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A comparison of orthographic processing in children with and without reading and spelling disorder in a regular orthography

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Abstract Orthographic processing is a construct that encompasses the skills of recognizing, storing, accessing, and applying the print conventions of a writing system. Few studies have investigated orthographic processing in dyslexic children and it is not yet clear whether lexical and sublexical orthographic processing are both impaired in these children. The present study examined orthographic processing in dyslexic children (N = 19, below-average word reading as well as below average spelling skills, T-values <40) and typically developing children (N = 32) aged 8–10 years. Different aspects of orthographic processing were measured. Word-specific knowledge (lexical level) was assessed with an Orthographic Choice Task. General orthographic knowledge (sublexical level) was assessed with three pseudoword tasks. The Freq-Choice-Task is a choice task that measures children's knowledge of frequent double consonants (e.g., nilemm–nilebb). The Pos-Choice-Task measures children's knowledge about legal positions of double consonants (e.g., sinnum–ssinum). The Pos-Speed-Task measures children's ability to identify orthographic irregularities in words presented singly (e.g., mmotin). Results show that dyslexic children are able to discriminate illegal/infrequent letter pattern from legal/frequent letter pattern. Seeing either a word with legal or illegal letter patterns singly (Pos-Speed-Task), dyslexic children show deficits in identifying illegal letter pattern as wrong, whereas they have no problems to identify legal letter pattern as correct. Furthermore, dyslexic children show a reduced word specific orthographic

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knowledge. Additionally, the present study demonstrated that word representations as well as sensitivity to legal letter pattern influence reading and spelling performance.

Keywords Orthographic processing · Reading and spelling disorder · Dyslexia · Pseudowords

Introduction

Dyslexia is characterized by severe problems in the development of reading and/or spelling skills that cannot be accounted for by impairments in general intelligence, poor education, uncorrected visual or auditory problems or neurological damage (Diagnostic and Statistical Manual of Mental Disorders, DSM IV-TR, 2000; International Classification of Diseases, ICD-10. Dilling, Mombour, & Schmidt, 2011). Dyslexia is among the most common learning disorders, with a prevalence rate of 4–8 % in school-aged children (Hasselhorn & Schuchardt, 2006; Katusic, Colligan, Barbaresi, Schaid, & Jacobsen, 2001; Landerl & Moll, 2010; Lewis, Hitch, & Walker, 1994; Moll, Kunze, Neuhoff, Bruder, & Schulte-Körne, 2014, Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). Dyslexia is associated with a greater risk for school dropout, low educational achievement, and emotional problems (Arnold et al., 2005; Daniel et al., 2006; Maughan, Pickles, Hagell, Rutter, & Yule, 1996; Maughan, Rowe, Loeber, & Stouthamer-Loeber, 2003). Structural and functional neurobiological correlates and a genetic disposition to reading and spelling disorders have been repeatedly observed (e.g., Becker et al., 2014; Hasko, Groth, Bruder, Bartling, & Schulte-Körne, 2013; Scerri & Schulte-Körne, 2010; Wimmer et al., 2010).

Numerous studies have contributed to our knowledge of the cognitive processes underlying typical as well as atypical literacy acquisition. There is clear evidence that children with reading and spelling disorder have difficulties in phonological processing, especially in phoneme awareness (the ability to identify and manipulate sounds in spoken words) as measured by tasks such as phoneme segmentation and phoneme deletion (Paulesu et al., 2001; Ramus et al., 2003; Snowling, 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004). There is further evidence that reading and spelling performance is influenced by lexical access (typically measured by naming speed tasks) and verbal short-term memory (typically measured with digit-span tasks) (Jongejan, Verhoeven, & Siegel, 2007; Landerl & Wimmer, 2008; Muter & Diethalm, 2001; Näslund & Schneider, 1996; Pae, Sevcik, & Morris, 2010), and that children with dyslexia perform poorly on these tasks (Badian, 1996; Brady, Mann, & Schmidt, 1987; Denckla & Rudel, 1976a, b; Georgiou, Papadopoulos, Zarouna, & Parrila, 2012).

