as letters, digits, objects, and colors (see Denckla & Rudel, 1976). Naming speed was shown to correlate with or to be a predictor of reading accuracy and speed (e.g., Bowers, 1995; Georgiou, Parilla, & Papadopoulos, 2008; Landerl & Wimmer, 2008; Moll et al., 2009), as well as reading comprehension (Arnell, Joanisse, Klein, Busseri, & Tannock, 2009; Georgiou, Das, & Hayward, 2008; Kirby et al., 2010; McCallum et al., 2006). Children with reading difficulties show deficits in RAN tasks compared to skilled readers (Georgiou et al., 2012).

However, even if considering these as well as further capabilities (such as general intelligence, listening comprehension or letter knowledge), there is still substantial unexplained reading variance left (e.g., Furnes & Samuelsson, 2009; Landerl & Wimmer, 2008; Pae, Sevcik, & Morris, 2010). Therefore, recent research has focused on orthographic knowledge, which is considered as one of the major contributors to word identification. Thus, it is considered as a further reading relevant component to explain additional reading variance (e.g., Cutting & Denckla, 2001; Holland, McIntosh, & Huffman, 2004). Since orthographic knowledge has not been investigated as much as phonological processes so far (Loveall, Channell, Phillips, & Conners, 2013), the focus of these dissertation is to examine the role of orthographic knowledge for reading processes.

1.2.3 Orthographic knowledge

There are several different definitions of orthographic knowledge in the literature. In this dissertation, the term orthographic knowledge is defined following the definition used by Apel (2011), where both the ability to develop and access mental representations of written words in the mental lexicon (i.e., word-specific orthographic knowledge) and the application of knowledge about rules and word patterns (i.e., general orthographic knowledge) are included. Word-specific orthographic knowledge is considered to involve the stored mental representations of familiar words and word parts. Typical tasks used to measure word-specific orthographic knowledge usually include words and pseudohomophones (i.e., constructed word with the same pronunciation as an existing word, but incorrectly spelled; e.g., *rain* – *rane*) decision tasks. In these tasks, children have to actively reflect on their knowledge of orthography and decide whether the presented stimulus is a real word or not by comparing it to the stored orthographic representations in the mental lexicon (Apel, Henbest, & Masterson, 2018). General orthographic knowledge consists of knowledge about the rules and legal patterns of a writing system, including the rules what letters can be combined with another, and where certain letters can occur in word positions (Apel et al., 2018). Typical tasks for measuring general orthographic knowledge involve orthographic word-likeness tasks, where children have to choose the one pseudoword (i.e., pronounceable letter combinations created by using certain legitimate language criteria) that most reassembles a real word. One pseudoword follows the legal orthographic patterns, whereas the other violates them (e.g., *lannag* vs. *llanag*). These tasks assess children's knowledge of permissible orthographic patterns, letter position rules, and/or orthographic sequence rules (Apel et al., 2018). These tasks capture children's knowledge of allowable letter patterns rather than the explicit use of that knowledge during reading.

Taken together, phonological awareness, naming speed and orthographic knowledge are considered to be highly interrelated, however, independent predictors to reading (LaBerge

& Samuels, 1974). Established pathways facilitate an efficient retrieval of representations stored in the mental lexicon and accelerate decoding processes, thus, enabling cognitive resources which can be used for higher processes, such as reading comprehension. This efficient and quick retrieval is only achievable, if words can be identified directly (Thaler, Ebner, Wimmer, & Landerl, 2004) via the orthographic/lexical route. If direct retrieval is not possible, phonological awareness is used for less automatized decoding, which impedes the storing of orthographic patterns. This can result in inefficient, slow recognition of orthographic patterns, leading to slower reading rate (Wolf & Bowers, 1999) and difficulties in reading comprehension (Landerl & Wimmer, 2008). Therefore, it is necessary to have a closer look at the influence of orthographic knowledge not only on basic reading processes, but also on fluent reading and higher reading processes, such as comprehension. This will be thematized in the next section.

1.3 Basic and higher reading processes: The link between orthographic knowledge, reading fluency and comprehension

Considering the fact that reading comprehension is the ultimate goal of reading, which depends on the interaction of different processes on basic and higher level, it is important to take a closer look at how orthographic knowledge influences these different levels of reading. Moreover, the focus in this section will be on the link between orthographic knowledge, leading to fluent and effortless reading, thus, enabling reading comprehension. Also, in order to better understand the importance of orthographic knowledge, the problematic reading performance will also be thematized in the following.

Basic reading processes. 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 is, hence, supported by a sufficient level of orthographic knowledge, which

enables quick recognition of written words with little cognitive effort (Ehri, 2005). In transparent languages, such as Dutch or German, repeated blending of graphemes and phonemes during decoding leads to successful phonological recoding, enabling the establishment of orthographic representations (De Jong & Messbauer, 2011), which are crucial for fluent reading (Rothe et al., 2015). Following the assumptions of the Dual-Route-Model, word-specific orthographic knowledge can be considered as useful when using the lexical, more efficient route, enabling quick access to stored mental representations of familiar words. When confronted with unknown words, for which no stored mental representations are available, the non-lexical, less efficient route is used. General orthographic knowledge can be useful in this process of translating print into words via the non-lexical route (e.g., Castles, 2006; Grainger & Ziegler, 2011). Several studies revealed that word-specific and general orthographic knowledge contribute to word-reading skills (e.g., Arab-Moghaddam & Senechal, 2001; Georgiou et al., 2008). Particularly regarding the findings from studies conducted in German, it was shown that word-specific and general orthographic knowledge contribute a significant amount of unique variance to word reading (Rothe et al., 2015; Rothe, Schulte-Körne, & Ise, 2014).

Higher reading processes. Higher reading processes depend on the input from basic reading abilities, with the construction of meaning beyond single words as a goal (Perfetti & Stafura, 2014). It is assumed that high-quality orthographic representations are necessary for higher reading processes, which have a direct impact on reading comprehension (see for example the Lexical Quality Hypothesis; Perfetti & Hart, 2002; Richter, Isberner, Naumann, & Kutzner, 2019). Therefore, word-specific and general orthographic knowledge could be considered as relevant contributors not only to reading at basic level (word-level), but also at higher level (i.e., sentence- and text-level comprehension). More particularly, it can be assumed that word-specific and general orthographic knowledge contribute to efficient single word reading, enabling their quick processing, therefore, enhancing reading fluency (i.e.,

effortless and fast decoding with correct prosody, and attention shift to higher processes, Wolf & Katzir-Cohen, 2001), which supports comprehension at sentence- and text-level. This line of argument is supported by findings regarding problematic reading. In transparent languages with consistent grapheme-to-phoneme correspondences (e.g., Dutch or German), reading difficulties are mainly characterized by deficits in reading fluency (Landerl & Wimmer, 2008; Wolf & Katzir-Cohen, 2001; Ziegler & Goswami, 2005; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). For instance, studies in German have shown that problematic reading achievement mainly manifests in impairments in reading fluency, resulting in very slow and laborious word decoding, without high numbers of reading errors (Landerl, Wimmer, & Frith, 1997; Wimmer, 1996; Wimmer, Mayringer, & Landerl, 1998). This is also referred to as automatic decoding deficit (Yap & Van der Leij, 1993), which is shown to be strongly associated with low reading comprehension scores (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Jenkins & Jewell, 1993). Low reading comprehension is attributable to inefficient word recognition and possibly insufficient orthographic knowledge, resulting in reduced attention and working-memory capacities. Therefore, fewer resources are available for reading comprehension (Jenkins et al., 2003). German impaired readers have shown lower scores in the task measuring word-specific (Bergmann & Wimmer, 2008) and general orthographic knowledge (Rothe et al., 2015) compared to their non-impaired peers, supporting the assumption that impaired reading could be influenced by deficient orthographic knowledge. Impaired readers seem to have deficits in forming, storing, and accessing orthographic representation in transparent languages, resulting in poor reading fluency (Rothe et al., 2015). The findings from a study in Greek support the significant role of orthographic knowledge for reading fluency (Georgiou, Parrila, & Papadopoulos, 2008). However, the body of research examining the role of word-specific and general orthographic knowledge on higher reading level is sparse. Previous studies examining the role of word-specific and general orthographic knowledge in reading mostly concentrated on basic reading skills, such as word-reading (e.g.,

Georgiou et al., 2008; Rothe et al., 2015). A study by Katzir et al. (2006) revealed that spelling recognition (i.e., recognition of the correct spelling out of four choices), operationalized in a similar way as word-specific orthographic knowledge in the present dissertation, contributed significantly to sentence- and text-comprehension in reading impaired and non-impaired English children. In German, only two studies examined the relationship between orthographic knowledge and higher reading processes (sentence- or text-reading) so far. In the study by Ise, Arnoldi and Schulte-Körne (2014), the task used to measure reading comprised of simple sentences, where children were asked to read silently and as quickly as possible, and to indicate after each item whether the content of the sentence is generally true or false. The results have shown that general orthographic knowledge does not correlate significantly with sentence-reading performance. However, only one task for measuring general orthographic knowledge (i.e., the knowledge about frequent double consonants) was used. In another study by Richter et al. (2019), word-specific orthographic knowledge was shown to be a significant predictor for text-reading comprehension, however, they did not simultaneously assess general orthographic knowledge. Therefore, further research is necessary in order to explore the influence of both word-specific and general orthographic knowledge to reading at higher level, such as sentence- and text-comprehension in a transparent language like German.

The presented findings show that a sufficient level of orthographic knowledge possibly enhances reading fluency, thus, supporting comprehension on sentence- and text-level. In turn, deficient reading fluency might also be influenced by a lower level of orthographic knowledge. However, the role of orthographic knowledge to higher reading processes is not clear yet. Considering that deficits in reading fluency can lead to reading impairments (Wimmer et al., 1998), it is crucial to foster children with reading problems in order to improve their reading skills and to prevent school failure. Improvement in reading fluency is assumed to reduce the cognitive load, and therefore, to enhance reading

comprehension, enabling the working memory capacity to extend and strengthen the connections to long-term memory, so that meaning of the words can be directly retrieved (Woltz & Was, 2006, 2007). Therefore, reading trainings aiming at reading fluency improvements represent a promising approach in order to counter reading difficulties, especially in transparent languages, such as German. Since orthographic skills were shown to differentiate between reading intervention outcomes (Berninger et al., 1999), and also to predict the growth of word reading performance after intervention (Stage et al., 2003), it is possible that orthographic knowledge proficiency level might influence the performance in a reading fluency training, and, therefore, its effects. In the next section, a brief overview of one approach aiming at reading fluency improvement in children with impaired reading performance is presented.

1.4 Countering reading fluency deficits: A text-fading based reading training

One promising approach for countering reading fluency deficits is the text-fading procedure, where reading material is faded out letter by letter in reading direction (i.e., in German from left to right) from a computer screen (Breznitz & Bloch, 2012; Breznitz & Nevat, 2006), depending on comprehension performance. The goal of this manipulation is to prompt participants to read faster than they would normally do due to the subjective feeling of time constraint generated by the text-fading method (Breznitz & Berman, 2003; Nagler, Lonnemann, Linkersdörfer, Hasselhorn, & Lindberg, 2014). This manipulation is supposed to improve reading performance, since increased reading rate is assumed to be associated with an increase in reading comprehension (Huemer, Landerl, Aro, & Lyytinen, 2008). Several studies support this assumption, showing that the text-fading manipulation is connected to faster reading rates and better reading comprehension (Breznitz, 1997, 1987; Nagler, Linkersdoerfer, Lonnemann, Hasselhorn, & Lindberg, 2016; Nagler et al., 2014). Most

training studies with implemented text-fading method report increased reading rate with improved or consistent reading comprehension performance in before and after training comparison for different age groups, different reading proficiency levels, and different orthographies (Breznitz et al., 2013; Horowitz-Kraus & Breznitz, 2014; Nagler et al., 2014). Especially regarding the studies conducted in German third-graders without reading difficulties, it was shown that children who received the text-fading method significantly improved their reading comprehension at word- and sentence-level compared to the control group, who read the same training material in their own pace (Nagler et al., 2015). However, this study was conducted in unimpaired German elementary school readers, thus, investigation of training effects for children in need of intervention is still pending. Moreover, the underlying mechanisms responsible for the reading performance improvement are still unclear. Considering the assumptions presented in previous section as well as the results showing that orthographic knowledge influences intervention success (Berninger et al., 1999; Stage et al., 2003), it is possible that orthographic knowledge proficiency level influences word-identification during the sentence-reading process, thus, affecting sentence-comprehension performance used to adapt the fading speed during the text-fading training. Therefore, it is important to investigate the role of orthographic knowledge for comprehension performance in a text-fading based reading training.

1.5 Summary and open questions

To sum up, orthographic knowledge is considered as a component relevant for reading, beside phonological awareness and naming speed. These components are assumed to be interrelated, however, independent contributors to reading. Previous studies have shown that word-specific and general orthographic knowledge contribute to basic (word-level) reading (e.g., Conrad et al., 2013; Rothe et al., 2015). Following the assumption that high-quality orthographic

representations are necessary for higher reading processes, like reading comprehension (Perfetti & Hart, 2002), word-specific and general orthographic knowledge could be considered as significant contributors to reading at basic (word) level as well as to reading at higher level (sentence and text). However, previous studies did not include both components of orthographic knowledge (word-specific and general) when examining higher reading processes (Ise et al., 2014; Katzir et al., 2006; Richter et al., 2019). In addition, considering studies conducted in German, only children without reading difficulties were included (Ise et al., 2014; Richter et al., 2019). Since studies with different samples (i.e., with and without reading difficulties) report different results (e.g., differences in correlation in samples of children with and without reading difficulties) concerning the relationship between reading relevant components and reading performance (e.g., Swanson, Trainin, Necoechea, & Hammill, 2003), the results from studies examining children without reading difficulties cannot be generalized to samples of children with reading problems. Therefore, it still remains unclear whether word-specific and general orthographic knowledge contribute to basic (word) as well as to higher reading processes (sentence and text) in children with and without reading difficulties. Moreover, a large body of research has shown that the course of reading acquisition and the deficits underlying reading difficulties might differ across opaque and transparent orthographies (Ziegler & Goswami, 2005), thus, the findings from a given orthography cannot be generalized. Since the previous research on orthographic knowledge is mostly conducted in opaque languages, such as English (e.g., Conrad et al., 2013), more studies in transparent languages, such as German, are necessary in order to better understand the role of orthographic knowledge for reading.

In transparent orthographies like German, difficulties in reading fluency are considered to be the key factor for reading problems (Landerl et al., 1997; Wimmer et al., 1998). A reading fluency training based on the text-fading method seems to be a promising approach in order to improve reading fluency as well as reading rate (e.g., Breznitz, 1997). In

a study conducted in German, the text-fading manipulation is used aiming at increasing individual reading rate, where individual fading rate (i.e., milliseconds per letter) was adaptively changed based on the individual's comprehension scores (Nagler et al., 2015). It is possible that orthographic knowledge proficiency level influences word-identification during the sentence-reading process, thus, affecting sentence-comprehension performance, which is used to adapt the fading speed during the text-fading training. Regarding previous findings that lower-level processes serve as the base for word- and sentence-performance (Wolf & Katzir-Cohen, 2001), it is important to investigate the influence of orthographic knowledge in a text-fading based reading training.

2. Research questions

In order to answer open research questions, the present dissertation focuses on two major aims: (1) Following the assumptions of automatic information processing theories (LaBerge & Samuels, 1974), and in line with previous findings (Conrad et al., 2013; Rothe et al., 2015), word-specific and general orthographic knowledge are both assumed to significantly influence basic (word) reading performance. In turn, an efficient word processing frees up cognitive resources, which can be used for higher reading processes (such as sentence- and text-comprehension; Perfetti & Hart, 2002). The focus here is to clarify to what extend word-specific and general orthographic also contribute to higher reading level processes. Since the transferability of results across different reading proficiency levels might be problematic (Swanson et al., 2003), the focus is on a sample of German children in Grade 3 without reading difficulties as well as on a sample of German children in Grade 3 with poor reading skills. More precisely, word-specific and general orthographic knowledge are both assumed to be significant predictors for reading at basic (word) level, as well as at higher level (sentence and text) in both children with and without reading difficulties.

(2) Regarding previous results showing orthographic knowledge to be relevant for reading training outcomes (Berninger et al., 1999; Stage et al., 2003), as well as considering the role of orthographic knowledge for efficient word recognition and possible facilitation of reading comprehension (Perfetti & Hart, 2002), the second focus of this dissertation is on the predictive value of this reading related component. The aim is to clarify to what extend orthographic knowledge can explain variance in comprehension performance during the text-fading training in both experimental and training group. More precisely, it is assumed that orthographic knowledge is a significant predictor for comprehension performance during the text-fading training in both training groups.

In order to answer these two research questions, the results from three empirical papers will be presented and discussed in the next section.

3. Empirical papers and their results

In this section, the first and the second empirical paper will be presented and their results will be used and discussed in order to answer the first research question regarding the role of orthographic knowledge on basic (word-level) and higher (sentence- and text-level) reading performance in children without and with reading difficulties. After that, the third empirical paper will be presented and its results will be used and discussed to answer the second research question regarding the role of orthographic knowledge in reading comprehension during a fluency reading training based on the text-fading method. The original papers can be found in the Appendix A, B, and C.

3.1 First empirical paper: Orthographic knowledge predicts reading and spelling skills over and above general intelligence and phonological awareness (Zarić, Hasselhorn, & Nagler, 2020)

In order to answer the first research question of this dissertation, the empirical paper "Orthographic knowledge predicts reading and spelling skills over and above general intelligence and phonological awareness" by Zarić, Hasselhorn, and Nagler (2020; see Appendix A) is implemented. This paper focuses on the predictive role of both word-specific and general orthographic knowledge to reading on basic (word-comprehension) and higher reading level (sentence- and text-comprehension) and to spelling in German third-graders without reading difficulties. Results regarding spelling will not be presented in detail, because the focus of the following dissertation is on reading performance, however, they can be found in the original paper in the Appendix A. The influence of orthographic knowledge on reading was examined over and above general intelligence and phonological awareness, considered as well-established reading predictors. For this purpose, data from 66 German elementary school children (29 girls; *mean age* = 9.25 years, *SD* = 0.43) with an average intelligence quotient (IQ; *mean* = 107, *SD* = 12.30) were analyzed via correlation and multiple regression analyses. Since this dissertation focuses on investigating the role of orthographic knowledge on basic, as well as on higher reading level, the reading performance was assessed by a standardized reading test (Ein Leseverständnistest für Erst- bis Sechstklässler – ELFE 1-6; [A reading comprehension test for first- till sixth-graders]; (Lenhard & Schneider, 2006), measuring reading comprehension on word-, sentence-, and text-level with a time limit. Previous studies conducted in German reported ceiling effects on tasks measuring orthographic knowledge (e.g., Rothe et al., 2015). Therefore, as a part of this dissertation, items for measuring word-specific and general orthographic knowledge were developed by using information from a child-oriented data base (childLex; Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015)

and were programmed in Psychology Software in Python (PsychoPy; Peirce, 2009). More particularly, in this first empirical paper, word-specific and general orthographic knowledge were assessed by an orthographic-choice task. The task measuring word-specific orthographic knowledge consisted of 20 self-developed randomly presented items, each containing a correctly spelled word and a corresponding pseudohomophone. An item analysis was conducted, where 8 items with poor degree of selectivity and difficulty were excluded out of initially 20 items. The remaining 11 items revealed to have less than satisfactory internal consistency (Cronbach's $\alpha = .57$). The task measuring general orthographic knowledge consisted of 40 self-developed randomly presented items, each consisting of two pronounceable pseudowords with six letters. 20 items addressed the knowledge about 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 (e.g., *dd*) in German. The other 20 items addressed the knowledge about the legal position 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*). After an item analysis, 28 out of initially 40 items remained, revealing to have a sufficient internal consistency (Cronbach's $\alpha = .75$). Data were collected on two testing days during regular school times in the morning. The analyses revealed that both word-specific and general orthographic knowledge correlate with reading on word-, sentence-, and text-level. Furthermore, both subtypes of orthographic knowledge were shown to contribute unique significant amount of explained variance in reading on word-, sentence-, and text-level, over and above the contribution of general intelligence and phonological awareness in German third-graders without reading difficulties. Even though these results seem promising, there are some limitations worth mentioning. The less than satisfying internal consistency of the orthographic choice task for measuring word-specific orthographic knowledge indicates that further item improvement and development

are necessary to reliably assess this subcomponent of orthographic knowledge. One further limitation is that an assessment of other skills relevant for reading, such as naming speed (e.g., Rothe et al., 2015) was not included. Since in this study only children without reading difficulties were included, the investigation of the role of orthographic knowledge for basic and higher reading processes in children with poor reading proficiency is still pending.

3.2 Second empirical paper: Reading comprehension on word- and sentence-level can be predicted by orthographic knowledge for German children with poor reading proficiency (Zarić & Nagler, 2021)

Following limitations and remained open questions of the first empirical paper presented in the previous section (see also Zarić et al., 2020; Appendix A), a second empirical paper "Reading comprehension on word- and sentence-level can be predicted by orthographic knowledge for German children with poor reading proficiency" by Zarić and Nagler (2021; see Appendix B) is implemented in order to answer the first research question of this dissertation. In addition to the first empirical paper, this second empirical paper aims at examining a sample of German third-graders with poor reading proficiency, and, therefore, to extend the body of research on the role of orthographic knowledge to reading at basic and higher reading level across different reading proficiency levels. Since naming speed was not included in the first empirical paper (see also limitation section, Zarić et al., 2020; Appendix A), in this second paper the role of orthographic knowledge was investigated over and above the influence of phonological awareness and naming speed, which are considered as reading relevant components. For this purpose, data from 103 German third-graders (48 girls; *mean age* = 8.87 years, *SD* = 0.48; *mean IQ* = 102.36, *SD* = 11.06) with poor reading proficiency (reading performance ≤ 30th percentile in a standardized reading test; Würzburger Leise Leseprobe- Revision – WLLP-R [Würzburger silent reading test-revised]; Schneider, Blanke,

Faust, & Küspert, 2011) were analyzed via correlation and multiple regression analyses. Following the methodological approach of the first empirical paper (Zarić et al., 2020; Appendix A), the reading performance was assessed by ELFE 1-6 (Lenhard & Schneider, 2006), measuring comprehension on word-, sentence-, and text-level. As mentioned in previous section, one important limitation of the first empirical paper was the less than sufficient internal consistency of the task used to assess word-specific orthographic knowledge. In addition, since children were presented two alternatives simultaneously (word vs. pseudohomophone), it is not excluded that children have used the method of elimination in order to solve the task, rather than really retrieving their knowledge about word-specific representations. This could have had an influence on the results, and probably on the reliability measures of this task. In order to capture word-specific orthographic knowledge more reliably, a further item development and improvement was conducted. Thus, in this second paper (Zarić & Nagler, 2021), word-specific orthographic knowledge was measured by an orthographic decision task with 30 self-developed items (15 real words and 15 pseudohomophones) programmed in PsychoPy (Peirce, 2009). Items were presented one at a time and participants were asked to decide whether the presented stimulus is a real word or not. This is considered to minimize the chance of using the method of elimination while solving the task, because children have to compare the one presented stimulus to their stored orthographic representations in the mental lexicon in order to solve the task correctly. After conducting an item analysis, 16 out of initially 30 items revealed to have a sufficient internal consistency (Cronbach's $\alpha = .72$). The item-analysis from the first empirical paper revealed that the general orthographic knowledge items excluded due to the poor degree of selectivity and difficulty were mainly items measuring the knowledge about frequency of double consonants. Therefore, in this second paper, general orthographic knowledge was assessed by items measuring the knowledge about legal positions of double consonants in German. Therefore, a computerized orthographic-choice task with 20 self-developed items was also

programmed in PsychoPy (Peirce, 2009). After the item analyses, 4 items revealed to have a poor degree of difficulty and selectivity, and were, therefore, excluded from further analyses. The remaining 16 out of 20 items revealed to have a sufficient internal consistency (Cronbach's $\alpha = .77$). Data were collected on three different testing days during regular school times in the morning. The analyses revealed that word-specific and general orthographic knowledge correlate with reading performance on word- and sentence-level, but not on text-level. Furthermore, word-specific and general orthographic knowledge contributed unique significant amounts to variance of reading on word- and sentence-level, but not on text-level, in addition to phonological awareness and naming speed. These result patterns differ to some extent from the ones presented in the first empirical paper (see Zarić et al., 2020; Appendix A). In the next section, the results from these two empirical papers will be discussed in order to answer the first postulated research question of this dissertation.

3.3 Orthographic knowledge as a significant predictor for basic and higher reading processes in children without and with reading difficulties

The first aim of this dissertation was to determine the incremental predictive value of word-specific and general orthographic knowledge to basic (word-reading) and higher reading processes (sentence- and text-comprehension) in German third-graders without and with reading difficulties.

For the sample of typically skilled readers, the incremental predictive value of orthographic knowledge to reading on word-, sentence-, and text-level was investigated in addition to the well-established reading related predictors general intelligence and phonological awareness. The analyses have shown that both word-specific and general orthographic knowledge provide unique contributions to reading at basic (word-level) and higher reading level (sentence- and text-comprehension), over and above the influence of

general intelligence and phonological awareness. This supports and extends previous results (e.g., Ise et al., 2014; Rothe et al., 2015). As proposed by Conrad et al. (2013), word-specific orthographic knowledge supports the direct recognition of familiar words, supporting their automatized reading as a single unit, thus, enabling their quick processing and enhancing comprehension at sentence- and text-level (see also Lenhard & Schneider, 2006). Word-specific orthographic knowledge can also be useful in reading of unfamiliar words through analogy to words stored in memory (Conrad et al., 2013). Word representations are established in memory through the linking of a word's spelling and its pronunciation and meaning (Ehri, 2005). These connections are also formed through the growing knowledge of recurring spelling patterns, regularities, and consistencies in different words. By using these recurring spelling patterns, readers can use larger units to form connections to memorize specific words. Hence, general orthographic knowledge can be considered to play an important role in the connection formation processes necessary to establish word-specific representations in memory (Conrad et al., 2013), thus, supporting basic (word-) reading. Regarding higher reading processes (sentence- and text-comprehension), general orthographic knowledge was revealed as a significant predictor, however, only when not considered simultaneously with word-specific orthographic knowledge in a regression model. These results indicate that general orthographic knowledge might support word identification, and therefore, facilitate sentence- and text-comprehension. However, when considered simultaneously with word-specific orthographic knowledge, general orthographic knowledge might be less relevant for higher level reading. In addition to word-specific orthographic knowledge, more complex processes, related to extraction of semantic meaning and the activation of background knowledge are assumed to have a large impact on sentence- and text-comprehension (Klicpera, Schabmann, Gasteiger-Klicpera, & Schmidt, 2017).

As assumed, in the sample of poor readers it was shown that both word-specific and general orthographic knowledge are significant predictors for reading at basic (word-) reading

level, explaining additional variance beside phonological awareness and naming speed. These results support previous reports (Conrad et al., 2013; Rothe et al., 2015) and extend the evidence of the importance of orthographic knowledge for basic reading skills for children with poor reading proficiency. It is assumed that poor readers use memorized word-specific orthographic representations in order to recognize familiar words and read them as a single unit, similar the way skilled readers do (Conrad et al., 2013). General orthographic knowledge, containing the knowledge about recurring letter patterns, regularities, and consistencies, is considered to assist the memorization of specific letter combinations and units necessary to establish word-specific representations in memory (Conrad et al., 2013). Therefore, general orthographic knowledge can be useful in reading (novel/unknown) words. In line with the results found for skilled readers (see Zarić et al., 2020), word-specific and general orthographic knowledge were shown to be significant predictors for reading on sentence-level, in addition to phonological awareness and naming speed in German poor readers. However, considering the results of the regression model comprising both components of orthographic knowledge, it seems that the knowledge about word-specific representations (i.e., word-specific orthographic knowledge) plays a more important role hereby than the knowledge about legal patterns (i.e., general orthographic knowledge). It is possible that the items used to measure sentence-level comprehension (see ELFE 1-6; Lenhard & Schneider, 2006) contain mostly of words familiar to the sample of poor readers. Thus, in order to solve the task, they mainly relied on their word-specific orthographic knowledge, and less on their general orthographic knowledge. However, when confronted with less familiar words, the participants used their general orthographic knowledge as well to solve the task, as shown in the regression model where only general orthographic knowledge was entered as a predictor. However, when considered simultaneously, only word-specific orthographic knowledge remained a significant predictor. This result pattern was also found in skilled readers (see Zarić et al., 2020). These results suggest that, regardless of the reading

proficiency level, word-specific orthographic knowledge might have a larger influence on comprehension on sentence-level than general orthographic knowledge. Contrary to the expectations, word-specific and general orthographic knowledge were not shown to be significant predictors for reading at text-level in German poor readers. Text-level comprehension is considered to comprise understanding of single words, for which word-specific and general orthographic knowledge play an important role, as suggested by previous (e.g., Rothe et al., 2015) and present (Zarić et al., 2020) results. However, in order to comprehend the content of the text, more complex processes, such as background knowledge and semantic skills, are assumed to play an important role (Klicpera et al., 2017). The results found in a sample of poor readers (see Zarić & Nagler, 2021) deviate from the findings found in typically skilled readers (see Zarić et al., 2020). One explanation for this divergent result pattern concerns the considered sample. Previous results (Constantinidou & Stainthorp, 2009; Cornwall, 1992) indicated that phonological awareness seems to be critical for text-reading comprehension, especially for reading impaired children. The results from the sample of poor readers support this, revealing that phonological awareness contributed significantly to text-level comprehension (see Zarić & Nagler, 2021). It is, therefore, possible that poor readers rely more on other skills (e.g., phonological awareness) when processing a text compared to typically skilled readers.

These results showing that orthographic knowledge contributes significantly to reading performance on word-, and sentence-level not only for typically skilled readers, but also for children with poor reading proficiency, strengthened the motivation to examine the role of orthographic knowledge during a text-fading based reading intervention. As mentioned before, the reading comprehension performance is used during the text-fading training to adapt the fading rate of the manipulation. Therefore, it is important to explore the influence of reading relevant components, such as orthographic knowledge, to the reading comprehension during training in order to better understand the mechanisms leading to possible training

effects. The third empirical paper presented in the next section focuses on filling this gap by exploring the role of orthographic knowledge to reading performance during the text-fading training in both the training and the control group.

3.4 Third empirical paper: Reading impaired children improve through text-fading training: Analyses of comprehension, orthographic knowledge and RAN (Nagler, Zarić, Kachisi, Lindberg, & Ehm, 2021)

In order to answer the second research question of this dissertation, the third empirical paper "Reading impaired children improve through text-fading training: Analyses of comprehension, orthographic knowledge and RAN" by Nagler, Zarić, Kachisi, Lindberg, & Ehm, 2021; see Appendix C) is implemented. The aim of this paper was to investigate the predictive value of orthographic knowledge and naming speed for reading comprehension performance during text-fading based reading training in both training and control group, and to examine potential and lasting training effects. For this purpose, data from 120 German reading impaired third-graders (reading performance < 30^{th} in a standardized reading test – WLLPR, Schneider et al., 2011; 58 girls; *mean age* = 8.87 years, *SD* = 0.53; *mean IQ* = 105.80, *SD* = 15.16) were analyzed. Since the focus of the present dissertation is on orthographic knowledge, the results regarding the potential and lasting training effects will not be presented in detail. However, further information concerning these aspects can be found in the original paper in the appendix (see Appendix C). The text-fading training programmed in PsychoPy (Peirce, 2009) included 16 offered training sessions (mean session completed for all children = 12.8 sessions). The training sessions included sentence reading either with the adaptive text-fading method (training group) or at self-paced reading rate (control group). After each of the 30 sentences within a training session, a multiple-choice question referring to the sentence's content with four alternatives was presented. Children

were asked to identify the correct answer by pressing the corresponding key on the keyboard, which was used to measure their comprehension performance during training. For the text-fading group, the comprehension performance was used to adjust the individual text-fading rate. Since both tasks used in the second empirical paper for measuring word-specific and general orthographic knowledge revealed a satisfying internal consistency (see Zarić & Nagler, 2021; Appendix B), the same items were used in this third empirical paper. In order to examine the predictive role of orthographic knowledge and naming speed for comprehension performance during the text-fading training, a multiple group regression model with latent variables was conducted. In this structural equation model (SEM), regression paths were evaluated for both orthographic knowledge and naming speed to the comprehension performance (dependent variable). Results of the SEM indicate that orthographic knowledge is significantly related to reading comprehension performance during training in the self-paced group, whereas no significant regression weight was found for the text-fading group. A reverse result pattern was found for naming speed – while a significant effect could be found in the text-fading group, no sufficient regression weight was found for the self-paced group. These results will be discussed in the next section in order to answer the second postulated research question of this dissertation.

3.5 Predictive value of orthographic knowledge for reading comprehension performance during a text-fading based reading training

The second aim of the present dissertation was to investigate the predictive value of orthographic knowledge to reading comprehension during a text-fading based reading training in a sample of German reading impaired third-graders (see Nagler et al., 2021, Appendix C) in both training and control group. The analyses of the applied structural equation model (SEM) revealed that orthographic knowledge was significantly related to comprehension

performance during text-fading training only in the control (self-paced) group, who read the training material in own pace, whereas no significant regression weight was found for the training (text-fading) group receiving the text-fading manipulation. For naming speed, a reverse result pattern was found, where naming speed contributed significantly in the text-fading, but not in the self-paced group. These results indicate that while reading in own pace, the knowledge about word-specific representations and legal letter patterns supports the automatized recognition and reading of single words, and enables their processing (e.g., Ehri, 2014). Hence, a higher level of orthographic knowledge frees up more resources for understanding the content of the sentences necessary to solve the comprehension task during the text-fading training correctly. These findings are in line with the results from the other two papers stressed in this dissertation (see Zarić et al., 2020; Zarić & Nagler, 2021), showing that orthographic knowledge contributes to sentence-comprehension performance when reading in own pace, as anticipated by both ELFE 1-6 (Lenhard & Schneider, 2006) and the training material including sentence-reading in own pace in the self-paced group. However, when reading under time constraint, as possibly evoked by the text-fading manipulation in the text-fading condition, the ability to quickly and accurately retrieve the stored orthographic representations from the mental lexicon (reflected in naming speed abilities) seems to play a more important role than the mere quality of these orthographic representations. These results are in line with the findings from Vaessen et al. (2010), where naming speed significance on reading measures increased when the reading measures were speeded. Considering the text-fading training procedure, the results of Nagler et al. (2021) suggest that naming speed seems to have a significant impact on the comprehension performance, which is used to adapt the text-fading rate. Thus, naming speed can be considered as a relevant underlying component supporting the training effects of the text-fading procedure. Orthographic knowledge, on the contrary, seems to influence reading comprehension performance as well, however, independently from the text-fading procedure.

5. General discussion

The first goal of this dissertation was to examine the predictive role of orthographic knowledge in German third-graders without and with reading difficulties for reading at basic (word-level) and higher level (sentence- and text-comprehension), in addition to well established predictors general intelligence, phonological awareness and naming speed. The analyses showed that for skilled readers, orthographic knowledge is a significant predictor for reading at word-, sentence- and text-level, in addition to general intelligence and phonological awareness. For poor readers, orthographic knowledge was identified as a significant predictor for word- and sentence, but not for text-reading, in addition to phonological awareness and naming speed. The second goal was to investigate the contribution of orthographic knowledge to reading comprehension during a text-fading based reading training. The analyses revealed that orthographic knowledge is a significant predictor for reading comprehension during text-fading training only for the self-paced (control) group, however, not for the text-fading (experimental) group. In the following section, the theoretical, empirical as well as practical implications of these results will be presented.

5.1 Theoretical implications

In the literature, the use and definition of orthographic knowledge varies, thus, leading to difficulties in interpreting research results and communicating concepts with reliable terms (Apel, 2011). There is a growing consensus that orthographic knowledge consists of two components – word-specific and general –, however, some researchers have defined and measured orthographic knowledge only on word-specific level (e.g., Barker, Torgesen, & Wagner, 1992; Deacon, Benere, & Castles, 2012; Deacon, Wade-Woolley, & Kirby, 2009), whereas others have measured it only on general level (e.g., Castles & Nation, 2006; Kim, Apel, & Al Otaiba, 2013; Vellutino, Scanlon, & Tanzman, 1994). The results from the first

and second paper included in this dissertation support the two-dimensional view of orthographic knowledge, including a word-specific and a general component (see Zarić et al., 2020; Zarić & Nagler, 2021). The results from hierarchical regression analyses have shown that both word-specific and general orthographic knowledge contribute a unique and significant amount to reading variance, thus, supporting the view that orthographic knowledge can be considered as an independent reading relevant component (Apel, 2011). The result patterns were similar for typically skilled and poor readers, thus, extending previous results (e.g., Conrad et al., 2013; Rothe et al., 2015), and adding to the importance of the role of orthographic knowledge in reading processes across different reading proficiency levels in a transparent orthography (i.e., German language). These results are especially important when considering previous concerns raised by several researchers, pointing out that phonological processes are elicited when performing orthographic knowledge tasks (Bowey, 1996; Olson, Forsberg, Wise, & Rack, 1994; Share, 1995). The results included in this dissertation, however, show that orthographic knowledge remains a significant predictor, even when considering other well-established reading related components, thus, supporting orthographic knowledge as an independent reading relevant component.

It also important to stress out that the results from all three papers included in this dissertation also add to the importance of orthographic knowledge to higher-level reading processes, thus, supporting the assumptions of automatic information processing theories (LaBerge & Samuels, 1974; Perfetti, 1985). Also, these results support the assumptions of the Lexical Quality Hypothesis that the quality of orthographic representations strongly influences reading comprehension (Perfetti & Hart, 2002; Richter et al., 2019). The results from this dissertation implicate that orthographic knowledge seems to be a basic reading related skill, contributing not only to word-identification and word-reading processes, but also enabling their quick processing in order to facilitate higher-level reading processes, such as comprehension.

5.2 Empirical implications

There are several aspects remained open from the three empirical papers presented in this dissertation that could be addressed in future studies. These will be presented in the following.

Assessment of other reading relevant components. It would be important to include the assessment of other reading relevant components simultaneously with word-specific and general orthographic knowledge, such as vocabulary knowledge, listening comprehension, literacy environment, morphological knowledge and awareness or letter knowledge. These components were shown to be important for basic as well as for higher reading processes (e.g., Verhoeven & van Leeuwe, 2012; Volkmer, Schulte-Körne, & Galuschka, 2019). The inclusion of more variables in future studies could contribute to better understanding of the relation patterns among a variety of components relevant for reading as well as their contribution to basic and higher reading processes. Future also longitudinal studies are necessary in order to better understand the predictive patterns of word-specific and general orthographic knowledge combined with other reading relevant components and their role in reading development.

Development of orthographic knowledge and its role in reading acquisition. Further empirical studies should also examine the development of orthographic knowledge. The findings from several studies suggest that children in kindergarten are already sensitive to legal letter patterns (e.g., Cassar & Treiman, 1997; Lehtonen & Bryant, 2005; Pacton & Fayol, 2004), thus, supporting the view that orthographic knowledge emerges before children receive formal reading instruction at school. However, some literacy development models suggest that orthographic knowledge development depends on phonological skill acquisition, and is, therefore, considered as a late-developing skill (e.g., Ehri, 2005; Frith, 1985; Gentry & Gillet, 1993; Siegel, Share, & Geva, 1995). This view is supported by results from studies showing that the contribution of orthographic knowledge to reading increases with age

(Badian, 2001; Juel, Griffith, & Gough, 1986). Considering these mixed reports, the development of word-specific and general orthographic knowledge and their contribution to reading development should be in focus of future studies.

Furthermore, the development of orthographic knowledge and its role for reading development should be investigated and compared between different languages varying in their transparency level in future studies. As suggested by the orthographic depth hypothesis (Katz & Frost, 1992), the degree to which children rely on phonological or orthographic information depends on the letter-to-sound consistency in a given language. In opaque languages (such as French or English), readers rely more on the visual-orthographic structure of written words to overcome decoding difficulties due to ambiguous and partly inconsistent letter-to-sound correspondences. In transparent languages (such as Greek or German) with consistent letter-to-sound correspondences, readers rely more on phonological information, which is easier accessible than in opaque languages (Ise et al., 2014). So far, only one longitudinal study was conducted in German examining the development of one component of orthographic knowledge (general orthographic knowledge) and its role in reading development in children from kindergarten to second grade (Ise et al., 2014). The results indicate that general orthographic knowledge improves significantly with increasing grade level, however, no significant correlations between general orthographic knowledge and reading performance in first and second grade were observed. These results were not in line with the reports from a study conducted in English first graders (Cunningham & Stanovich, 1993), where general orthographic knowledge was related to the reading ability. Ise et al. (2014) argued that German-speaking children might be less sensitive to the legal letter patterns than English-speaking children, because in German children rely more on phonological information due to consistent letter-to-sound correspondences, as suggested by the orthographic depth hypothesis (Katz & Frost, 1992). Considering these divergent results,

future longitudinal studies are necessary in order to expand the current knowledge about the development of orthographic knowledge and its role in reading development.