Several studies have shown that phonological awareness and naming speed are reliable and strong concurrent and longitudinal predictors of literacy skills across alphabetic orthographies (e.g., Moll et al., 2014), whereas the impact of verbal short-term memory seems to be comparatively small (Landerl et al., 2013; Moll et al., 2014). Phonological awareness and naming speed also distinguish between children with and without developmental dyslexia (Landerl et al., 2013) across different orthographies. Thus, findings suggest that in the early stages of literacy development both predictors are of similar importance across orthographies. However, it has been argued that the time course and the relative importance of these predictors for literacy development depend on orthographic consistency. While phonological awareness is a strong predictor throughout the school years in less consistent orthographies, the impact of phonological awareness decreases after about one year of formal reading instruction in consistent orthographies (e.g., Vaessen et al., 2010). In addition, decoding skills develop faster in consistent than in less consistent orthographies (Seymour, Aro, & Erskine, & COST Action A8 network, 2003), due to the consistent mapping between graphemes and phonemes in consistent orthographies. Given that repeated decoding is a pre-requisite for building-up word-specific orthographic representations (e.g. Share, 1999), the development of word-specific representations might also depend on the consistency of the orthography.

In addition to phoneme awareness and naming speed, orthographic knowledge has been suggested to play an important role in developing reading and spelling skills. Orthographic knowledge is a construct that encompasses the processes of recognizing, storing, accessing, and applying the print conventions of a writing system. Due to that, orthographic knowledge has been conceptualized and operationalized in very different ways within the research literature. Conrad, Harris, and Williams (2012) provide an overview of different definitions of orthographic knowledge and how different aspects of orthographic processing have been measured. They conclude that one common factor of all definitions of orthographic processing is that it involves an "understanding of the print conventions used in a writing system'' (Conrad et al., 2012, p. 2).

There is evidence that children before the onset of formal reading instruction are already sensitive to at least some conventions of the writing system (e.g. Cassar & Treiman, 1997; Ouellette & Senechal, 2008; Pollo, Kessler, & Treiman, 2009). Ouellette and Senechal (2008) as well as Pollo et al. (2009) showed that even prereaders were sensitive to basic conventions (e.g. "dada" looks more like a word than "dddd"). Similarly, Cassar and Treiman (1997) demonstrated that English-speaking preschool children were able to make correct decision with respect to legal and illegal positions of double consonants in written nonwords. As these children have not received any formal spelling instruction yet, it can be assumed that they have acquired the sensitivity to permissible letter patterns implicitly. The sensitivity to permissible letter patterns (e.g., knowledge about the frequency of letters or letter combinations and legal positions for letter combinations; e.g., "Which looks more like a real word: *yill* or *yihh*?") is defined as *orthographic processing at the sublexical level* (general orthographic knowledge). In addition to orthographic processing at the sublexical level, there is also evidence that children form, store, and access orthographic representations of real words (for an overview and discussion see Ziegler & Goswami, 2005). As these processes lead to knowledge about the correct spelling of specific words (*word-specific knowledge*; e.g., "Which spelling is correct: *rain* or *rane*?") they are termed as *orthographic processing at the lexical level.*

One of the most widely used tasks to measure orthographic processing at the lexical level is the Orthographic Choice Task (Olson, Forsberg, Wise, & Rack, 1994). The Orthographic Choice Task is a discrimination task where the child has to determine which of two phonologically plausible alternatives (a word and a corresponding pseudohomophone; e.g., rain–rane) is the orthographically correctly spelled word. In order to come to a decision, both words have to be read and compared with representations in the mental lexicon (Deacon, Benere, & Castles, 2012).

It has been found that orthographic processing on the lexical level is a predictor of reading and spelling performance in different languages and in children of different ages (Persian: Arab-Moghaddam & Sénéchal, 2001; Dutch: Bekebrede, Leij, & Share, 2009; English: Cunningham & Stanovich, 1990; Deacon, 2011; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009; Greek: Georgiou, Parrila, & Papadopoulos, 2008). Arab-Moghaddam and Sénéchal (2001) examined the impact of word specific orthographic knowledge (measured by an orthographic choice test) in Persian and English bilingual children (grade two and three). Persian has a very regular grapheme-to-phoneme correspondence whereas the phoneme-grapheme correspondence is more complex. Results demonstrated that word specific orthographic knowledge (for English) predicted a significant and comparable amount of variance in reading (8 %) and spelling English (5 %). In contrast, word specific orthographic knowledge (for Persian) could explain a higher amount of variance in spelling (22 %) than in reading (9 %). In line with these findings, Bekebrede et al. (2009) showed that for Dutch-speaking adolescents word specific orthographic knowledge explains a higher amount of spelling performance (23 %) than of reading performance (8 %).