Items for measuring word-specific and general orthographic knowledge. Another relevant aspect concerns the items used to measure word-specific and general orthographic knowledge in the three empirical papers included in this dissertation. The tasks and items used for measuring word-specific and general orthographic knowledge seem to be a promising approach. Previous studies reported ceiling effects in the task measuring word-specific orthographic knowledge (e.g., Bekebrede, van der Leij, & Share, 2009; Rothe et al., 2015). This was not the case in the three papers included in this dissertation. For item-development in the three papers included here, a child-oriented data base (childLex; Schroeder et al., 2015) was used. Especially regarding the items for word-specific orthographic knowledge, only low frequent words were selected, thus, no ceiling effects were observed. However, concerning the less than satisfying internal consistency reported in the first paper (see Zarić et al., 2020) for the task measuring word-specific orthographic knowledge, it is obvious that further item development is necessary.

Factors influencing the efficacy of the text-fading method. The results regarding comprehension performance during the text-fading training suggest that orthographic knowledge contributes significantly to sentence-comprehension only when reading in own pace. The fast and accurate retrieval from mental lexicon, as assessed by RAN, seems to be of greater importance for the text-fading manipulation. Further studies examining the differential mechanisms of these two components for comprehension performance, which is used to adapt fading speed in the text-fading condition, are necessary in order to better understand how training effects emerge.

5.3 Practical implications

The results from the three empirical papers included in this dissertation add to the understanding of orthographic knowledge as one further component relevant for basic and higher reading processes across different reading proficiency levels. As suggested by Badian (2001), impairments in orthographic knowledge might lead to reading difficulties in some children, thus, supporting the role of orthographic knowledge role in reading. Also, considering the results from a study by Rothe et al. (2015) showing that children with reading difficulties show lower scores on orthographic knowledge tasks compared to non-impaired peers, the importance of orthographic knowledge for reading is indisputable. Therefore, the assessment of orthographic knowledge is not only important in research contexts, but also in diagnostic processes in order to identify students at risk for developing reading difficulties and promptly intervene. As a desirable prospect, the development of a standardized test for measuring word-specific and general orthographic knowledge could enable their reliable assessment, and could also reduce methodological discrepancies and enhance the comparability of results in a given language. Considering the findings from studies showing that even children in kindergarten are sensitive to legal letter patterns (Cassar & Treiman, 1997; Pacton & Fayol, 2004), assessing orthographic knowledge (at least at general level) could provide information about potential risks of developing reading problems and allow an intervention at an early stage. Furthermore, development of a suitable orthographic knowledge training, which could be implemented in the regular school curriculum, might be helpful in acquisition of specific word spellings and orthographic rules. Especially considering the reading requirements in German, where letter-to-sound correspondences are more regular than sound-to-letter correspondences in spelling, it could be helpful to include the training of explicit orthographic rules early to facilitate the reading acquisition process.

5.4 Conclusion

The aim of this dissertation was to clarify the role of orthographic knowledge for basic and higher reading processes in German children with and without reading difficulties and to investigate its predicting role for comprehension performance in a text-fading based reading training.

The first research issue concerns the question whether both components of orthographic knowledge (word-specific and general) are significant predictors for basic (word-level) and higher reading processes (sentence- and text-comprehension) in German third-graders with and without reading difficulties. Based on the results from the first (see Zarić et al., 2020) and second empirical paper (see Zarić & Nagler, 2021) included in this dissertation, the conclusion is that word-specific and general orthographic knowledge can be considered as relevant components for both basic and higher level reading processes across different reading proficiency levels.

The second research issue was to investigate the predictive value of orthographic knowledge for reading comprehension performance during a text-fading based reading training. Based on the results from the third empirical paper included in this dissertation (see Nagler et al., 2021), it can be concluded that orthographic knowledge influences comprehension performance only when reading in own pace, but not when reading under time constraint.

Considering the importance of the role of orthographic knowledge for reading skills, its assessment is not only reasonable in the research context, but also in diagnostic processes for identifying children at risk for developing reading difficulties. As a desirable prospect, the development of a standardized orthographic knowledge test might enable its more reliable assessment, at best at an early stage, thus, minimizing the chance of developing reading difficulties (see Valtin et al., 2016). The findings showing that orthographic knowledge seems

to particularly influence reading comprehension when reading in own pace should be considered for further development of the text-fading based reading interventions.

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Appendix

Appendix A

Zarić, J., Hasselhorn, M., & Nagler, T. (2020). Orthographic knowledge predicts reading and spelling skills over and above general intelligence and phonological awareness. *European Journal of Psychology of Education*. https://doi.org/10.1007/s10212-020-00464-7

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 sub-types 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.

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 & 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 & Tunmer, 1986; Lenhard & 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 & Berninger, 1993). Spelling skills were shown to have an influence on writing productivity (Kim et al., 2011), writing quality (Kent, Wanzek, Petscher, Al Otaiba, & Kim, 2014), and writing fluency (Kim, Al Otaiba, Wanzek, & Gatlin, 2015). Moreover, knowledge of the spelling of a word enables its fluent reading, since both build and rely on the same mental representation (Snow, Griffin, & Burns, 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, Rastle, Perry, Langdon, & Ziegler, 2001; Siddaiah & Padakannaya, 2015; Steinbrink & Lachmann, 2014). General intelligence (e.g., Horn & Packard, 1985; Stanovich et al., 1984) and phonological awareness (e.g., Caravolas et al., 2001; Castles & Coltheart, 2004; Ehri et al., 2001; Kirby et al., 2008;

Schulte-Körne, 2011; Ziegler & Goswami, 2005) are among the most important prerequisites of reading and spelling acquisition. For instance, in a longitudinal study Ennemoser, Marx, Weber, and Schneider (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 & 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 & Samuelsson, 2009; Jongejan, Verhoeven, & Siegel, 2007; Landerl & Wimmer, 2008; Muter & Diethelm, 2001; Näslund & Schneider, 1996; Pae, Sevcik, & Morris, 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 & Denckla, 2001; Holland, McIntosh, & Huffman, 2004). It is generally agreed that orthographic knowledge is acquired through repeated exposure to print (Barker, Torgesen, & Wagner, 1992; Berninger, 1994; Fletcher-Flinn & Thompson, 2004; Stanovich & 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, Channell, Phillips, & Conners, 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 & 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, Parrila, & Papadopoulos, 2008). Another view considers orthographic knowledge as a knowledge about regularities of visual and orthographic aspects of written language (Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 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 & Massaro, 1979). Analogous to the stored representations of the spoken words (phonological representations; e.g., Claessen, Heath, Fletcher, Hogben, & Leitão, 2009; Foy & 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, Harris, & Williams, 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, Cornell, Ise, & Schulte-Körne, 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 & 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 & 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, Forsberg, Wise, & Rack, 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, Parrila, & Papadopoulos, 2008; Persian: Arab-Moghaddam & Sénéchal, 2001; Dutch: Bekebrede, Van Der Leij, & Share, 2009; English: Conrad et al., 2013; Cunningham & 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 & 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 & Sénéchal, 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 & 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, Scanlon, & Tanzman, 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 & Treiman, 1997; *baff* vs. *bbaf*; Cunningham & 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, Pratt, & Johnston, 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, Arnoldi, Bartling, and Schulte-Körne (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 & Stanovich, 1990; Deacon et al., 2012; Pacton & Fayol, 2004; Pacton, Perruchet, Fayol, & Cleeremans, 2001). There are only few studies from more transparent languages like Persian or German (e.g., Arab-Moghaddam & 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 & 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 levels (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 sub-types 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; [A *trail making test*]; Oswald & 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 & 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 & 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 & Roth, 1987). The test consists of four matrices with different configurations of digits ranging

from 1 to 90. Within a time limit of 30 seconds 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, Seibert, Dierks, & Körkel, 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 α = .88 and Cronbach's α = .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, Würzner, Heister, Geyken, & Kliegl, 2015). Both subtypes of orthographic knowledge were applied using two orthographic choice tasks programmed in *Psychology software in Python* (PsychoPy; Peirce, 2009) and presented on a laptop with 14.1-in. monitor on a black screen

[1] The results of an explorative factor analysis (see Appendix, Table 8) indicates 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.

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. 20 Items addressed the knowledge about 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

[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.

[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

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 minutes 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 & Roth, 1987), and then the standardized reading test (ELFE 1-6; Lenhard & Schneider, 2006). After completing the reading test, children conducted the standardized spelling test (SLRT-II; Moll & 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 α = .57). The number of correct answers of the

[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

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 α = .75).

Results

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

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

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, 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.

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 ≤ .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

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.

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		
			ß	R^2	Δ R^2	ß	R^2	Δ R^2	ß	R^2	Δ R^2
1				.16			.23			.12	
	1	IQ	.35*			.43**			.24*		
		PA	.18			.21*			.25*		
	2			.33	.17**		.38	.15**		.20	.08*
		IQ	.36*			.43**			.25*		
		PA	.12			.16			.21*		
		Word-specific orth. know.	.42**			.39**			.28*		
2				.16			.23			.12	
	1	IQ	.35*			.43**			.24*		
		PA	.18			.21*			.25*		
	2			.25	.09*		.31	.08*		.17	.05*
		IQ	.35*			.42**			.24*		
		PA	.18			.13			.18		
		General orth. know.	.32*			.29*			.22*		
3				.16			.23			.12	
	1	IQ	.35*			.43**			.24*		
		PA	.18			.21*			.25*		
	2			.36	.20**		.40	.17**		.21	.09*
		IQ	.35*			.42**			.24*		
		PA	.18			.12			.18*		
		Word-specific orth. know.	.35*			.33*			.24*		
		General orth. know.	.19*			.17			.14		

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

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 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.

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

Model	Step	Predictor	ß	R^2	Δ R^2
1				.10*	
	1	General intelligence (IQ)	.26*		
		Phonological awareness	.19		
	2			.38**	.28**
		General intelligence (IQ)	.26*		
		Phonological awareness	.12		
		Word-specific orthographic knowledge	.53**		
2				.10*	
	1	General intelligence (IQ)	.26*		
		Phonological awareness	.19		
	2			.23**	.13**
		General intelligence (IQ)	.24*		
		Phonological awareness	.08		
		General orthographic knowledge	.37**		
3				.10*	
	1	General intelligence (IQ)	.26*		
		Phonological awareness	.19		
	2			.41**	.31**
		General intelligence (IQ)	.25*		
		Phonological awareness	.07		
		Word-specific orthographic knowledge	.46**		
		General orthographic knowledge	.21*		

* $p \leq .05$, ** $p \leq .01$, IQ = Intelligence quotient

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 Table 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 Table 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 & 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 levels 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, Schabmann, Gasteiger-Klicpera, & Schmidt, 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 & 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 & 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 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 levels (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 & 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, Fletcher, Snowling, & Scanlon, 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 & Padakannaya, 2015), or for reading at the higher level, such as listening comprehension (e.g., Verhoeven & 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).

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 occuring			**Rarely occuring**		
Stimuli	**Bigramfreq.**	**Trigramfreq.**	**Stimuli**	**Bigramfreq.**	**Trigramfreq.**
sittor[a]	630328	38239	siddor[a]	471866	10524
bellab	804082	56918	beggab	579106	19018
bettab*	658065	8278	beddab*	728860	8506
dihett*	790950	2455	dihegg*	729714	2012
dallan*	919441	31511	dahhan*	838610	7960
getemm*	1576248	48822	getekk*	1459920	45863
gettie*	1366786	19271	geggie*	1245649	19408
hassic	1222851	110064	haddic	930323	14759
henemm*	2098605	178496	henekk*	1982277	148098
kebemm*	648118	35442	kebekk*	531790	41776
kemman	736851	29294	kekkan	569485	21588
lammei	1064939	34623	lakkei	912505	25471
liramm	586021	5192	lirabb	599570	7801
mellig*	726245	21588	mehhig*	520578	19191
mizull	337837	1562	mizudd	316233	948
nelles	1168607	24568	nehhes	1112866	9952
nedutt*	603388	1994	nedugg*	559565	1597
rissau	784698	12062	riddau	734196	6212
ritemm*	1322411	45606	ritekk*	1206083	42647
walann	865323	34870	walabb	590743	4206
wisamm*	551105	33806	wisabb*	564654	16940

*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]	2147677	258604	lloden[a]	2152641	212635
fahopp*	209152	9611	ffahop*	218147	7322
fosupp*	118094	4964	ffosup*	127089	1044
fuppat*	232213	5276	ffupat*	241208	876
lannag*	927832	112628	llanag*	932796	39967
leminn*	1412114	29622	llemin*	905998	97451
linnur*	1244304	54952	llinur*	1249268	56678
matell	1526302	86744	mmatel	1441786	45866
misett	1475675	196837	mmiset	1441786	45208
mugott*	873142	46826	mmugot*	839253	30426
narell*	1038418	64317	nnarel*	1033454	24932
nellus*	996278	57524	nnelus*	991314	51863
nillau*	900006	54367	nnilau*	895042	30282
nomell	706712	63128	nnomel	701748	20619
paffab*	242943	6116	ppafab*	233948	1177
pasaff*	508841	12790	ppasaf*	499846	7644
pateff*	1111250	18167	ppatef*	1102255	16520
puffan*	608541	11744	ppufan*	599546	9418
tammit*	610325	98796	ttamit*	644214	93110
timmac*	531645	84176	ttimac*	565534	41395
tokamm*	289750	31979	ttokam*	323639	15464

*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%

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 sub-types of orthographic knowledge (word-specific and general).

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Appendix B

Zarić, J., & Nagler, T. (2021). Reading comprehension on word- and sentence-level can be predicted by orthographic knowledge for German children with poor reading proficiency. *Reading and Writing*, *0123456789*. https://doi.org/10.1007/s11145-021-10126-9

Abstract

Previous studies mostly examined the role of orthographic knowledge in basic reading processing (i.e., word-reading), however, regarding higher reading processing (i.e., sentence- and text-comprehension), mixed results were reported. In addition, previous research in transparent languages, such as German, focused mostly on typically skilled readers. The aim of this study was to examine the role of orthographic knowledge in basic reading processing (word-reading) as well as in higher reading processing (sentence- and text-comprehension), in addition to phonological awareness and naming speed in a sample of German elementary school poor readers. For this purpose, data from 103 German third-graders with poor reading proficiency were analyzed via multiple linear regression analysis. Analyses revealed that orthographic knowledge contributes to reading at word- and sentence-level, but not at text-level in German third-graders with poor reading proficiency, over and above phonological awareness and naming speed. These findings support that orthographic knowledge should be considered as a relevant reading related predictor. Therefore, it would be reasonable to include the assessment of orthographic knowledge skills in diagnostic procedures to identify children at risk to develop reading difficulties, besides phonological awareness and naming speed.

Keywords: orthographic knowledge, phonological awareness, naming speed, reading, poor readers

Reading is one of the most important academic skills in our society. However, some children struggle to reach sufficient reading proficiency during and after elementary school education. Between 3-8% of the children show serious difficulties in acquiring adequate reading skills (e.g., Landerl & Moll, 2010; Moll, Kunze, Neuhoff, Bruder, & Schulte-Körne, 2014). Difficulties in reading can lead to limited education, resulting in higher chance of unemployment as well as financial and economic disadvantages (Valtin, 2017; Vellutino et al., 1996). Also, there is a higher risk for children with reading difficulties to develop comorbid psychological problems, such as social phobia or depression (e.g., Bäcker & Neuhäuser, 2003; Carroll, Maughan, Goodman, & Meltzer, 2005; Willcutt & Pennington, 2000). To counter such unfavorable development, identification of factors relevant for (un)successful reading proficiency, as well as development and improvement of instruments for recognizing children at risk are crucial (Castles, Rastle, & Nation, 2018; Tippelt & Schmidt-Hertha, 2018).

It is widely accepted that reading includes a variety of processes, which differ in their complexity. These processes include identifying written words, comprehending sentences, and also establishing coherence between sentences (Perfetti, Landi, & Oakhill, 2005; Vellutino, Fletcher, Snowling, & Scanlon, 2004). In this paper, we focus on the processing steps necessary for understanding a text while concentrating on different complexity levels, including basic level (i.e., word-reading) and higher level (i.e., sentence-, and text-level comprehension; see Lenhard & Schneider, 2006). The word level represents the basic level of reading, which includes decoding of single words, and understanding the meaning of the words (Castles et al., 2018; Karageorgos, Müller, & Richter, 2019). Single word reading is mostly associated with lower level processing skills, such as fast and efficient orthographic and phonological processing and identification (Wolf & Katzir-Cohen, 2001). In an often cited model of reading processes (i.e., Dual Route model; Coltheart, Curtis, Atkins, & Haller, 1993), word reading proceeds in two different ways via (1) lexical or (2) non-lexical route.

When confronted with frequent and/or familiar words, representations of words and letter patterns stored in the mental lexicon can be retrieved automatically via the lexical route. When confronted with low frequent and/or unfamiliar words, letter-to-sound-conversion via the non-lexical route is applied. Especially in orthographically consistent languages, such as Greek, Finnish, Italian, or German, children who are learning to read rely more on letter-to-sound recoding because the relationship between letters and sounds is straightforward (Ziegler & Goswami, 2005). Skilled readers are characterized by increased use of the lexical, more efficient route during reading. The automatized word decoding processes free up cognitive resources which can then be used for higher-demanding processes, such as comprehension processes at the sentence and text level (Perfetti & Hart, 2002; Pikulski & Chard, 2005; Roberts, Good, & Corcoran, 2005). Less skilled readers use the non-lexical, less efficient route more often, resulting in decreased reading fluency and therefore impaired reading comprehension (Fuchs, Fuchs, Hosp, & Jenkins, 2001). In addition, at the word level, poor readers show difficulties in their decoding skills compared to good readers (Cain, 2009).

The successful identification of the words, interpretation of its meaning in the given context as well as the integration between different words enable reading comprehension at higher level (i.e., sentence-level; Lenhard & Schneider, 2006). In order to understand the content of the sentence it is necessary to analyze semantic and syntactic elements within the sentence (Richter & Christmann, 2002). The processing of the semantic and syntactic elements is assumed to run parallel, and enables the understanding of the content of the sentence (Lenhard & Schneider, 2006; Taraban & McClelland, 1990). At the sentence-level, poor readers seem to have lower syntactic knowledge and they show more problems in creating a coherent representation of related sentences compared to skilled readers (Cain, 2009).

The last level of reading we want to examine in this study is text-level comprehension, defined as an understanding of the relationship between different sentences, which enables the

processing of texts (Gough & Tunmer, 1986; Lenhard & Schneider, 2006). Successful text-level comprehension processes therefore include extraction of information, establishing cross-reference (anaphoric) connections, and also drawing inference conclusions (in a sense of "reading between the lines"; Lenhard & Schneider, 2006). At the text-level, poor readers seem to have problems in building a situational model described in the text due to the problems in generating text-based inferences, and they seem to have problems integrating the propositions from the text with their own prior knowledge (Cain, 2009).

To sum up, efficient word-level reading frees up cognitive resources which are then available for sentence- and text-level comprehension (Perfetti & Hart, 2002). Since word-level reading is mostly associated with lower level processing skills, such as fast and efficient retrieval as well as orthographic and phonological processing and identification, it is important to have a closer look at skills relevant for reading. In this respect, especially the automatized and fast retrieval of information (i.e., naming speed), the quality of orthographic representations and access to linguistic information stored in the mental lexicon (i.e., orthographic knowledge) as well as the awareness of the sound structure of the language (i.e., phonological awareness) have shown to be important for reading operations.

Phonological Awareness, Naming Speed, and Orthographic Knowledge

Following the assumptions of automatic information processing theories (LaBerge & Samuels, 1974; Perfetti, 1985), phonological awareness, naming speed and orthographic knowledge are considered to be highly interrelated, however, independent contributors to reading. An efficient representation retrieval from the mental lexicon due to established pathways facilitates and accelerates decoding processes, thus, free cognitive resources can be used for higher processes, such as reading comprehension. This fast and efficient retrieval is, however, only achievable, if direct word identification is possible (Thaler, Ebner, Wimmer, & Landerl, 2004) via the lexical route from the mental lexicon. If the direct retrieval is not

available, phonological awareness helps to translate print into words via the less automatized and less efficient letter-by-letter identification through phonological re- and decoding processes. However, this impedes the storing of commonly occurring orthographic patterns and representations. As a result, inefficient, slow recognition of orthographic patterns can lead to slower reading rate (Wolf & Bowers, 1999) and difficulties in reading comprehension (Landerl & Wimmer, 2008). As suggested by the orthographic depth hypothesis (Katz & Frost, 1992), the letter-to-sound consistency of the language influences the degree to which readers rely on phonological or orthographic information. In opaque languages (such as English or French), readers rely more on the visual-orthographic structure of printed words to overcome decoding difficulties resulting from ambiguous and partly inconsistent letter-to-sound correspondences. In transparent languages (such as German or Greek) with consistent letter-to-sound correspondences readers rely more on more easily available phonological information (Ise, Arnoldi, & Schulte-Körne, 2014).

Phonological awareness. Phonological awareness enables the recognition and manipulation of sound units of the spoken language (e.g., Anthony & Francis, 2005; Steinbrink & Lachmann, 2014). Therefore, it is considered as a prerequisite of early decoding development, with an impact on later reading comprehension (Vellutino, Tunmer, Jaccard, & Chen, 2007). A large body of research supports the predictive value of phonological awareness for the acquisition of reading skills (e.g., Ennemoser, Marx, Weber, & Schneider, 2012; Heath & Hogben, 2004; Moll, Fussenegger, Willburger, & Landerl, 2009). A recent meta-analysis by Pfost (2015) identified phonological awareness as a significant predictor for reading speed, reading accuracy, and reading comprehension. However, the differences in letter-to-sound correspondences in transparent vs. opaque languages have been shown to lead to different impacts of phonological awareness on reading (see Ziegler et al., 2010). In transparent orthographies, the differences in preliterate phonological awareness become homogenized more quickly due to consistent letter-to-sound connections than in opaque

languages, leading to weaker correlations between phonological awareness and reading in transparent languages (Ziegler et al., 2010). It is assumed that deficits in phonological awareness lead to difficulties in building and storing associations between phonological and orthographic representations in the mental lexicon, thus, evoking difficulties in reading acquisition (Landerl & Thaler, 2006; Scheerer-Neumann, 2015). Children with reading difficulties also show deficits in different aspects of phonological awareness, such as segmentation and phoneme deletion tasks (e.g., "say the word 'mouth' without /m/"; Melby-Lervåg, Lyster, & Hulme, 2012; Paulesu et al., 2001; Ramus et al., 2003).

Naming speed. Naming speed is considered as a basic cognitive process which influences reading speed development (Moll, Wallner, & Landerl, 2012). It is usually measured by rapid automatized naming (RAN) tasks requiring the speeded naming of lists of familiar stimuli, such as letters, pictured objects, color patches, and digits (Denckla & Rudel, 1976). Typical tasks used to measure reading at the word-level, such as tasks focusing on word reading speed and/or pseudoword (i.e., pronounceable letter combinations, created by using certain linguistic criteria) reading as well as tasks measuring reading accuracy and speed, are usually correlated with or predicted by RAN measures (e.g., Bowers, 1995; Georgiou, Parrila, & Papadopoulos, 2008; Landerl & Wimmer, 2008; Moll et al., 2009). Furthermore, several studies reported that RAN is also correlated with or predicts reading comprehension measures (e.g., Arnell, Joanisse, Klein, Busseri, & Tannock, 2009; Georgiou, Das, & Hayward, 2008; Kirby, Parrila, & Pfeiffer, 2003; McCallum et al., 2006). It is assumed that in consistent orthographies where readers decode words by applying letter-to-sounds conversion rules (e.g., Goswami, 2002), naming speed is strongly related to reading because the phonological representation of graphemes must be retrieved quickly for letter-to-sound conversion to be effective (Georgiou et al., 2008). Children with reading and spelling difficulties show slower naming speed in the RAN tasks compared to unimpaired controls (e.g., Georgiou, Papadopoulos, Fella, & Parrila, 2012; Wimmer, 1993).

Orthographic knowledge. Orthographic knowledge is considered as one of the major individual prerequisites of word identification (Cutting & Denckla, 2001), which contains specific sequences of graphemes representing written words (i.e., mental graphemic representations; Apel, 2011). In order to accurately identify a word, it is crucial to know how letters are combined to form a specific word (Apel, 2011; Loveall, Channell, Phillips, & Conners, 2013). Hence, fluent reading is supported by a sufficient level of orthographic knowledge, which enables the individual to quickly recognize written words with little cognitive effort (e.g., Ehri, 2005; 2014). In transparent languages, such us Dutch, repeated blending of graphemes and phonemes during decoding leads to successful phonological recoding, and enables establishment of orthographic representations (De Jong & Messbauer, 2011), which are crucial for developing fluent reading (Rothe, Cornell, Ise, & Schulte-Körne, 2015).

There are several different definitions of orthographic knowledge in the literature. In this paper, we use the term orthographic knowledge consistent with Apel (2011), where both the ability to develop and access mental representations of written words in the mental lexicon (i.e., word-specific orthographic knowledge) as well as the application of knowledge about rules and word patterns (i.e., general orthographic knowledge) are included. Word-specific or lexical orthographic knowledge involves the stored mental representations of familiar words and word parts. Tasks used to measure word-specific orthographic knowledge usually involve words and pseudohomophones decision tasks, where children have to actively think or reflect on their knowledge of orthography and decide whether the presented stimuli is a real word or not by comparing it to the orthographic representation stored in the mental lexicon (e.g., Apel, Henbest, & Masterson, 2018). General or sub-lexical orthographic knowledge contains knowledge about the rules and legal patterns of a writing system, including the rules that govern where certain letters can occur in word positions, and what letters can be combined with another (Apel et al., 2018). General orthographic knowledge is typically measured by

orthographic word-likeness task, where children are asked to choose the one pseudoword that most reassembles a real word. One pseudoword in these tasks follows legal orthographic conventions whereas the other violates them. For instance, these tasks measure children's knowledge of permissible orthographic patterns, word position rules, and/or orthographic sequence rules (Apel et al., 2018). With these tasks, the children's knowledge of allowable orthographic patterns is measured rather than the explicit use of that knowledge during reading or spelling. Children with reading and spelling difficulties show lower scores in the tasks measuring word-specific (Bergmann & Wimmer, 2008) and general orthographic knowledge compared to their typically reading peers (Rothe et al., 2015).

Several studies revealed that word-specific and general orthographic knowledge contribute to word-reading skills (e.g., Arab-Moghaddam & Senechal, 2001; Bergmann & Wimmer, 2008; Georgiou, Parrila, et al., 2008; Rothe et al., 2015; Rothe, Schulte-Körne, & Ise, 2014). In previous studies examining the role of orthographic knowledge in reading performance, typical tasks used to measure reading skills included real word/pseudoword reading and/or reading fluency, however, without including any higher reading processes, such as reading comprehension (Apel et al., 2018). To our knowledge, there are only few studies examining the relationship between orthographic knowledge and both reading at word level and sentence and/or text-level simultaneously in transparent languages with relatively consistent letter-to-sound-correspondences, such as German (e.g., Ise, Arnoldi, & Schulte-Körne, 2014; Zarić, Hasselhorn, & Nagler, 2020). Ise et al. (2014) have shown no significant correlations between orthographic knowledge and reading speed and comprehension in children from kindergarten to 2nd grade. In the reading task used by Ise et al. (2014), children are presented with simple sentences and are asked to read them silently as quickly as possible, and to indicate whether the content of the sentence is generally false or true. In this study, however, only one task measuring orthographic knowledge at the general level (i.e., the knowledge about frequent and infrequent double consonants) was used. Another study

conducted in German by Zarić et al. (2020), however, reported that word-specific and general orthographic knowledge show significant correlations with reading at word-, sentence, and text-level. Moreover, the analyses have shown that both word-specific and general orthographic knowledge are significant predictors for reading at word-level, as well as at sentence- and text-level in German 3rd graders without reading difficulties. Since reading accuracy reaches ceiling at the end of Grade 1 in transparent languages (Seymour, Aro, & Erskine, 2003), age differences between the examined samples in these two studies might have an influence on different result patterns. In addition, the differences in the tasks used to measure orthographic knowledge and reading performance might explain differences in the findings.

To sum up, it still remains unclear whether orthographic knowledge with its two components (i.e., word-specific and general) contributes to sentence- and text-level in German. Furthermore, the previous studies regarding the contribution of word-specific and general orthographic knowledge at sentence- and text-level in German examined typical readers (Ise et al., 2014; Zarić et al., 2020). Therefore, it is still unclear whether both subtypes of orthographic knowledge (i.e., word-specific and general) also contribute to reading at sentence- and text-level in German poor readers.

The Present Study

Phonological awareness and naming speed have shown to be important predictors for basic as well as for higher reading processes (e.g., Kirby et al., 2003; Landerl & Wimmer, 2008; Pfost, 2015). Word-specific and general orthographic knowledge, on the contrary, were mostly examined in basic reading skills (i.e., word and/or pseudoword reading; e.g., Conrad et al., 2013; Rothe et al., 2015). Regarding higher reading skills (i.e., sentence- and text-level reading), mixed results were reported (Ise et al., 2014; Zarić et al., 2020).

Previous studies in German examining the role of orthographic knowledge in basic and higher reading processes simultaneously included samples of children without reading difficulties. However, studies with different samples (i.e., with and without reading difficulties) report different results (e.g., different correlations for impaired and non-impaired readers) regarding the relationship between reading and components relevant for reading (i.e., phonological awareness, RAN, orthographic knowledge; e.g., Swanson, Trainin, Necoechea, & Hammill, 2003). Therefore, the results from studies examining children without reading difficulties cannot be generalized to children with reading difficulties. Thus, it is important to examine the role of orthographic knowledge to reading in children with reading difficulties as well, as anticipated in the present study. A large body of research also suggests that the course of reading acquisition and the deficits underlying reading difficulties might differ across orthographies (Ziegler & Goswami, 2005). Thus, findings from opaque languages, such as English, cannot be transferred onto more transparent languages, such as German, which is in focus of the present study.

The aim of this study is to address the gaps in past empirical research by exploring the relationship between word-specific and general orthographic knowledge and reading at basic reading level (i.e., word-level), as well as at higher reading level (i.e., sentence- and text-level) in German elementary school poor readers. Since word-specific and general orthographic knowledge seem to play an important role in word-identification, it can be assumed that children with low reading proficiency use their orthographic knowledge when reading single words. Therefore, in line with previous results (e.g., Rothe et al., 2015; Zarić et al., 2020), we hypothesize that word-specific and general orthographic knowledge contribute significantly to reading at word-level, over and above the contribution of phonological awareness and RAN in poor readers.

Furthermore, following the assumption that high-quality orthographic representations are necessary for higher reading processes, like reading comprehension (see for example the

Lexical Quality Hypothesis; Perfetti & Hart, 2002), it is assumed that word-specific and general orthographic knowledge can contribute to efficient single-word reading, enabling their processing, and therefore enhancing reading fluency, resulting in comprehension at sentence-and text-level. Thus, we hypothesize that word-specific and general orthographic knowledge also contribute to reading comprehension at sentence- and text-level, in addition to phonological awareness and RAN in poor reading children.

Method

Participants

In a screening at 13 schools with a total of 484 participants, 103 German third-graders (*mean age* = 8.87 years, *SD* = 0.48, 46.6% girls; average IQ, *mean* = 102.36, *SD* = 11.06) from 10 public elementary schools in Frankfurt/Main in Germany were identified to meet the criteria to participate in the study: (1) reading performance ≤ 30th percentile in a standardized reading test; Würzburger Leise Leseprobe- Revision[8][WLLP-R; *Würzburger silent reading test-revised*]; Schneider, Blanke, Faust, & Küspert, 2011); (2) average and above average non-verbal intelligence (85 ≤ IQ ≤ 130) assessed by a standardized test (Zahlen-Verbindungs-Test, ZVT; [A *trail making test*]; Oswald & Roth, 1987). Parental consent was obtained for each child. The study was approved by a research ethics board.

Materials

Decoding speed (WLLP-R). To identify poor readers in a screening process, the standardized WLLP-R (Schneider et al., 2011) reading test was used in the present study[9]. This paper-pencil test measures decoding speed. Participants are asked to choose one out of

[8] WLLP-R T-Value mean of the sample = 26,55 (*SD* = 5,28); the decoding speed ≤ 30. percentile was used as an inclusion criterion, thus, children with severe as well as mild reading problems are considered, without including the clinical definition of reading impairment

[9] The WLLP-R percentile range from 0-30th percentile in the sample

four pictures that corresponds to the word presented as fast as possible within a time-limit of five minutes. The authors report good parallel-test reliability (r = .93).

Reading at word-, sentence-, and text-level. Reading performance was assessed using the computer version of a standardized German reading test (Ein Leseverständnistest für Erst- bis Sechstklässler – ELFE 1-6; [A reading comprehension test for first- till sixth-graders]; Lenhard & Schneider, 2006). This test is divided into three subtest and measures reading at word-, sentence-, and text-level with a time-limitation. Reading at word-level is measured through 72 items composed of a picture accompanied by four-word alternatives. Participants have to choose the word corresponding to the picture. The subtest for measuring reading comprehension at sentence-level contains 28 sentences. Participants are asked to complete the sentences by choosing one of five possible word alternatives. For measuring reading comprehension at text-level, participants are asked to process 20 items comprising a connected text and a corresponding multiple- choice question. According to the authors the three subtests show high internal consistency (word-level $\alpha = 0.97$, sentence-level $\alpha = 0.93$, and text-level $\alpha = .97$). Standardized T-scores of each of the three subtests were used for further statistical analyses.

General (non-verbal) intelligence. For assessing participant's general (non-verbal) intelligence a standardized test (ZVT; Oswald & Roth, 1987) was used. The test contains four matrices with different configurations of digits from 1 to 90. Participant are instructed to connect the digits in the counting order as fast as possible within a time limit of 30 seconds per matrix. The authors report that this test measures cognitive speed of processing, and can be therefore considered to represent a basic (general) and non-verbal component of intelligence, classifies by the indication of intelligence quotient (IQ) scores. The retest-reliability data vary from r_{tt} = .84 to r_{tt} = .97. For further statistical analyses, IQ-scores provided by the manual were used.

Phonological awareness. Phonological awareness was measured by the subtest of a German sound differentiation test (Heidelberger Lautdifferenzierungstest – H-LAD; [Heidelberg sound differentiation test]; Brunner, Seibert, Dierks, & Körkel, 1999). Participants are instructed to decide whether they hear two same or two different words/syllables for each of the 32 items (23 word-pairs and 9 syllable-pairs). Authors report internal consistency between α = .88 and α = .86. In addition, satisfying correlations (r = .61 for the 2nd grade; r = .54 for the 4th grade) with a sound differentiation and auditive memory test (see Mottier-Test; Linder & Grissemann, 2000) were found, supporting H-LAD's convergent validity. Standardized T-scores were used for further analyses.

Naming speed. Naming speed was assessed by using four RAN-task-matrices in DIN-A3 format, each containing either objects (candle, car, dog, fish, hammer), colors (blue, green, red, yellow, black), letters (f, k, r, s, t), or digits (1, 4, 5, 6, 8; see also Denckla & Rudel, 1976). In this RAN task, participants are instructed to name the presented stimuli as fast and as accurately as possible. Time required for each of the four matrices as well as the number of errors was measured. For further analyses, the processing time of the correctly named items of all four subtests was summarized into an overall RAN sum score.

Orthographic knowledge. To assess orthographic knowledge at the word-specific and general level, new item sets according to the construction principle of previous studies (e.g., Rothe et al., 2015; Zarić et al., 2020) were generated. For item development, the child-oriented childLex database (Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015) was used. The tasks measuring word-specific and general orthographic knowledge were programmed in *Psychology software in Python* (PsychoPy; Peirce, 2009) and were presented on a laptop with 14.1-in. monitor on a black screen with white letters in font size 35.

Word-specific orthographic knowledge was measured by using an orthographic decision task, consisting of 30 self-developed individually and randomly presented items (15 real words and 15 pseudohomophones – i.e., a constructed word with the same pronunciation

as an existing word, however, incorrectly spelled, e.g., *rain – rane*) and two practice items (see Appendix, Table 4). Pseudohomophones were developed by manipulating real words (e.g., by alternating the letters /ä/ and /e/: *bärtig - bertig*), which were similarly pronounceable. The selected words used for creating pseudohomophones, as well as all selected real words, were low frequent[10]. To assess word-specific orthographic knowledge children were asked to decide whether the presented item was a real word or not by pressing the corresponding button on a computer keyboard.

General orthographic knowledge was assessed using an orthographic-choice task, consisting of 20 self-developed randomly presented test items and two practice items (see Appendix, Table 5). Each item contained two pronounceable pseudowords (i.e., pronounceable letter combinations, created by using legitimate linguistic criteria) with six letters. The test items measured the knowledge about the legal positions of double consonants in German. One pseudoword in each pair contained a double consonant in a legal position (e.g., *lannag*, *fahopp*), and the other contained a double consonant in an illegal position (e.g., *ffosup*). The frequency of all bigrams[11] and trigrams[12] was 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 5). Children were asked to choose which one of the two presented pseudowords closest resembles a real German word, and to press the corresponding button on a computer keyboard.

[10] Type frequency of the selected words was ≤ 500 times per million continuous words in the corpus, and were therefore classified as low frequent in comparison to other words..
[11] $U = 193.00$, $p = .85$; no significant difference between bigram frequencies of the pseudowords containing double consonants in the legal vs. pseudowords containing double consonants in illegal position.
[12] $U = 154.00$, $p = .21$; no significant difference between trigram frequencies of the pseudowords containing double consonants in the legal vs. pseudowords containing double consonants in illegal position

Procedure

Participants were tested on three days during regular school times in the morning. Trained examiners conducted the different tasks, and ensured a child-appropriate atmosphere with enough brakes during the testing periods. On the first day (screening day), a total of 484 participants were first asked to complete the *trail-making-test* (ZVT; Oswald & Roth, 1987) in a classroom setting. Afterwards, they completed the standardized German reading test (WLLP-R; Schneider et al., 2011). After the screening day, the children who were identified to meet the criteria to participate in the study were tested on the second and third test day. The second test day was realized in smaller group settings (up to 12 persons). The participants first completed the standardized German reading test ELFE 1-6 (Lenhard & Schneider, 2006), followed by the standardized phonological awareness task H-LAD (Brunner et al., 1999). Subsequently, participants conducted the tasks measuring the word-specific and general orthographic knowledge. On the third day participants completed the RAN task (see also Denckla & Rudel, 1976) in a single-participant test situation.

Data Preparation

For each of the four RAN subtest (i.e., colors, digits, letters, and objects) errors[13] were subtracted from the total sum of the items per subtest (50), providing the number of correctly named items per subtest. Then, the total time of all four subtest was divided by all correctly named items, providing the total average naming speed (items per second) for all four subtests together. This RAN measure was subsequently used for further statistical analyses.

Before running statistical analyses regarding orthographic knowledge data, an item-analysis for the items measuring word-specific and general orthographic knowledge was

[13] Subtest color-naming: mean error = .45, SD = .69 (range 0-3); subtest digit-naming: mean error = .14, SD = .54 (range 0-5); subtest letter-naming: mean error = .53, SD = 1.55 (range 0-10); subtest object-naming: mean error = .30, SD = .84 (range 0-7)

conducted. The analysis regarding the items measuring word-specific orthographic knowledge revealed that several items had a poor degree of selectivity (≤ .02) and difficulty (≤ .30 and ≥ .87), and therefore, these items were excluded from further calculations. With the remaining 16 items this task revealed to have a sufficient internal consistency (Cronbach's α = .72). The raw score of the task measuring word-specific orthographic knowledge represents the number of correct answers (see Appendix, Table 4). The analysis regarding the items measuring general orthographic knowledge also revealed several items with poor degree of selectivity (≤ .10) and difficulty (≥ .87). The number of correct answers of the remaining 16 out of 20 items of the task measuring general orthographic knowledge represents its raw score (see Appendix, Table 5) with a sufficient internal consistency (Cronbach's α = .77).

Results

Means and standard deviations for all measures used in the current study for the entire sample (N = 103) included are presented in Table 1.