These findings indicate in languages with high consistency between graphemes and phonemes, decoding words via the nonlexical route results in correct pronunciations. However, repeated blending of letter-sounds during decoding is supposed to exert its influence on building-up of word specific representations. These word-specific representations are crucial for developing fluent reading and for producing orthographically correct spellings.

A few studies have investigated orthographic processing on the lexical level (word specific orthographic knowledge) in dyslexic children. Bergmann and Wimmer (2008) examined orthographic processing on the lexical level in German-speaking adolescent dyslexic readers (15–18 year-olds with a reading score below the 15th percentile) and unimpaired controls. They used a lexical decision task in which participants were presented with either a correctly spelled word or a pseudohomophone (e.g., *Vogel–Fogel* [bird]). Participants were asked whether the word they saw was a correctly spelled word. The error rate of dyslexic readers was enhanced by 27 %, compared to controls. Furthermore, dyslexic readers were significantly slower than controls in reaching a correct decision.

In a similar manner, Georgiou et al. (2012) examined performance on an Orthographic Choice Task (comparing a word and a corresponding pseudohomophone) in Greek-speaking sixth graders with dyslexia compared to a chronological age-matched control group, and a reading age-matched control group (third graders). Children with dyslexia identified significantly fewer real words correctly compared to the chronological age-matched control group. No difference was found between the children with dyslexia and reading age-matched controls regarding the number of correctly identified real words. A comparable result was obtained for children's reaction time. Dyslexic children were significantly slower when comparing words and pseudohomophones than the chronological age-matched control group, but there was no group difference between the dyslexic children and the reading age-matched control group. These findings indicate that poor orthographic processing is associated with decelerated development of reading skills.

Together, these findings provide evidence that dyslexic children show deficits in orthographic processing on the lexical level. According to findings that in consistent orthographies dyslexic children show accurate word decoding skills but poor reading fluency (e.g. de Jong & van der Leij, 2003) it can be assumed that children with dyslexia (learning a consistent orthography) have problems to form, store and access word-specific representations.

As noted above, there is also orthographic processing on a *sublexical level*, which results in *general orthographic knowledge* (i.e. knowledge about permissible letter patterns in written words). General orthographic knowledge is commonly measured using pseudoword choice tasks in which children are presented with pseudoword pairs. One of the presented pseudowords contains a letter pattern that occurs frequently in written words or a bigram (e.g., a double consonant) in a legal position. The other pseudoword contains a letter pattern that occurs rarely or never in written words or a bigram in an orthographically illegal position (e.g., yill–yihh; Cassar & Treiman, 1997; baff–bbaf; Cunningham & Stanovich, 1993; Treiman, 1993). Children are asked to determine which pseudoword looks more like a real word. Because children do not have representations of pseudowords in their mental lexicon, they must draw on their knowledge about frequent or permissible letter patterns to reach the correct decision. Pseudoword choice tasks therefore measure children's knowledge about permissible letter patterns independently of the existing representations for whole words in their mental lexicon.

As previously mentioned already very young children are sensitive to writing conventions within their language and show some kind of general orthographic knowledge (sublexical level). Implicit knowledge of permissible letter patterns might play an important role for spelling unfamiliar words orthographically correctly. The role of implicit knowledge is supported by a study by Cassar and Treiman (1997) who found that children's performance on a pseudoword choice task (e.g., yill–yihh) improved with increased spelling ability as determined by the level of spelling development (prephonetic, semiphonetic, phonetic or 'nearly correct' stage) for each child in their study (kindergarten, first and second grade). The relationship between general orthographic knowledge and reading was not examined in this study. A recent study (Rothe, Schulte-Körne, & Ise, 2014) found evidence for a relationship between first graders' reading and spelling performance and their general orthographic knowledge. In this study, general orthographic knowledge explained a significant amount of unique variance in children's reading (11 %) and spelling (7 %) performance after controlling for the influence of known predictors (nonverbal IQ, letter knowledge, phonological awareness, verbal naming fluency, and verbal short term memory). Conrad et al. (2012) demonstrated that general orthographic knowledge correlates significantly with reading and spelling performance in children aged 7–9 years (reading: $r = .53$, $p < .01$; spelling: $r = .61$, $p < .01$; Conrad et al., 2012). However, there is no study that examined general orthographic knowledge in dyslexic children.