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Relationship Between Reading Measures, Phonological Awareness, Naming Speed, and Orthographic Knowledge

In Table 2 correlations between word-specific and general orthographic knowledge, phonological awareness, naming speed, and reading at word-, sentence-, and text-level (based on ELFE 1-6) are shown. Since RAN, word-specific and general orthographic knowledge, and phonological awareness violated the normal distribution, we report Spearman's Rho rs correlation coefficients.

Word-specific and general orthographic knowledge, phonological awareness and naming speed significantly correlated with reading at word- and sentence-level. There was no significant correlation between reading at text-level and word-specific and general

orthographic knowledge, and naming speed. However, phonological awareness significantly correlated with reading at text-level. In addition, there were no significant correlations between phonological awareness, naming speed and word-specific and general orthographic knowledge. Reading at word-, sentence-, and text-level correlated significantly. Word-specific and general orthographic knowledge showed significant correlations.

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Predictive Patterns of Word-specific and General Orthographic Knowledge for Reading Measures

Multiple hierarchical regression analyses were conducted to explore whether word-specific and general orthographic knowledge explain unique variance in reading at word-, sentence-, and text-level. To explore the two subtypes independently of each other, separate regression models for word-specific (Model 1) and general orthographic knowledge (Model 2) for reading at word-, sentence-, and text-level were calculated. In addition, both subtypes of orthographic knowledge were entered simultaneously into the regression model (Model 3). In all regression models (Model 1, Model 2, and Model 3, see Table 3)[14], phonological awareness and RAN were entered in Step 1. In Step 2 word-specific (Model 1) or general orthographic (Model 2) knowledge, or both word-specific and general orthographic knowledge (Model 3) were entered to explore the unique amount of explained variance of orthographic knowledge, over and above phonological awareness and naming speed. Although the predictor variables violated the normal distribution, the residuals showed normal distribution, thus, indicating homoscedasticity.

[14] The same regression analyses were performed for the subpopulation of really poor readers with a reading proficiency below the 16th percentile. The results are presented in the Appendix, Table 6. In general, the results from this subpopulation differ slightly from the results of the whole sample, however, due to a smaller sample size, the statistical power was lower.

---------- insert Table 3 about here ----------

Reading at basic level. The analyses show that phonological awareness and RAN are both significant predictors for reading performance at basic level (i.e., word-level), and together they explain 18% of variance of word-level reading performance. After entering word-specific and/or general orthographic knowledge into the regression model, both phonological awareness and naming speed remain significant predictors. Word-specific orthographic knowledge explains additional 4% of variance of reading at word-level (Table 3, Model 1, column *Word-level*). General orthographic knowledge explains additional 5% of variance of word-level reading (Table 3, Model 2, column *Word-level*). Together, word-specific and general orthographic knowledge explain additional 7% of variance of reading at word-level, over and above explained variance by phonological awareness and naming speed.

Reading at higher level. The results show that phonological awareness and naming speed are both significant predictors for reading performance at sentence-level, and together they explain 13% of variance of sentence-level reading performance. After entering word-specific and/or general orthographic knowledge into the regression model, both phonological awareness and RAN remain significant predictors. Word-specific (Table 3, Model 1, column *Sentence-level*) and general orthographic knowledge (Table 3, Model 2, column *Sentence-level*) each explain additional 4% of variance of reading at sentence-level. Together, word-specific and general orthographic knowledge explain additional 6% of variance of reading at sentence-level, over and above explained variance of phonological awareness and naming speed. However, when both components of orthographic knowledge are entered together in the model (Table 3, Model 3, column *Sentence-level*), general orthographic knowledge is no longer a significant predictor for reading on the sentence-level.

The results show that phonological awareness is a significant predictor for reading performance at text-level explaining 16% of variance of text-level reading performance. After entering word-specific and/or general orthographic knowledge into the regression model, phonological awareness remains a significant predictor. However, neither naming speed (Table 3, Model 1 and 2, column *Text-level*), nor word-specific (Table 3, Model 1, column *Text-level*), nor general orthographic knowledge (Table 3, Model 2, column *Text-level*) are significant predictors of reading at text-level.

Discussion

The goal of this study was to determine whether word-specific and general orthographic knowledge contribute to basic level as well as to higher level reading processes among German elementary school children with poor reading proficiency, in addition to the well-established predictors phonological awareness and naming speed.

Reading at Basic Level

As assumed, the results show that both word-specific and general orthographic knowledge are significant predictors for reading at word-level, explaining additional variance to phonological awareness and naming speed among German poor reading children. The knowledge about word-specific representations as well as the knowledge about legal patterns stored in the mental lexicon are therefore important for word-reading processes. The results of the present study support previous reports (e.g., Conrad et al., 2013; Rothe et al., 2015; Zarić et al., 2020) and extend the evidence of the importance of orthographic knowledge for basic reading skill for children with poor reading proficiency. It can be assumed that poor readers use the memorized word-specific representations in order to recognize familiar/frequent words, and read them as a single unit, similar to the way typical readers do (Conrad et al., 2013). Since the knowledge about recurring spelling patterns, regularities, and consistencies (i.e., general orthographic knowledge) is considered to assist the memorization of specific

letter combinations and units necessary to establish word-specific representations in memory (Conrad et al., 2013), poor readers seem to use this knowledge when reading (novel/unknown) words.

The analyses also revealed that phonological awareness is a significant predictor for reading at word-level, which supports previous results (e.g., Vaessen & Blomert, 2010). This is also in line with the Dual Route model (Coltheart et al., 1993), where phonological awareness is considered to be especially important for the recoding of low frequent and/or unknown words by using letter-to-sound conversion via the non-lexical route. Our sample consisted of German children with poor reading proficiency. It is assumed that they used the letter-to-sound conversion via the non-lexical route frequently, and therefore relied more on phonological awareness during reading than on word representation automatized retrieval via the lexical route (Wimmer, 1993). Thus, it is not surprising that in the present study phonological awareness was identified as a significant predictor for word-reading. Concerning the contribution of naming speed, the results show that naming speed is a significant predictor for word-reading, which is also compatible with previous results (e.g., Georgiou et al., 2008). This might be taken as a support for the argument that efficient word-reading is supported through a quick retrieval of orthographic representations stored in the mental lexicon even among poor readers.

Reading at Higher Level

Sentence-level comprehension. In line with our expectations, the results show that word-specific and general orthographic knowledge predict reading comprehension at sentence-level, additionally to phonological awareness and naming speed. Sentence-reading requires the integration of the words within the sentence in order to comprehend the content (Castles et al., 2018). The knowledge about word-specific representations (i.e., word-specific orthographic knowledge) and the knowledge about legal letter patterns (i.e., general

orthographic knowledge) support the automatized recognition and reading of single words, thus, enabling their quick processing. By doing so, more free resources are available for understanding the content of the sentence. However, considering the results of the regression model comprising both components of orthographic knowledge, it seems that the knowledge about the word-specific representations (i.e., word-specific orthographic knowledge) plays a more important role hereby than the knowledge about the legal positions of the double-consonants (i.e., general orthographic knowledge). It is possible that the items used to measure sentence-level comprehension (see ELFE 1-6; Lenhard & Schneider, 2006) comprise mostly of words which are familiar to the participants. Thus, they mainly relied on their word-specific knowledge in order to solve the task, and less on their general orthographic knowledge. However, when confronted with less familiar words, the participants used their general orthographic knowledge to solve the task. Therefore, when included separately in the regression model, both components of orthographic knowledge made a significant contribution. However, when considered simultaneously, only word-specific orthographic knowledge remained a significant predictor. This pattern was also found in children without reading difficulties (Zarić et al., 2020). Hence, it can be assumed that, regardless of the reading proficiency level, word-specific orthographic knowledge might have a larger influence for comprehension at sentence-level than general orthographic knowledge. Considering these results, future studies examining possible differential effects of both word-specific and general orthographic knowledge on reading are necessary.

The analyses also revealed that phonological awareness and naming speed are both significant contributors to reading comprehension at sentence-level. These results indicate that the awareness of letter-to-sound correspondences as well as the quick retrieval of words from the mental lexicon both not only support the single-word recognition, but also enable the comprehension at sentence-level in poor readers.

Text-level comprehension. Contrary to our expectations, the results revealed that word-specific and general orthographic knowledge do not contribute significantly to reading comprehension at text-level in German children with poor reading proficiency. Text-level comprehension comprises understanding of single words, for which word-specific and general orthographic knowledge play an important role as indicated by the present results. However, more complex processes, such as background knowledge and semantic skills are assumed to have a larger influence on text processing (Castles et al., 2018). Thus, the contribution of word-specific and general orthographic knowledge in reading at text-level might be not as relevant as the influence from more complex processes. These results are contrary to results found in a study by Katzir et al. (2006). They indicated that spelling recognition (i.e., recognition of the correct spelling out of four choices), which was operationalized in a similar way as word-specific knowledge in the present study, contributed significantly to comprehension of sentences and text-passages in reading impaired English children. However, in their study, Katzir et al. (2006) used a task for measuring sentence- and text-comprehension in which participants had to choose a word that fits the meaning of each sentence or passage. A comparable task was used in the present study to operationalize reading comprehension at sentence-level. Thus, it is possible that the task used in the study of Katzir et al. (2006) can better be compared to the present task measuring comprehension at sentence-level. In this case, the results of the present study would be in line with the findings from Katzir et al. (2006) regarding the previously mentioned reading comprehension at sentence-level. The results of the present study also deviate from those found in a recent study by Zarić et al. (2020). In this study, word-specific and general orthographic knowledge both contributed to reading comprehension at text-level in German typically skilled readers. One explanation for the divergent result pattern regarding text-level reading in the present study concerns the considered sample. Previous results (e.g., Constantinidou & Stainthorp, 2009; Cornwall, 1992) indicated that phonological awareness seems to be critical for text-passage

comprehension especially for reading impaired children. It is, therefore, possible that the poor readers of the present sample also relied more on other skills (e.g., phonological processing) when processing a text compared to typically skilled readers. This assumption was supported by our results, which revealed phonological awareness to be a significant predictor for reading comprehension at text-level in our sample.

Furthermore, again contrary to our expectations, naming speed was not identified to be a significant predictor for reading at text-level in poor readers. This results are in line with the results from Wolff (2014), indicating naming speed to be a significant predictor for reading speed, however, not for connected text comprehension (i.e., text-level reading comprehension) in reading impaired children. The results of the present study suggest that quick access to the representations stored in the mental lexicon facilitates reading of single words and understanding of the sentences. However, for higher reading processes, such as text-level comprehension, phonological processes can be considered to play a more important role in poor readers than naming speed. An alternative explanation concerns the way naming speed is measured. Neuhaus, Foorman, Francis, and Carlson (2001) suggest that when assessing naming speed, interest should be turned to the two RAN-components, namely the *pause time* (i.e., the sum of the length of pauses that are the intervals between the correctly sequenced articulations) and the *articulation time* (i.e., the sum of the length of all correctly articulated RAN stimuli). In the present study, the average reaction time per item per second of the four RAN subtests was used to operationalize naming speed. It is, however, possible that more differentiated RAN-scores, including the two components pause time and articulation time, might have provided more sophisticated information regarding the contribution of naming speed to reading processes on the text-level in children with reading difficulties. Further studies using more differentiated RAN-components should be considered to examine their relationship to basic and higher reading processes.

Limitations

Despite promising results, this study has at least four main limitations. We did not include an assessment of spelling and other reading-relevant components, such as morphological knowledge and awareness, listening comprehension, vocabulary knowledge or letter knowledge. These components were shown in previous studies to be important for basic as well as for higher reading processes (e.g., Verhoeven & van Leeuwe, 2012; Volkmer, Schulte-Körne, & Galuschka, 2019). By including more variables in future studies, we could better understand the relation pattern among a variety of components relevant for reading as well as their contribution to basic and higher reading processes. Furthermore, the current study was conducted with poor reading German-speaking children. Therefore, the generalization of these results to other orthographies and reading proficiency levels is restricted. One further limitation concerns the tasks used to measure word-specific and general orthographic knowledge. These two tasks consisted of a smaller number of items than originally intended once we conducted the item analysis. This indicates that further item improvement is necessary. An additional limitation concerns the task used to measure general intelligence in this study. We used an older version of the ZVT (Oswald & Roth, 1987), which might have led to overestimation of the IQ of the sample. Future studies should either use the newer version of this test or some other non-verbal, time-efficient intelligence test.

Summary and Outlook

The current study indicates that the knowledge about word-specific representations and legitimate letter patterns are important for word identification as well as for the understanding of relations between words in sentence in German poor readers, over and above phonological awareness and naming speed. However, these two components of orthographic knowledge do not seem to support any higher processes, such as text-level comprehension. As mentioned before, reading includes a variety of processes. An impairment in one or more of these processes might result in reading deficits. The present study adds to the understanding

of orthographic knowledge as one further component relevant for basic and some higher reading processes in poor readers. Acknowledging that impairments in orthographic knowledge skills might lead to reading deficits in some children (Badian, 2001), both word-specific and general orthographic knowledge should be considered as relevant reading related predictors, as the present data reinforces. Regarding a practical application of the present results, it would be reasonable to develop a standardized test for measuring orthographic knowledge, and to use it in diagnostic procedures to reliably identify children at risk to develop reading difficulties. Another practical implication concerns the role of orthographic knowledge in a reading intervention. Since orthographic knowledge has an impact on reading performance, its assessment should be considered when applying a reading intervention, for instance a reading speed training. Assessment of orthographic knowledge might be helpful in understanding the underlying mechanism of such a reading intervention. The possible improvements in reading performance after applying a reading speed intervention might be a result of orthographic knowledge enhancement during the intervention. It is also possible that the initial orthographic knowledge proficiency level at the onset of the intervention might have an influence on training effects – children with better orthographic knowledge proficiency level might benefit more from such a reading intervention. As shown by Berninger et al., (1999), orthographic skills were shown to differentiate between reading intervention outcomes, thus, they should be included in future studies when measuring reading trainings effects.

Appendix

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Table 1

Means and Standard Deviations of All Measures

	Mean	*Standard deviation*
Phonological awareness	43.77[a]	9.99
RAN	0.86[b]	0.13
Word reading	40.33[a]	7.60
Sentence reading	38.47[a]	6.82
Text reading	42.29[a]	7.78
Word-specific orthographic knowledge	8.06[c]	3.25
General orthographic knowledge	11.91[c]	3.35

Note. RAN = Rapid automatized naming; [a] T-score; [b] Average reaction time per correct item per second of the four RAN subtests; [c] Raw score (maximum 16)

Table 2

Intercorrelations Between Reading Measures, Phonological Awareness, RAN, and Word-specific and General Orthographic Knowledge

	1	2	3	4	5	6	7
1. Word-level	–						
2. Sentence-level	.73**	–					
3. Text-level	.33**	.48**	–				
4. Phon. awareness	.19*	.30**	.40**	–			
5. RAN	-.37**	-.21*	-.11	-.06	–		
6. Word-specific orth. know.	.28**	.22**	.15	.11	-.10	–	
7. General orth. know.	.26*	.22*	.13	-.06	-.15	.21*	–

Note. *$p \leq .05$; ** $p \leq .01$; phon. = phonological; RAN = Rapid automatized naming; orth. know. = orthographic knowledge

Table 3

Hierarchical Multiple Regression Analyses for Reading at Basic (i.e., Word-level) and Higher Level (i.e., Sentence- and Text-level) Based on ELFE 1-6

Model	Step	Predictor	Basic level			Higher level					
			Word-level			Sentence-level			Text-level		
			ß	R^2	Δ R^2	ß	R^2	Δ R^2	ß	R^2	Δ R^2
1				.18**			.13*			.16*	
	1	Phon. awareness	.20*			.27*			.41**		
		RAN	-.35**			-.21*			-.01		
	2			.22*	.04*		.17*	.04*		.17	.01
		Phon. awareness	.18*			.25*			.40**		
		RAN	-.34**			-.20*			-.00		
		Word-specific orth. know.	.20*			.20*			.08		
2				.18**			.13*			.16*	
	1	Phon. awareness	.20*			.27*			.41**		
		RAN	-.35**			-.21*			-.01		
	2			.23*	.05*		.17*	.04*		.18	.02
		Phon. awareness	.21*			.28*			.41**		
		RAN	-.31*			-.18*			.02		
		General orth. know.	.22*			.18*			.14		
3				.18**			.13*			.16*	
	1	Phon. awareness	.20*			.27*			.41**		
		RAN	-.35**			-.21*			-.01		
	2			.25*	.07*		.19*	.06*		.19	.03
		Phon. awareness	.19*			.26*			.41**		
		RAN	-.30*			-.17*			.02		
		Word-specific orth. know.	.16*			.17*			.05		
		General orth. know.	.19*			.15			.13		

Note. * $p \leq .05$, ** $p \leq .01$; Phon. = phonological; RAN = Rapid automatized naming; orth. know. = orthographic knowledge

Table 4

Items of the Task Measuring Word-specific Orthographic Knowledge – Words and Pseudohomophones

Word	**Pseudohomophone**	
		Original word[b]
Aal[a] [eel]	fättig[a]	fettig [greasy]
ähnlich [similar]	ainsam	einsam [lonely]
ändern [to change]	bezaalen	bezahlen [to pay]
Bahn* [train]	fäucht*	feucht [moist]
Beil* [axe]	Feeler*	Fehler [failure]
Beule* [dent]	Gaist	Geist [ghost]
Bier* [beer]	gemain	gemein [nasty]
Fee [fairy]	Hächt*	Hecht [pike]
friedlich* [peaceful]	haiß	heiß [hot]
Haufen* [pile]	Kaffeh	Kaffee [coffee]
hohl* [hollow]	Kaim*	Keim [germ]
Leim [size]	Raifen	Reifen [tire]
mächtig [mighty]	Schaibe	Scheibe [slice]
Nest* [nest]	stail	steil [steep]
Pech [misfortune]	zaam*	zahm [tame]
weich* [soft]	Zaitung	Zeitung [newspaper]

Note. *Words and pseudohomophones excluded after item-analysis; [a] practice item; [b] Original, real words used for creating pseudohomophones

Table 5

Items of the Task Measuring General Orthographic Knowledge – Knowledge About Legal Positions of Double Consonants

Legal			**Illegal**		
Stimuli	**Bigramfreq.**	**Trigramfreq.**	**Stimuli**	**Bigramfreq.**	**Trigramfreq.**
fahopp	209152	9611	ffahop	218147	7322
fosupp	118094	4964	ffosup	127089	1044
fuppat	232213	5276	ffupat	241208	876
lannag	927832	112628	llanag	932796	39967
leminn	1412114	29622	llemin	905998	97451
linnur	1244304	54952	llinur	1249268	56678
lodenn*	2147677	258604	lloden*	2152641	212635
mattel*	1475675	196837	mmatel*	1441786	45208
misett	873142	46826	mmiset	839253	30426
mugott	251696	9610	mmugot	217807	1330
nellus*	996278	57524	nnelus*	991314	51863
nillau	900006	54367	nnilau	895042	30282
nomell	706712	63128	nnomel	701748	20619
paffab	242943	6116	ppafab	233948	1177
pasaff*	508841	12790	ppasaf*	499846	7644
pateff	1111250	18167	ppatef	1102255	16520
puffan	608541	11744	ppufan	599546	9418
tammit	610325	98796	ttamit	644214	93110
timmac	531645	84176	ttimac	565534	41395
tokamm	289750	31979	ttokam	323639	15464

Note. *pseudoword-pairs excluded 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 the childLex-database

Table 6

Hierarchical Multiple Regression Analyses for Reading at Basic (i.e., Word-level) and Higher Level (i.e., Sentence- and Text-level) Based on ELFE 1-6 for the Subgroup of Very Poor Readers (Reading Performance ≤ 16th Percentile, N = 55)

Model	Step	Predictor	Basic level			Higher level					
			Word-level			Sentence-level			Text-level		
			ß	R^2	Δ R^2	ß	R^2	Δ R^2	ß	R^2	Δ R^2
1				.08			.08			.16*	
	1	Phon. awareness	.10			.19			.37**		
		RAN	-.23**			-.17			-.10		
	2			.12	.04		.15	.07*		.16	.00
		Phon. awareness	.11			.20			.37**		
		RAN	-.24*			-.18			-.10		
		Word-specific orth. know.	.20			.27*			.00		
2				.08			.08			.16*	
	1	Phon. awareness	.10			.19			.37**		
		RAN	-.23*			-.17			-.10		
	2			.15*	.07*		.09	.01		.21	.05*
		Phon. awareness	.15			.21			.41**		
		RAN	-.20			-.15			.07		
		General orth. know.	.27*			.10			.22		
3				.08			.08			.16*	
	1	Phon. awareness	.10			.27*			.41**		
		RAN	-.23*			-.21*			-.01*		
	2			.18*	.10*		.17	.07		.21	.05
		Phon. awareness	.16			.19			.37**		
		RAN	-.21			-.17			.10		
		Word-specific orth. know.	.18			.26*			-.02		
		General orth. know.	.24*			.07			.23*		

Note. * $p \leq .05$, ** $p \leq .01$; Phon. = phonological; RAN = Rapid automatized naming; orth. know. = orthographic knowledge

Appendix C

Nagler, T., Zarić, J., Kachisi, F., Lindberg, S., & Ehm, J.-H. (submitted). Reading impaired children improve through text-fading training: Analyses of comprehension orthographic knowledge and RAN. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-021-00229-x

Abstract

Early intervention for children with reading impairments is crucial in order to achieve reading improvements and avoid school failure. One line of reading intervention research focuses on the experimental manipulation of reading rate through a text-fading training approach. Considering relevant reading related predictors (i.e., orthographic knowledge and Rapid Automatized Naming; RAN), we aim at evaluating the text-fading training's efficiency for a sample of German reading impaired third graders (n = 120). The purpose of the present study was to examine (1) the predictive value of orthographic knowledge and RAN and their contribution of explained variance in comprehension performance during training, (2) text-fading training effects on reading rate and comprehension in a pre-post comparison, as well as (3) (lasting) text-fading training effects at word and sentence level in a pre-post-follow-up design. Results of structural models indicated RAN to be significantly related to comprehension performance for the experimental group, whereas no sufficient regression weight was found for orthographic knowledge. A reverse pattern was found for the self-paced group. No significant improvements regarding reading rate and comprehension were revealed for the experimental group after training. However, significant positive effects on word and sentence level at post-test time point indicate stronger reading improvements for the experimental compared to the control group. The retention of training gains was indicated at sentence-level reading six months after the training. Possible explanations for the presented

positive training effects as well as the mixed results for reading rate, comprehension and follow-up preservation are discussed.

Keywords: Reading comprehension, reading rate, text-fading training, reading impaired children, RAN, orthographic knowledge

Most children successfully master the acquisition of complex reading processes during elementary school, through formal education and reading practice (Huemer, Landerl, Aro, & Lyytinen, 2008). Practice and exposure to print are considered to foster more automatic processing, which enables the reader to identify and coordinate words into sentences without paying much attention to this process. Thus, automatized word recognition leads to increased reading speed and reading fluency, often defined as fast and effortless decoding with correct prosody and a shift of attention to higher processes (Wolf & Katzir-Cohen, 2001). Increased reading fluency is strongly associated with improved reading comprehension (Huemer, Landerl, Aro, & Lyytinen, 2008), which is considered as the ultimate goal of reading (Pennington, 2009). It comprises accessing and constructing meaning from written text and coordinating multiple levels of language and cognitive functions (Johnston, Barnes, & Desrochers, 2008; Landi & Ryherd, 2017). However, about 4-9% of children show significant reading acquisition difficulties (Moll, Kunze, Neuhoff, Bruder, & Schulte-Körne, 2014). Empirical evidence supports the notion that especially deficits in reading fluency characterized by slow and laborious reading performance (de Jong & van der Leij, 2003), are a major component of reading impairments (e.g., Kuhn & Stahl, 2003; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). Impaired reading is closely related to problematic reading comprehension performance (Landerl & Wimmer, 2008). Different reading relevant precursors, such as the automatized and fast retrieval of information (i.e., Rapid Automatized Naming; RAN) and the orthographic knowledge, defined as the quality of orthographic

representations allowing access to linguistic information stored in the mental lexicon, affect successful reading development, and therefore reading comprehension (Catts, Herrera, Nielsen, Bridges, 2015), as well as reading intervention outcome.

Obviously, children with reading impairments are in special need for reading intervention, which should be introduced as early as possible, best during elementary school years (Brassel & Rasinski, 2008; Potocki, Magnan, & Ecalle, 2015), to improve reading skills and prevent school failure. The purpose of the present study is to evaluate the efficiency of a reading fluency training approach (i.e., text-fading training) with specific consideration of relevant reading related predictors. More precisely, we firstly aim at examining the predictive value of orthographic knowledge and RAN and their contribution of explained variance in comprehension performance during training. Secondly, we investigate text-fading training effects on reading rate and comprehension performance in a pre-post comparison. Thirdly, we engage in analyzing (lasting) text-fading training effects at word and sentence level in a pre-post-follow-up design after controlling for predictive reading related variables.

Lower- and Higher-Level Reading Processes

With regard to the complexity of the reading process, it is important to distinguish between different levels and preconditions necessary for successful reading development and reading intervention. Particularly, the structure and nature of the reading material has to be considered. Single word reading, which can be acknowledged as the basis for connected text reading, requires mostly orthographic and phonological skills that are considered as lower-level processing (Wolf & Katzir-Cohen, 2001). For connected text reading, such as sentence reading, language processing and comprehension skills are also necessary (Jenkins, Fuchs, van den Broek, Espin, & Deno, 2003), which are considered to be higher-level reading processes. Furthermore, to comprehend more complex reading material an efficient reading rate is necessary (Kuhn & Stahl, 2003). Considering the interplay of lower-level and higher-

level reading processes with the bi-directional interaction of decoding, reading comprehension and reading rate, it is essential to have a closer look at relevant reading related subskills. In this regard, especially orthographic knowledge as well as RAN have been identified as highly predictive for reading operations (Loveall, Channell, Phillips, & Conners, 2013).

Orthographic Knowledge and Rapid Automatized Naming as Reading Predictors

Orthographic knowledge comprises the knowledge of conventions and rules about a specific orthography (Conrad, Harris, & Williams, 2013). There is a consensus that orthographic knowledge consists of two components: a word-specific component containing the knowledge about the spelling of specific words and a general component containing the knowledge about permitted letter patterns of a written language (Apel, 2011; Rothe, Cornell, Ise, & Schulte-Körne, 2015). Fluent reading is supported by a sufficient level of orthographic knowledge, enabling the individual to recognize written letter patterns as words with little cognitive effort (e.g., Ehri, 2005, 2014). Empirical research has shown that orthographic processing predicts reading fluency in different languages, such as English and Greek (Georgiou et al., 2008). Furthermore, both subtypes of orthographic knowledge have been revealed as significant predictors for lower-level reading, such as word reading accuracy and speed, in different orthographies varying in the transparency level, indicating that lower reading performance is associated with fewer orthographic knowledge skills (e.g., English: Deacon, Chen, Luo, & Ramirez, 2013; Greek: Georgiou, Parrila, & Papadopoulos, 2008; German: Rothe et al., 2015; Zarić, Hasselhorn, & Nagler, 2020; Zarić & Nagler., 2021). Additionally, both word-specific and general orthographic knowledge have been identified to be relevant also for higher-level reading performance, such as sentence (Katzir et al., 2006; Zarić & Nagler, 2021) and text comprehension (Zarić et al., 2020).

RAN is characterized by fast and automatized naming of known stimuli, such as digits, letters, objects, and colors (Denckla & Rudel, 1976). According to Bowers and Newby-Clark (2002) and Bowers and Wolf (1993), it represents the general processes of cognitive speed. Empirical research studies suggest RAN to be a timing mechanism reflecting the speed of retrieval of phonological information as well as the formation of orthographic patterns and their integration with phonological codes (Manis, Seidenberg, & Doi, 1999; Mayringer & Wimmer, 2000). RAN is suggested to reflect the ability to recognize adjacent letters, thus, allowing their chunking into familiar letter patterns. Therefore, it is assumed that RAN is closely connected to the acquisition of orthographic knowledge, and hence, to contribute to efficient reading (Bowers & Newby-Clark, 2002; Wolf & Bowers, 1999). A large body of research shows that RAN is a significant predictor for reading skills (e.g., English: Georgiou, Das, & Hayward, 2008; McCallum et al., 2006; English/Greek: Georgiou et al., 2008; German: Landerl & Wimmer, 2008; Moll, Fussenegger, Willburger, & Landerl, 2009) and among the most robust correlates of reading impairments (Landerl et al., 2013). A meta-analysis by Araújo, Reis, Petersson and Faísca (2015) furthermore indicates that RAN is significantly associated with several different reading sub-components on lower-level (i.e., word reading, pseudo-word reading) as well as higher-level (i.e., reading comprehension) processing.

Besides the predictive value of orthographic knowledge and RAN for reading acquisition and reading difficulties, several studies have pointed out that both components can significantly influence intervention success. In a meta-analysis from Nelson, Benner and Gonzalez (2003) for example, the responsiveness to reading interventions was more strongly associated with RAN than with other cognitive components, such as phonological awareness or phonological memory. Similarly, orthographic skills were shown to differ between reading intervention outcomes (Berninger et al., 1999). Orthographic skills and naming speed were shown to predict the improvement of word reading performance after intervention

(Scheltinga, van der Leij, & Struiksma, 2010; Stage, Abbott, Jenkins, & Berninger, 2003). Consequently, orthographic knowledge and RAN should be considered as predictors when measuring training efficacy and possible training effects.

Reading Fluency Intervention Approach: Text-Fading Training

One approach to supporting children with impaired reading performance is to increase reading fluency through training. Reading fluency trainings are manifold, and reading rate as well as reading comprehension have been manipulated in several ways. Most often, reading rate has been treated as an outcome variable depending on effective word recognition and comprehension (Carver, 1990; Gough & Tunmer, 1986). The specific research line presented in the following, however, suggests considering individual reading rates as an independent and experimentally manipulable variable (Breznitz & Berman, 2003).

Text-Fading Manipulation

The text-fading approach is based on a text-fading procedure manipulating the rate in which reading material is faded out from a computer screen letter by letter in reading direction, i.e., in German from left to right (Breznitz & Bloch, 2012; Breznitz & Nevat, 2006). The aim of this manipulation is to prompt the individual to read at a faster rate than usual as a subjective feeling of time constraint is generated by the text fading manipulation (Breznitz & Berman, 2003; Nagler, Linkersdörfer, Lonnemann, Hasselhorn, & Lindberg, 2016). As increased reading speed is associated with an increase in reading comprehension (Huemer et al., 2008), the manipulation is supposed to provoke improved reading performance. This notion is tested through the comparison of an experimental group with a control group which receives the same reading material to read in a self-paced manner. Several studies have supported the underlying assumptions, indicating that the text-fading manipulation is associated with faster reading rates and better reading comprehension performance (e.g.,

Breznitz, 1987, 1997; Nagler et al., 2016; Nagler, Lonnemann, Linkersdörfer, Hasselhorn, & Lindberg, 2014).

Text-Fading Training

The promising findings from cross-sectional research designs prompted attempts to implement the text-fading principles into a training procedure aiming at long-term reading fluency improvements. Most text-fading training studies report increased reading rates combined with improved or consistent comprehension performance in pre-post-training comparisons for different orthographies (for a review see Korinth & Nagler, 2021). In general, new reading material is presented for each training trial, providing a direct comparison of comprehension performance during training. Considerable differences and open questions between text-fading training studies can, however, be found regarding the research design, the selected sample and detectable training effects in standardized tests.

Research sample selection and research design are obviously crucial for any empirical study, however, for intervention studies they are essential to estimating training efficacy. To capture training effects for children in need of intervention, it is sensible to target samples of reading impaired participants. Although text-fading training has generally been reported to also be effective for unimpaired elementary school readers (see for example Nagler et al., 2015; Nevo, Brande, & Shaul, 2016), the training potential should be assessed with regard to samples of impaired readers.

Furthermore, especially long-term effects can only be captured in designs comprising pre-, post- and follow-up test time points. To our best knowledge, so far only one study has included a pre-post as well as follow-up measurement within a text-fading training approach: Breznitz and colleagues (2013) reported significant training effects (i.e., increased reading rate and comprehension) from pre- to post-test time point for a group of dyslexic adults receiving a text-fading training compared to a control group of dyslexic adults reading at their

self-paced reading routine. In the course of training the experimental group's reading performance eventually leveled the performance of a sample of typically reading adults. The reading gains were retained over a 6-month period at follow-up test time point. However, this study tested reading performance of adult readers, so information about long-term effects for elementary school children is still pending.

Questions also remain open regarding whether training effects can be found in standardized tests, and if so, at which reading level (lower- vs. higher-level processing). As reading improvements through training should optimally be transferable to general reading performance, it is advisable to test reading enhancements in an independent, standardized reading test to optimally objectify the training results. Using a standardized test with different reading competency levels (i.e., lower- vs. higher-levels) will furthermore allow to locate the training's efficacy. One text-fading training study by Nagler et al. (2015) shows significant reading fluency improvements for an experimental group receiving text-fading training compared to a control group reading at their self-paced reading routine in a standardized reading test. Results indicated that reading improvements were attributable to lower as well as higher-level processing, as children in the experimental group improved on word and especially on sentence level reading comprehension. However, this study included typically reading participants, so the transferability of results to a reading impaired sample has so far not been demonstrated.

Present Study

To address open research questions, the present study focuses on three major aims: (1) With respect to previous findings, showing orthographic knowledge and RAN to be relevant for training outcomes (Berninger et al., 1999; Nelson et al., 2003), we focus on the predictive value of these two reading-related preconditions. We aim at clarifying to what extent orthographic knowledge and RAN are predictors also for the text-fading training approach

and can explain variance in comprehension performance during training in both experimental and control group. We predict that both RAN and orthographic knowledge are significant predictors for comprehension performance during the text-fading training in both training groups. Therefore, children with higher orthographic knowledge and RAN performance are expected to show better reading comprehension performance during text-fading training in both experimental and control group than peers with lower skill levels. (2) To validate the assumption that training effects from text-fading training are detectable also for children needing intervention, we focus on a sample of German elementary students in Grade 3 with reading impairments. In line with previous text-fading training research (e.g., Breznitz, 2013, Nagler et al., 2015), we expect to capture potential training effects immediately after the end of the training. For this purpose, we examine the reading rate and comprehension performance in a pre-post comparison of the two training groups. We expect the experimental group to show better reading rate and better comprehension performance after the training compared to the control group. (3) We focus not only on investigating potential, but also lasting training effects associated with text-fading training. Training effects are examined in a standardized reading test on lower and higher reading levels (i.e., word and sentence reading) to capture possible training benefits from the reading intervention. In line with Nagler et al. (2015), we assume that training effects should be detectable at lower as well as higher reading levels. We therefore expect the experimental group to show better reading performance on word as well as sentence level in a standardized reading test after performing the text-fading training in a pre-post comparison. To examine the mere training effects, we will run analyses controlling for individual reading performance before training (i.e., RAN, orthographic knowledge at pre-test point and reading comprehension performance during training). With respect to previous findings by Breznitz et al. (2013), we expect these training effects to be lasting. Hence, predictably the experimental group will show better reading performance on word and sentence level compared to the control group at a follow-up test time point.

Materials and Methods

Participants

Following a screening of 13 schools with overall 38 classes, a preselected sample of 484 students participated in the tests. From this preselected sample, 129 children (61 female, mean age: 8.87 years, SD = 0.53) were identified as meeting the criteria for participation in the training study. These children showed significant reading impairments given their reading performance between percentile rank (PR) 0-30 in a standardized reading test (Würzburger Leise-Leseprobe Revision, WLLP -R; [Würzburg Silent Reading Test- Revision], Schneider, Blanke, Faust, & Küspert, 2011; mean reading performance: T-score = 26.63, SD = 5.20), while their intelligence quotient (IQ) was classified as average (IQ between ≥ 85 and ≤ 130; mean IQ = 105.80, SD = 15.16) in a standardized test (Zahlen-Verbindungs-Test, ZVT, [A trail making test]; Oswald & Roth, 1987). Parental informed and written consent was obtained for each child. Out of the qualified sample nine children were not considered for further analyses because they did not attend the training (i.e., the parents withdrew their consent or the children were missing due to personal reasons). Hence, data of 120 German third graders (58 female, mean age: 8.87 years, SD = 0.53) was included for final data analysis. A Monte Carlo power analysis using MPlus 8 (Muthén & Muthén, 1998-2017) indicated that a minimum of 94 participants were required to detect an effect size equal to $\beta = .3$, with an alpha set at .05 and power set at .80 (Muthén & Muthén, 2002), hence, the present sample size of N = 120 is presumed to be appropriate for further analyses. Ethical approval was received from the local ethical review board before data collection.

Design and Procedure

The applied training consisted of overall 16 training sessions lasting approximately 45 minutes each, which were offered twice per week, distributed over a period of 8 weeks. In a

pre- (T1), post- (T2), follow-up (T3) design, reading comprehension on word and sentence level was furthermore measured at three test time points. Pre- and post-tests were conducted in a time frame of three weeks before and after the training, the follow-up test was realized 6 months after the end of training, also within a time period of three weeks. The training and pre-, post-, follow-up tests were accomplished on the relevant school premises. Children were excused from class for the participation. Participants were randomly assigned to one of two training groups, counterbalanced for gender. The experimental group received training with a text-fading procedure (text-fading group; n = 60), the control group was trained without text-fading, thus, at their individual self-paced reading rate (self-paced group; n = 60). An initial assessment session (i.e., start session) served to measure the participant's individual reading rate base level. Here, participants of both groups were instructed to read 30 test items (i.e., sentences with corresponding questions and multiple-choice answer possibilities) at their own self-paced reading rate. The obtained reading rate base level was used for the text-fading group to determine the individually set fading rates (in milliseconds per character), which were applied and adapted during the subsequent text-fading training. The self-paced group continued to read presented text material at their own self-paced reading rate during all training sessions. All participants read 30 sentences per training session. Figure 1 provides an overview of the number of participants included in the screening process, as well as in pre-, post-, and follow-up test sessions and training.

---------- insert Figure 1 about here ----------

Test Materials

Screening Tests

In order to identify and recruit children who meet the criteria for participation in the training, a standardized reading test measuring reading (decoding) speed (WLLP-R;

Schneider et al., 2011) and a standardized nonverbal intelligence test measuring intellectual abilities via perceptual speed (ZVT; Oswald & Roth, 1987) were applied. Both tests were administered as paper-pencil tests in a classroom setting at the particular schools.

The WLLP-R reading test material for third grade students consists of 7 test sheets, which have to be processed consecutively within 5 minutes. Each test sheet comprises 20 words accompanied by four pictures, one picture illustrating the target word. In total 140 items are presented on the consecutive test sheets. Within the time limit, children have to process as many items as possible by choosing the picture matching the word. According to the authors, the WLLP-R shows a high parallel test reliability (third grade: $r = .93$). Conversion tables for individual raw test scores (number of correctly marked test items) to grade- and gender-dependent standardized scores are provided for grade 1 through grade 4.

The ZVT nonverbal intelligence test can be administered in individual and group settings with participants aged between 7 and 80 years. In group settings, as administered in this study, four matrices showing 90 apparently arbitrarily arranged numbers (i.e., 1-90) are consecutively introduced. Within 30 seconds per matrix, participants have to connect as many numbers in their ascending numerical order as possible. The test's reliability (retest reliability between $r = .95$ und $r = .98$) is indicated to be mostly independent from age and educational background. Conversion tables for individual raw test scores to age-dependent standardized scores are provided. IQ scores were used for sample selection.

Pre-, Post- and Follow-up Tests

Standardized Reading Comprehension Test. To capture possible training effects, a computerized standardized reading comprehension test (Ein Leseverständnistest für Erst- bis Sechstklässler, ELFE 1-6; [A reading comprehension test for first to sixth-graders]; Lenhard & Schneider, 2006) was assessed at T1, T2 and T3 to measure reading performance before and after training as well as after a six-month intermission period. The two subtests of ELFE

1-6 administered in this study measure reading comprehension at the word and sentence level. Word reading comprehension is measured via 72 items, each item consisting of a picture and four word alternatives with similar graphemes and phonemes. Children were asked to choose the word corresponding to the picture. The number of correctly marked items represents the word reading raw score. Sentence reading comprehension is assessed through a sentence completion task. In this subtest five possible word alternatives are presented within a total of 28 interrupted sentences. Children have to identify the words completing the sentences. The number of correctly answered items reflects the sentence reading raw score. The two subtests show high internal consistency (word reading: Cronbach's $\alpha = 0.97$, sentence reading: $\alpha = 0.93$). Raw test scores were used for further statistical analyses.