In summary, current studies suggest that orthographic processing on both, the lexical and sublexical level, play a role in the development of reading and spelling skills (Conrad et al., 2012; Deacon et al., 2012). However, there is no evidence whether reading and spelling disabled children show deficits in orthographic processing on the sublexical level. Furthermore, there is no study that examined the predictive pattern of lexical and sublexical orthographic processing for reading and spelling performance. The present study seeks to fill this gap by investigating orthographic processing on the lexical and sublexical level in children with both, reading and spelling disorder and to compare their performance with an unimpaired control group.

Orthographic processing on the lexical level was operationalized as word-specific knowledge and assessed with an Orthographic Choice Task based on work by Olson et al. (1994). Orthographic processing on the sublexical level was operationalized as general orthographic knowledge and was measured with three different tasks. First, two pseudoword choice tasks were constructed in which participants are presented with two pseudowords and are asked to select the word that looks more like a real German word. The Freq-Choice-Task measures children's knowledge of frequent double consonants (e.g., nilemm–nilebb). The Pos-Choice-Task measures children's knowledge about legal positions of double consonants (e.g., sinnum–ssinum). Second, a decision task (Pos-Speed-Task) was constructed in which participants are presented pseudowords (e.g., mmotin) for 50 ms each and are asked to indicate whether the word looks like a real German word or not.

The first aim was to investigate whether children with reading and spelling disorder have problems to form, store, and access orthographic information (orthographic processing on the lexical and sublexical level) or if they have only a deficit of word-specific representation. More specifically, we examined whether children with reading and spelling disorder show less word-specific knowledge on the lexical level and less general orthographic knowledge on the sublexical level than unimpaired controls. As reviewed above, dyslexic children have problems to form, store and access word-specific representations. Therefore we hypothesized that children with reading and spelling disorder would show impairments in word-specific orthographic knowledge on the lexical level (Orthographic Choice Task). Following findings from Martens and de Jong (2006) showing that dyslexic children have problems in lexical decision even for short words (3 letter length, therefore trigrams) we hypothesized that dyslexic children might have a general deficit in building-up representations of letter patterns (bi- and trigrams). More specifically, we expected significant group differences between children with reading and spelling disorder and unimpaired controls in terms of the percentage of correct answers on all four orthographic measures. In addition, we aimed to examine potential group differences regarding the performance of identifying orthographically conform pseudowords (as correct) or to identifying orthographically nonconform pseudowords (as incorrect). Bergmann and Wimmer (2008) showed that in a discrimination task consisting of words and pseudohomophones dyslexic children had more difficulty identifying nontargets (70 % correct) than targets (85 % correct). These results also support the hypothesis that dyslexic children miss orthographic lexicon entries. As the pseudohomophones sounds like a real word and orthographic representation are lacking, children identify pseudohomophones more often as a correct spelled word. Therefore, we hypothesized that children with reading and spelling disorder identify less orthographically nonconform pseudowords as incorrect than orthographically conform pseudowords as correct. In order to examine these hypotheses, each pseudoword must be presented separately (Pos-Speed Task). We expected that in the Pos-Speed Task children with reading and spelling disorder identify fewer pseudowords with a double consonant in an illegal position as incorrect than they identify pseudowords with a double consonant in a legal position as correct.

The second aim was to investigate the predictive pattern of lexical and sublexical orthographic processing for reading and spelling performance. As for reading fluency and orthographically correct spellings word-specific representations are crucial we hypothesized that the impact of word specific orthographic knowledge is comparable for reading and spelling. To have representations (within the mental lexicon) of letter pattern with a length of three letters (trigrams) might be also helpful for reading fluency and orthographically correct spellings. There is only one existing study in German speaking first graders showing that general orthographic knowledge explains variance in reading as well as in spelling performance (Rothe et al., 2014). Therefore, we hypothesized that there is a comparable impact of general orthographic knowledge to reading and spelling performance.