Orthographic Knowledge. To capture the participants' orthographic knowledge at the word-specific and general level at T1, we used the item sets applied in a previous study by Zarić et al. (2020). For assessing orthographic knowledge at word-specific level, an orthographic decision task with 30 items (15 real words and 15 pseudohomophones; i.e., words with the same pronunciation as existing words, but incorrectly spelled; e.g., word: *rain*, pseudohomophone: *rane*) was used. Children were instructed to decide whether the presented item was a real word or not. The sum of correctly identified items (raw score) was used for further statistical analyses.

To assess orthographic knowledge at general level, an orthographic choice task with 20 items consisting of two pronounceable pseudo-words was used. In each pair, one of the pseudo-words contained a double consonant in a permitted position (central: e.g., *tammit*, or end position: e.g., *pateff*), while the other contained a double consonant in an illicit position (e.g., *ttokam*). Children were instructed to decide which of the two alternatives presented resembled a real German word more closely. The sum of correctly identified items (raw score) was used for further calculations.

An item analysis regarding orthographic knowledge data was conducted prior to statistical analyses, in order to detect items with a poor level of selectivity and difficulty. For the items used to measure word-specific orthographic knowledge, 14 out of 30 items revealed a poor degree of selectivity (≤ .02) and difficulty (≤ .30 and ≥ .87), hence, they were excluded from further calculations. The sum of the correctly answered remaining 16 items was used for further calculations, showing a sufficient internal consistency (Cronbach's α = .72). For the items used to measure general orthographic knowledge, 4 out of 20 items revealed a poor degree of selectivity (≤ .10) and difficulty (≥ .87). The remaining 16 items showed a sufficient internal consistency (Cronbach's α = .77).

RAN. To assess participants' naming speed, a RAN task (based on Denckla & Rudel, 1976) was used. In this task, four matrices in DIN-A3 format were presented, each containing either digits (1, 4, 5, 6, 8), letters (f, k, r, s, t), objects (candle, car, dog, fish, hammer), or colors (blue, green, red, yellow, black). Children were instructed to name the presented stimuli as accurately and as fast as possible. The time required as well as the numbers of errors were measured for each of the four matrices. For each of the four subtests, errors were subtracted from the total score of 50 per subtest, providing the number of correctly named items. Then, the average naming speed (items per second) for each of the four subtests was computed by dividing the total time per subtest by all correctly named items in that subtest for each participant for T1, which was used for further statistical analyses.

Training Stimuli

A pool of overall 546 items was created for training purposes (6 practice items, 30 items for start session, 30 items for end session, 480 items for the max. of 16 training sessions). Items were self-developed following the reading material used in a previous study by Nagler et al. (2015). Each item comprised a sentence (7-21 words long; mean: 14.07 words) and a corresponding multiple-choice question with four answer possibilities (for

training stimuli examples, see Appendix, Table A1). To assure attentive reading of the training items, questions and multiple-choice answers included different phrasing and reasonable distractor items (see Rost & Sparfeldt, 2007). Training stimuli were randomly allocated to the training sessions. Hence, all children read the same reading material within the same session, yet in a randomly assigned order.

Training Paradigm

Participants were trained in a group setting with five to 12 children per session. Training stimuli were presented left-justified in white letters (font: Courier New; letter size: 0.1 height) on a dark background on 15.75-inch laptop computers running the text-fading training paradigm programmed in Psychology software in Python (PsychoPy; Peirce, 2009). Laptop computers were provided by the research team and arranged in an order assuring an undisturbed training procedure. The training started with a start session, followed by max. 16 offered training sessions and ended with an end session. The end session followed the same procedure as the start session. The procedure for the training sessions differed between the two training groups. The number of total completed training sessions varied between children because of absence during the training days, resulting in a range from 4-16 completed sessions (M = 12.8)[15].

The start session was identical for both groups and served to determine the initial individual reading rate. After two practice trials, each trial started with the presentation of a single sentence. The children were instructed to read the sentence as fast and as accurately as possible at their own reading pace and press a designated button on the laptop keyboard when finished. The button-press triggered the presentation of the multiple-choice question referring

[15] Since the average number of training sessions for the whole sample was 12.8, the comprehension score used for further statistical analyses comprised of the comprehension scores from training sessions 1-12. The number of training sessions did not differ significantly between the text-fading and the self-paced group (t-test = .381, p = .751).

to the respective sentence's content. The corresponding four answer possibilities comprised the correct answer as well as three incorrect distractors. Children were asked to identify the correct answer and press the according key on the keyboard. Once the children entered their decision, the next trial started. Feedback was not provided. Trials with a reading rate below 50 characters per millisecond were marked as invalid and excluded, as it was considered to be unlikely that the presented sentence was read at such speed. For all remaining correctly answered items, the average reading rate in milliseconds per character and the reading comprehension performance (percent correct) was calculated. Consequent upon the start session the training sessions were introduced. During the first two training sessions, the children received again two practice trials as well as instruction by the trained examiners. Afterwards the children proceeded to work independently. Two examiners were present during all training sessions to answer open questions and supervise the course of events.

Text-Fading Group (Experimental Group)

To ensure that the children were able to fully visually orient, the fading procedure started after a delay of 500 milliseconds. During this time, the sentence was presented in its entirety. The individual average reading rate recorded in the start session was used for the initial text-fading rate in which the reading material disappeared from the screen letter by letter. The multiple-choice questions appeared automatically after the sentence was completely erased. After five trials, the text-fading rate was adjusted depending on the individual's comprehension performance. If all five items were answered correctly (100% correct), the text-fading rate was accelerated by 2%. At four correct items (80% correct), the text-fading rate was kept constant and with three or less correct items (< 80% correct), the text-fading rate was decelerated by 2%. The last determined text-fading rate of one training session was set as the initial text-fading rate for the following training session.

Self-Paced Group (Control group)

The self-paced group read the same sentences and multiple-choice questions as the text-fading group. However, the self-paced group did not receive a text-fading manipulation. Instead, the sentences remained on the screen as long as the children needed to read the sentence and press the designated key to continue. As mentioned above, trials with a reading rate below 50 characters per millisecond were marked as invalid and were excluded. The reading rates (milliseconds per character) and comprehension performance during training (percent correct) were recorded for each trial and each child.

Statistical Analyses

Different statistical approaches were used to address the research questions. For research question 1 a latent variable approach was chosen, for research question 2 a repeated measures analysis of variance (ANOVA) was conducted, and for research question 3 both a repeated measures ANOVA as well as a latent variable approach were implemented. The analyses were conducted using IBM SPSS (Version 26) and MPlus 8 (Muthén & Muthén, 1998-2017). The latent variables were used to minimize measurement error. To estimate the structural equation model (SEM), the full information maximum likelihood method (ML) was used. To evaluate the goodness of fit for the model, we used the chi-square test statistic and several commonly recommended descriptive measures of model fit (Hu & Bentler, 1998): the standardized root mean squared residual (SRMR), the root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the Tucker-Lewis Index (TLI). Models were evaluated as fitting well when the baseline fit indices (SRMR and RMSEA) were < 0.08 and the incremental fit index (CFI) was ≥ 0.95.

Analyses of missing data lost due to attrition showed that the overall percentage of missing values for the sample was 2.31% with 25 total cases containing missing data (in one

to four cells). Little's missing completely at random (MCAR) test was not significant, χ^2= 161.92, *df* = 177, *p* = .785, suggesting no definitive pattern to the missing data. In order to prevent a loss of power (Graham, Olchowski, & Gilreath, 2007) missing data was addressed via multiple imputation (MI). With this approach, several new data sets were created from original data, in which missing values were replaced by probable values. Overall 10 imputations were conducted in Mplus. The SEMs were conducted on the imputed and non-imputed data sets. Comparisons yielded no significant differences in the interpretation of results, indicating that magnitude, directions, and statistical significance of effects were consistent. Therefore, all analyses reported are conducted using the imputed data sets to maximize the sample size available.

Results

As outlined in the following, repeated measures ANOVAs as well as a more sophisticated SEM was chosen as statistical analyses to best answer the three research questions. Table 1 depicts an overview of means and standard deviations of all variables at pre-, post-, and follow-up test time points.

---------- insert Table 1 about here ----------

Explaining Variance in Comprehension Performance during Training

For the first research question, concerning the predictive value of orthographic knowledge and RAN and their contribution of explained variance in comprehension performance during training, a multiple group regression model with latent variables was evaluated with comprehension performance during training as the dependent variable (single indicator latent variable; see Matsunaga, 2008). In this structural equation model (SEM), regression paths were evaluated from both predictors (RAN and orthographic knowledge) to

the dependent variable (comprehension performance) while correlations between the predictors were permitted. Four items were used as indicators of RAN, two items for orthographic knowledge. Model identification was achieved by fixing one unstandardized factor loading to 1. Factor loadings and intercepts were set as equal across groups (strong invariance[16]). This multiple group model fitted the data well, χ^2 (32) = 36.79; p = .26, CFI = .976, TLI = .968, RMSEA = .050, SRMR = .071, and accounted for a substantial proportion of the variance of comprehension in the self-paced group (R^2 = .38, p < .05), but not in the text-fading group (R^2 =.12, p = .12). As presented in Table 2, orthographic knowledge was significantly related to comprehension performance during training in the self-paced group (β = .58), whereas no sufficient regression weight was found for the text-fading group (β = .10). A reverse result pattern was found for RAN. While a significant effect was detected for the text-fading group (β = -.31), no sufficient regression weight was revealed for the self-paced group (β = .13). To test whether the standardized regression paths from the predictors on comprehension differ between the two groups, these paths were constrained to be equal across groups and were tested by the Wald test. No significant differences were found for orthographic knowledge, Wald test $\chi^2(1)$ = 2.93, p = .087, nor for RAN, Wald test $\chi^2(1)$ = .71, p = .40.

---------- insert Table 2 about here ----------

Potential Training Effects on Reading Rate and Comprehension Performance

To examine whether there were any significant differences between the self-paced and the text-fading group accountable to the training time course, we carried out ANOVAs with time as a repeated measure variable and group as the between subject variable for reading rate

[16] Model comparison (scalar against configural): χ^2 (8) = 8.617, p = 0.3756.

and comprehension as dependent variables. Mean and standard deviation of reading rate and comprehension as a function of time and group can be found in Table 3. The ANOVA revealed that the Group x Time interaction for reading rate was not significant, $F(1, 118) = .53$, $p = .47$, $\eta^2 = .004$, and there was no significant main effect of group, $F(1, 118) = .15$, $p = .70$, $\eta^2 = .001$. However, there was a significant main effect of time $F(1, 118) = 25.31$, $p < .001$, $\eta^2 = .18$, indicating that for both groups, reading rate significantly increased during the time course from start to end of the training. For the comprehension measure, a significant interaction effect of Group x Time $F(1, 118) = 4.10$, $p < .05$, $\eta^2 = .034$ was shown, but no significant main effect of group, $F(1, 118) = 1.81$, $p = .18$, $\eta^2 = .015$ or time $F(1, 118) = 1.84$, $p = .18$, $\eta^2 = .015$ was found. Considering the changes in the mean value of the comprehension score (see Table 3), the significant interaction effect of Group x Time is attributable to the decline of the self-paced group at the end of the training. Figure 2 provides an overview of the time course and changes during and after the training in reading rate and comprehension for both text-fading and self-paced group.

---------- insert Table 3 and Figure 2 about here ----------

Lasting Training Effects on Word and Sentence Level

To find out whether the intervention has a positive effect on reading outcomes in a standardized reading test on word and sentence reading levels, firstly several ANOVAs with time as a repeated measure variable and group as the between subject variable were carried out. We compared (1) T1 and T2 scores controlling for comprehension during training and reading baseline (at T1), as well as (2) T2 and T3 scores for both text-fading and self-paced group controlling for reading performance after training (at T2). The results are presented in Table 4. Regarding the pre-post-test comparison (T1 vs. T2), the analyses revealed a significant interaction of Group x Time for word and sentence reading, indicating that the

text-fading group improved significantly more compared to the self-paced group. Regarding the post-follow-up-test comparison (T2 vs. T3), a significant interaction of Group x Time was found for word reading, accountable to the fact that the text-fading group was not able to preserve the performance level and the self-paced group caught up with the text-fading group at T3. For sentence reading, no significant interaction of Time x Group was revealed, indicating that both groups stayed at their performance level in this task six months after the text-fading training.

---------- insert Table 4 about here ----------

In a second step, we applied SEM to verify the results obtained from the ANOVAs in order to get a more detailed picture of the training effects. Different structural models were calculated to explain variance of word and sentence reading at T2 and T3 (dependent variables) by controlling for the predictors RAN, orthographic knowledge, and comprehension performance during training. All models included a dummy variable representing group condition (0 = self-paced group, 1 = text-fading group) regressed on reading outcomes. To consider initial reading skills and to test possible intervention effects more rigorously, autoregressive effects among the reading outcome (i.e., the effect of a construct on itself measured at a later time) were included in the model. Reading performance at the different test time points (T1, T2, T3) were specified as latent variables, with word and sentence reading as different constructs (single indicator latent variable).

Figure 3 shows the final structural model. This model fitted the data well, $\chi^2(66) = 99.11$, $p < .001$, CFI = .960, TLI = .945, RMSEA = .065, SRMR = .061, and accounted for a substantial proportion of the variance of sentence-reading at T2 ($R^2 = .85$), and T3 ($R^2 = .70$), as well as word reading at T2 ($R^2 = .77$), and T3 ($R^2 = .75$). As depicted in Figure 3, significant autoregression effects are found for word- ($\beta = .86/.88$) and sentence-reading ($\beta =$

.74/.83). Furthermore, sentence-reading at T2 was significantly and positively related to the comprehension performance during training (β = .30). However, most importantly, the group variable explained additional variance in word and sentence reading at T2. The significant positive effects on word and sentence reading at T2 (β = .27/.31) indicate that the text-fading group improved their reading performance stronger from T1 to T2 compared to the self-paced group. A significant negative effect of the group variable on word reading was found at T3, whereas for sentence reading no group effects were shown at T3 test point (see Figure 3).

---------- insert Figure 3 about here ----------

Discussion

The focus of the present study was set on (1) the explanation of variance in comprehension performance during training, as well as on (2) the investigation of potential and (3) also lasting text-fading training effects for a sample of German reading impaired third graders, after controlling for predictive reading-related variables (i.e., RAN, orthographic knowledge and comprehension performance during training).

Concerning our first research question, we found orthographic knowledge to be significantly related to comprehension performance during training in the applied structural models for the self-paced group, whereas no sufficient regression weight was found for the text-fading group. For RAN, a reverse result pattern was found, where RAN was identified as a significant predictor for comprehension performance for the text-fading group, but not for the self-paced group. These results indicate that while reading at their own pace, the knowledge about word-specific representations and permitted letter patterns (i.e., orthographic knowledge) supports students' automatized recognition and reading of single words and enables their processing (e.g., Ehri, 2014). Thus, the better the orthographic

knowledge, the more resources are available for understanding the content of the sentences necessary to solve the comprehension task in the present study correctly. However, when reading under time constraint, as provoked in the text-fading condition, the ability to quickly and accurately retrieve the stored orthographic representations from the mental lexicon (reflected in RAN) seems to play a more important role than the mere quality of these orthographic representations. This pattern of results taps into findings from previous research, demonstrating that serial processing is a common mechanism and explanation for the RAN-reading-relationship (e.g., Altani, Protopapas, & Georgiou, 2018; de Jong, 2011; Georgiou, Parrila, Cui, & Papadopoulos, 2013; Protopapas, Katopodi, Altani, & Georgiou, 2018). Following this suggestion, it may be assumed that the text-fading manipulation induces seriality in a task that might otherwise allow for skimming and, more importantly, re-reading. As a consequence, serial processing may have provoked a more fluent (quick and accurate) processing for the text-fading group.

The presented pattern of results concerning predictive values for RAN and orthographic knowledge for comprehension performance during text-fading training is, however, limited to the current data for German reading impaired children. Whether samples with a normal range of reading variance (i.e., typical reader) would show comparable results, still needs to be investigated. Furthermore, as the predictive effect of RAN and orthographic knowledge to reading performance is modulated by the transparency of the orthography, future studies are needed to explore the specific role of both reading predictors in languages with different transparency levels (i.e., transparent, intermediate and opaque). Additionally, the relevance of other reading precursors (e.g., phonological awareness and verbal working memory) should also be included to better understand the impact and interplay of reading-relevant skills with reading performance during the text-fading training. However, considering the assumption that text-fading training may be an effective tool to increase seriality and consequently enhance reading fluency of children in need for intervention, it

seems fruitful to follow the RAN-reading-relationship for text-fading training effects in future studies.

The results of the repeated measures ANOVA were pivotal to answer the second research question regarding the potential training effects on reading rate and comprehension performance accountable to the time course of the training. The analyses revealed that the text-fading and self-paced group equally improved their reading rate during the text-fading training, thus, no significant interaction between Group x Time was detected after the training was completed. Regarding the comprehension performance, the analyses revealed a significant interaction between Group x Time. However, this effect is attributable to the decline of the self-paced group comprehension score at the end of the text-fading training. Taken together, the present pattern of results indicates a stable comprehension and reading rate performance during training for both training groups (see Figure 2). These results are not in line with previous findings showing a significant reading rate improvement in combination with improved or stable comprehension performance in the text-fading group compared to the self-paced group after the text-fading training (for a review see Korinth & Nagler, 2021).

At first sight these findings seem to be incompatible with our findings regarding our third research question: The results of the repeated measures ANOVA and SEM served to analyze whether or not the text-fading training is effective to produce not only potential but also lasting training effects in German impaired readers on different reading levels measured in a standardized reading test. Significant reading improvements were observable for word and sentence level reading, showing stronger performance increase from T1 to T2 for the text-fading group. These findings seem perplexing at first, as reading rate and reading comprehension did not differ between groups during training and previous research indicates a connection between improved reading rate and improved reading performance through the text-fading manipulation. However, taking a closer look at the nature of the text-fading manipulation, the results do correspond, suggesting that the reading rate performance and the

adaptation of fading rate as an instrument to increase the genuine reading rate in the text-fading group during training may not be the crucial mode of action leading to improved reading performance. It rather supports the notion, as proposed by Korinth, Dimigen, Sommer and Breznitz (2016) as well as Nagler et al. (2016), that the mere time constraint induced through the text-fading manipulation may be the meaningful mechanism.

With regard to previous findings that fundamental reading processes serve as the basis for word and sentence reading performance (e.g., Wolf & Katzir-Cohen, 2001; Zarić et al., 2020), we propose that the results in our training study can be ascribed to a switch to more efficient reading processes in the text-fading group due to participation in the text-fading training. More precisely, the perceived time constraint may have encouraged the children to switch from basal phonological recoding to more efficient retrieval of complete words or at least parts of words, positively influencing word as well as sentence reading performance. In other words, the feeling of time pressure to read the presented items may have forced the participants in the text-fading group to optimize their reading strategies, possibly engaging in more sophisticated reading strategies, such as direct fact retrieval, while participants in the self-paced group maintained their usual reading strategies. This may have affected the general reading performance, as measurable in a standardized test, resulting in better performance for the text-fading group compared to the self-paced group. These results are in line with previous findings of Nagler et al. (2015) who showed similar results for a sample of non-impaired German elementary school children. Reading impaired and unimpaired children therefore seem to profit from the fading manipulation in a comparable way, as in both samples participants were able to effectively align their reading behavior on lower- and even on higher-level reading processes resulting in improved reading performance on word and sentence level in a pre-post training comparison.

Finally, the analyses of lasting effects at T3 revealed mixed results, which need to be interpreted cautiously. On the one hand, a negative group effect on word-level was found,

indicating that children in the text-fading group stayed at a comparable level at T3 compared to T2, while the self-paced group caught up with the text-fading group. It is possible that the children in the self-paced group made comparable progress in word reading as the text-fading group, however, over a longer period of time, resulting in significant improvement at T3 compared to T2. On the other hand, the absence of negative effects at sentence level indicates that both groups stayed at a comparable reading level at T3 compared to T2. Hence, the reading performance of the text-fading group stayed at a comparable high level at T3, suggesting a preservation of positive training effects for the text-fading group at sentence level observed at T2. Following this suggestion, one interpretation of the maintained high performance at sentence level at T3 test time point for the text-fading group focuses on the training stimuli. It might be that the preservation of training effects was only possible at sentence level because the applied text-fading training contains sentence-based training items, hence especially sentence reading is trained in this specific intervention approach. However, compared to the present pattern, the long-term effects reported in the study of Breznitz et al. (2013), were clearly more robust. Divergent results between these two studies may be particularly attributed to different samples and training terms. The selected sample in the study by Breznitz et al. (2013) consisted of dyslexic and typically reading adults, hence, the results are not generalizable to children's reading performance. It has been proposed that adults are more selective and partially more effective regarding the consolidation of memory for specific language skills compared to children (Ferman & Karni, 2010). Therefore, it might be easier for adults to retain improved reading skills acquired during text-fading training than it is for reading impaired children. Furthermore, Breznitz et al. (2013) conducted more training sessions (24 sessions) than we did in the present study (max. 16 sessions), which might not have been enough to allow for lasting and stable effects in the text-fading group. The validation of lasting effects of the text-fading training approach for reading impaired

children is, hence, not yet clarified and needs further controlled research studies with pre-, post-, follow-up designs.

Limitations

The presented data indicates that the text-fading training is effective to produce significant reading improvements for reading impaired children. However, the underlying mechanisms attributable to the training gains can still not be identified with certainty. Although we were able to identify RAN as relevant predictor for comprehension performance during training for the text-fading group and orthographic knowledge for the self-paced group, we still do not know for sure how training effects emerge and which modes of action trigger the reading improvements. Despite promising results, this study has several limitations: especially methodological and motivational factors will be discussed in the following.

One methodological limitation focuses on the used reading material. Compared to other text-fading training studies, the average reading comprehension performance during training was rather low. Hence, the used reading material might have been too difficult and it was not specifically controlled for age appropriateness. As outlined in a previous study by Nagler and colleagues (2014), the nature of the reading material used during the text-fading procedure directly influences the manipulation's effectiveness. The authors stressed that only processing of reading material with preconditions for direct lexical retrieval was associated with reading improvements attributable to the manipulation. Considering that the here included sample showed significant reading impairments, the reading material might have been too challenging to allow for direct lexical access, and in turn, for the full efficacy of the manipulation's potential.

One further limitation concerns the number of training sessions. As stated above, not all children were able to complete the planned 16 training sessions for various reasons.

According to a meta-analysis by Galuschka, Ise, Krick and Schulte-Körne (2014), reading training approaches should last more than 12 weeks to reveal their full potential and effectiveness. Hence, the implemented max. 8 weeks of training in this study and the comparatively low number of overall completed training sessions (mean: 12.8) might have been insufficient to allow for stable effects in the text-fading group. In order to prevent children from missing a training session, future training studies should be more flexible and provide more time slots during a school day and week, allowing children to catch up on a missing session.

Another methodological limitation is the task used to measure general orthographic knowledge. The task used in this study only measured one aspect of general orthographic knowledge (i.e., the knowledge about permitted /illicit double consonant positions). By including further aspects of general orthographic knowledge (e.g., the knowledge about frequent double consonants) it would be possible to explore its role for reading and reading intervention on a broader scope.

An additional limitation concerns motivational factors. There is an increased risk of motivational problems for children experiencing difficulties in reading (e.g., Alexander-Passe, 2006; Polychroni, Koukoura, & Anagnostou, 2006). Poor readers show lower reading motivation than typical readers (e.g., McGeown, Norgate, & Warhurst, 2012; Vaknin-Nusbaum, Nevo, Brande, & Gambrell, 2018). It is possible that low reading motivation of the sample might have influenced the participants' endurance during the training, thus affecting the results. Monitoring of motivational state variables as well as motivational support (e.g., through visually more appealing training sessions) could be realized in future text-fading training studies to take care of motivational influence.

Conclusions

Text-fading training can be acknowledged as an efficient intervention approach for improving reading performance on word as well as sentence level for German elementary school children with reading impairments. However, the detected training gains in a standardized reading test were only explicitly observable in a pre-post comparison; the preservation over a period of six months at follow-up test time point was not as clear cut. Although results indicate a potential maintenance of reading performance on sentence level for the text-fading group, the results need further validation. Several possible explanations of mixed results as well as the accentuation of limitations (e.g., lower consolidation skills of reading impaired children, difficult nature of reading material, low number of training sessions, motivational effects) might serve to better understand potential influencing factors that need to be considered in applying the text-fading manipulation during training. However, the identification of underlying mechanisms attributable to the training's effectiveness is still pending and should be further evaluated in order to support children needing intervention.

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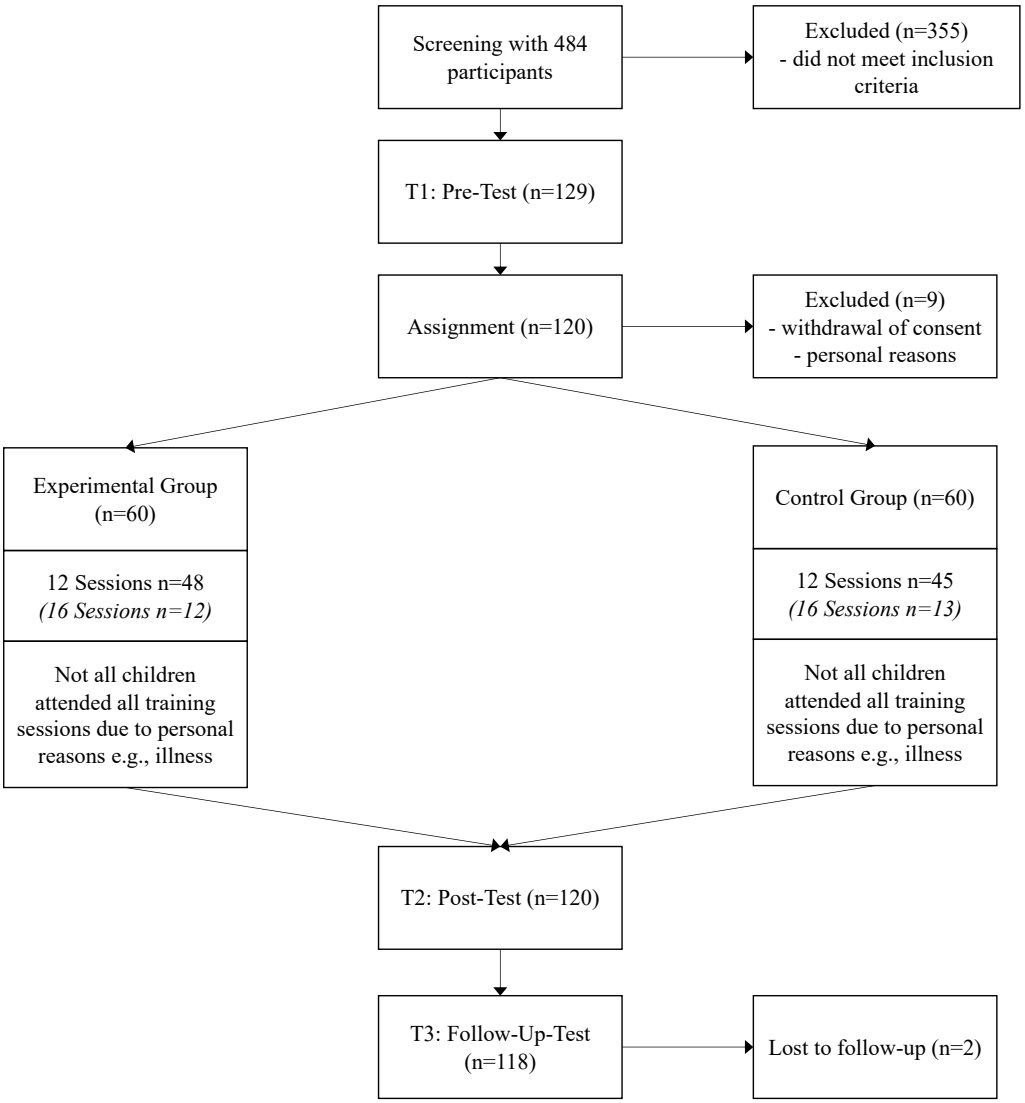
Appendix

-- insert Table A1 about here --------------------------------------

Figure 1

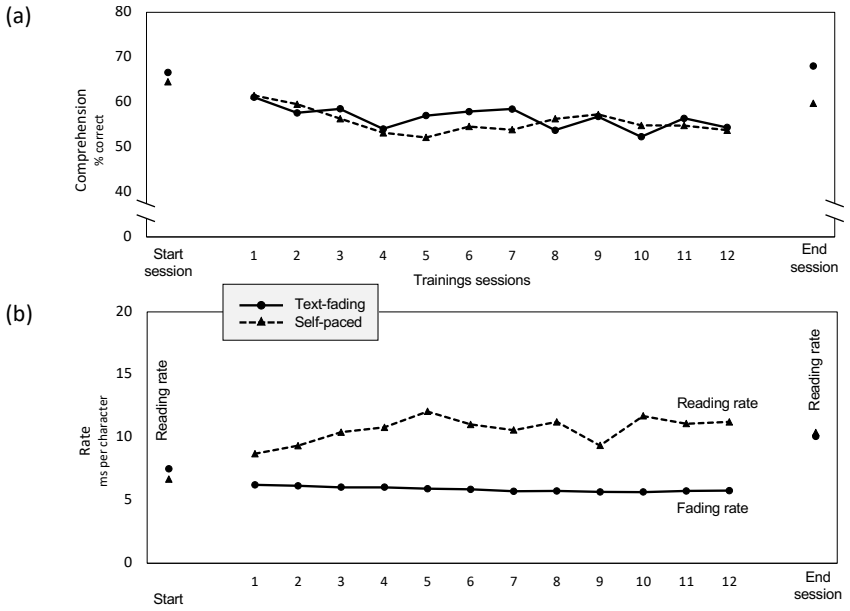
Overview of the Number of Participants Included in the Screening, Pre-, Post-, and Follow-up Test Sessions, as well as Training



Figure

Figure 2

Overview of the Text-fading Training Time Course Regarding Reading Comprehension and Rate Performance for both groups

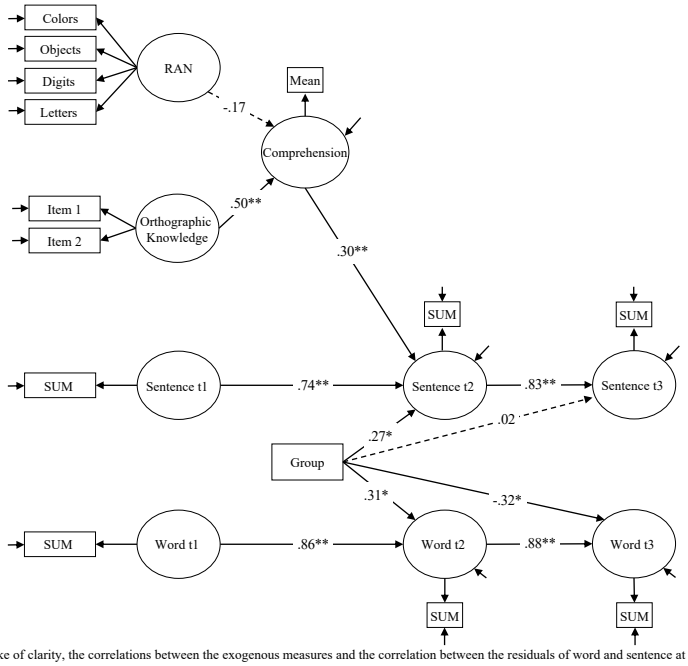


Note: (a) Depicts the time course of reading comprehension performance during training for both groups; (b) illustrates the time course of reading rate for the self-paced group and fading speed for the text-fading group; Start and end sessions are comparable for all participants.

Figure

Figure 3

Final Structural Model Showing Reading Performance on Word and Sentence Level at Pre-, Post-, and Follow-up Test Being Related to Group Condition (Intervention), Orthographic Knowledge, and RAN



Note: For the sake of clarity, the correlations between the exogenous measures and the correlation between the residuals of word and sentence at T2 and T3 respectivly are not depicted. Dashed lines indicate nonsignificant paths. *p < .05; **p < .01.

Table

Table 1

Means (Standard Deviation in Brackets) of the Manifest Variables for the Self-paced Group and the Text-fading Group at Pre-, Post-, and Follow-up Test Time Points

	T1 (Pre-test)		T2 (Post-test)		T3 (Follow-up-test)	
	Control	Intervention	Control	Intervention	Control	Intervention
RAN letters	.73[a] (.16)	.71[a] (.19)				
RAN digits	.62[a] (.14)	.63[a] (.11)				
RAN colours	1.10[a] (.30)	1.08[a] (.23)				
RAN objects	.96[a] (.17)	.97[a] (.15)				
Word-specific OK	8.61[b] (3.27)	8.08[b] (3.19)				
General OK	12.19[b] (2.96)	11.87[b] (3.36)				
Word Reading	27.12[c] (7.85)	28.42[c] (6.56)	30.48[c] (8.02)	34.03[c] (7.81)	35.66[c] (9.69)	36.53[c] (8.55)
Sentence Reading	9.81[d] (4.21)	10.73[d] (3.75)	11.12[d] (4.27)	12.58[d] (3.42)	12.89[d] (4.37)	14.25[d] (4.05)

Note. RAN = Rapid Automatized Naming, a = Average reaction time per correct item in seconds, b = Raw score (max. 16), c = Raw score (max. 72), d = Raw score (max. 28).

Table

Table 2
Standardized Effects on Comprehension

	Self-paced		**Text-fading**	
Model Variable	B	SE	B	SE
RAN	-.13	.15	-.31*	.16
Orthographic Knowledge	.58**	.17	.10	.24
	$R^2 = .38$		$R^2 = .12$	

Note. B = standardized regression coefficient, SE = standard error, RAN = rapid automatized naming. ** $p < .01$, * $p < .05$ Model fit: χ^2 (32) = 36.79; $p = .26$, CFI = .976, TLI = .968, RMSEA = .050, SRMR = .071.

Table

Table 3
Mean and Standard Deviation (SD) of Reading Rate and Comprehension as a Function of Time (Start and End of Training) and Group (Self-paced vs. Text-fading)

	Start				**End**			
	Self-paced		**Text-fading**		**Self-paced**		**Text-fading**	
Model Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Reading rate	6.71	2.30	7.47	3.87	10.33	7.76	10.19	6.58
Comprehension in %	64.50	21.68	66.80	21.22	59.72	25.07	67.80	21.04

Note. Reading rate = milliseconds per character; comprehension in % = the percentage of correct answers in the multiple-choice questions after each sentence.

Table 4
Results of Repeated Analysis of Variance (ANOVA) for Pre- vs. Post-Test and Post- vs. Follow-up Test

Task measure	Main effects and interactions	*F (df)*	*p*	η^2
(A) Pre- vs. Post-test				
Word reading	Group	6.43 (1,117)	<.05	.05
	Time	83.68 (1,117)	<.05	.42
	Group x Time	6.43 (1,117)	<.05	.05
Sentence reading	Group	4.09 (1,116)	<.05	.03
	Time	5.49 (1,116)	<.05	.05
	Group x Time	4.09 (1,116)	<.05	.03
(B) Post-test vs. Follow-up				
Word reading	Group	3.84 (1,117)	<.05	.03
	Time	48.55 (1,117)	<.05	.29
	Group x Time	3.84 (1,117)	<.05	.03
Sentence reading	Group	0.14 (1,116)	.71	.00
	Time	42.84 (1,116)	<.05	.27
	Group x Time	0.14 (1,116)	.71	.00

Table

Table A1
Examples of Training Stimuli in German with an English translation

Sentence in German [English translation]	Word Length	Multiple-choice Comprehension Question [English translation]	Answer Alternatives [English translation]
Lisa und die Zwillinge gingen ins Kino. [Lisa and the twins went to the cinema.]	7	Wie viele Personen gingen ins Kino? [How many persons went to the cinema?]	drei [three][a]; zwei [two]; vier [four]; keine [none]
Wenn Pia groß ist, möchte sie Schriftstellerin werden. [When Pia grows up, she wants to be a writer.]	8	Was möchte Pia machen, wenn sie erwachsen ist? [What does Pia want to do when she grows up?]	Bücher schreiben [write books][a]; Bilder malen [paint pictures]; Fotos machen [take pictures]; Auto fahren [drive a car]
Der schönste Apfel hing am höchsten Ast des Baums. [The most beautiful apple hung on the highest branch of a tree.]	9	Wo hing der schönste Apfel? [Where did the most beautiful apple hang?]	ganz oben [at the very top][a]; ganz unten [at the very bottom]; in der Mitte [in the middle]; an der Seite [on the side]
Weil es draußen regnet, können wir heute nicht mehr auf den Spielplatz gehen. [Because it is raining outside, we cannot go to the playground today.]	13	Wie ist es draußen? [What is it like outside?]	nass [wet][a]; kalt [cold]; heiß [hot]; dunkel [dark]
Mila ist nicht sehr gut im Tennis, deshalb möchte sie an ihrer Technik arbeiten. [Mila is not very good at tennis, that is why she wants to work on her technique.]	14	Was möchte Mila? [What does Mila want to do?]	sich verbessern [improve her skills][a]; immer gewinnen [win always]; viel spielen [play a lot]; sofort aufhören [stop immediately]
Ben freut sich auf den Sommer, weil es dann wieder frische Beeren und Trauben gibt. [Ben is looking forward to summer because then there are fresh berries and grapes.]	15	Worauf freut sich Ben im Sommer? [What is Ben looking forward to in the summer?]	auf das Obst [to fruits][a]; auf die Sonne [to sun]; auf den Urlaub [to vacation]; auf das Gemüse [to vegetables]
Emil kennt sich gut mit Dinosauriern aus und ist traurig, dass sie alle schon vor langer Zeit gestorben sind. [Emil is well informed about dinosaurs and is sad that they died a long time ago.]	19	Was sind die Dinosaurier? [What are the dinosaurs?]	ausgestorben [extinct][a]; gefährlich [dangerous]; bedroht [endangered]; aufgewacht [awoken]
Melanie suchte ihren Schlüssel, den sie sonst immer an die Anrichte im Flur legte, nur heute war er nicht dort. [Melanie searched for her key, which she usually puts on the sideboard in the hallway, but today it was not there.]	20	Was hat Melanie mit dem Schlüssel gemacht? [What did Melanie do with the key?]	ihn verlegt [misplaced it][a]; ihn verschenkt [gave it away]; ihn abgegeben [passed it on]; ihn gefunden [found it]
Als Isa den Klassenraum verließ, bemerkte sie, dass jemand seinen Block, sein Mäppchen und sein Buch auf dem Tisch vergessen hatte. [When Isa left the classroom, she noticed that someone has forgotten his pad, his pencil case and his book on the desk.]	21	Was hat Isa gefunden? [What did Isa find?]	Schulsachen [school things][a]; Essen [food]; Zeitschriften [magazines]; Geld [money]

Note. [a] = correct answer.

Appendix G

Lebenslauf

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Studium

09/2011 – 09/2014	**Goethe-Universität, Frankfurt a. M.** Bachelorstudium in Psychologie
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Wintersemester 2016/17	**Hochschule Fresenius, Frankfurt a. M.** Lehrauftrag im Modul 12 „Soziale Arbeit im Gesundheitswesen“
Sommersemester 2017	**Hochschule Fresenius, Frankfurt a. M.** Lehrauftrag im Modul 12 „Soziale Arbeit im Gesundheitswesen“
Wintersemester 2017/18	**Goethe-Universität, Frankfurt a. M.** Lehrauftrag im Modul BW-D/Sb2 “Grundlagen psychologischer und pädagogischer Diagnostik“
Sommersemester 2018	**Goethe-Universität, Frankfurt a. M.** Lehrauftrag im Modul BW-D/Sb2 “Grundlagen psychologischer und pädagogischer Diagnostik“
Wintersemester 2018/19	**TU Darmstadt** Lehrauftrag im Modul “Grundlagen der Persönlichkeits- und Leistungstests“
Sommersemester 2020	**Goethe-Universität, Frankfurt a. M.** Lehrauftrag im Modul BW-B/Sb1 “Grundlagen des Lehrens und Lernens im Unterricht“ Lehrauftrag im Modul BW-D/Sb1 „Lernstörungen und psychische Auffälligkeiten: Klinisch psychologische Diagnostik bei Kindern und Jugendlichen“
Wintersemester 2020/21	**Goethe-Universität, Frankfurt a. M.** Lehrauftrag im Modul BW-B/Sb1 “Grundlagen des Lehrens und Lernens im Unterricht“ Lehrauftrag im Modul BW-D/Sb1 „Lernstörungen und psychische Auffälligkeiten: Klinisch psychologische Diagnostik bei Kindern und Jugendlichen“

Mörfelden-Walldorf, den 19.05.2021

Appendix H

Danksagung

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