Method

Children (aged 8–10 years) were initially recruited for an MRI-Study of structural brain differences between children with and without reading and spelling disorders. Therefore only right-handed boys participated in this study. Measures included (a) orthographic processing on the lexical and sublexical level, (b) nonverbal IQ, (c) phonological awareness (PA), (d) rapid automatized naming (RAN), (e) short-term memory for digits and one-syllable nonwords, (f) reading, and (g) spelling. Children were tested individually in quiet rooms at the university.

Participants

Participants were recruited in Munich (Germany). Parents of fourth grade boys (born between January 2002 and December 2002) were contacted and informed about the study by mail and/or information brochures that were distributed in schools and doctor’s offices. All children who showed interest in participating were screened through telephone interviews (parent report) in order to pre-select for the following inclusion criteria: (a) male, (b) right-handed, (c) native German speaker, (d) no diagnosis of attention deficit hyperactivity disorder (ADHD), (e) no neurological or psychiatric disorder (because these disorders preclude the diagnosis of reading and spelling disorder, ICD-10; Dilling et al., 2011). Ninety-four children passed the initial telephone screening and were invited to participate in further testing. All 94 children and their parents gave informed consent to participate in the study. Fifty-five children met the remaining inclusion criteria and completed all test sessions.

To be included in the study, children had to show average or above average nonverbal intelligence (IQ $\geq$ 85) as assessed by the Culture Fair Intelligence Test (CFT-20R; Cattell, Weiß, & Osterland, 1997). Behavioural, emotional, and attentional problems were assessed with the Child Behaviour Checklist (CBCL/4-18; Achenbach, 1991, 2001; German version: Döpfner et al., 1998; Döpfner, Plück, & Kinnen, 2014). Only boys whose score on the CBCL total scale fell within the normal range (T $<$ 59) and whose raw score on the CBCL subscale Attention Problems was <8 (which is within the normal range), were included in the present study. All children with a reading and spelling disorder (following termed as dyslexic group) showed below-average word reading as well as below average spelling skills (T-values <40. M = 50. 1 SD = 10 T-values, in standardized word reading and word spelling tasks, age-discrepancy criterion). Children in the control group showed at least average word reading and spelling skills (T-value >40 in the standardized word reading and spelling tasks). Of the 55 children that completed all test sessions, four were excluded from data analysis because of difficulties in the legal position speed task. Therefore, the final sample consisted of 51 children ($N = 19$ dyslexic and $N = 32$ controls) with a mean age of 9 years 7 months (SD = 0.5; range 8 years 11 months to 10 years 8 months). Means, standard deviations, group differences, and effect sizes (Cohen's d, see "Data analysis" section) for the variables age, nonverbal IQ, phonological awareness, rapid naming, short-term memory, reading, and spelling are shown in Table 1.

Measures

Reading

Word reading accuracy and speed were assessed with the reading subtest of the standardized reading and spelling test SLRT II (Salzburger Lese-und Rechtschreibtest II [Salzburg reading and spelling test II]; Moll & Landerl, 2010). In this test children are asked to read aloud a list of words as fast and accurate as possible (time limit: 1 min). Scoring is based on the number of correctly read words. Moll and Landerl (2010) report high reliability (parallel test reliability: $r > .90$) and satisfactory validity (convergent validity: $r > .69$).

Spelling

Spelling was assessed using a standardized spelling test (WRT 3+: Weingartener Grundwortschatz Rechtschreibtest für dritte und vierte Klassen [Weingarten basic vocabulary spelling test for third and fourth grades]; Birkel, 2007). Children are asked to insert 60 dictated words into sentence frames. Scoring is based on the

Table 1 Descriptive data for participants (N = 51)

Variable	Group				Group difference	Cohen's d
	RS-D (*N* = *19*)		Controls (*N* = *32*)			
	M	*SD*	*M*	*SD*		
Age in years	9.7	0.6	9.7	0.5	−.61	–
Nonverbal IQ[a]	107.6	12.7	110.8	10.0	−.99	−.28
CBCL[b]	53.8	9.2	50.9	9.4	1.07	.31
Phonological awareness[c]	70.2	14.4	81.5	10.9	−3.17**	−.88
RAN letters[d]	32.7	6.8	24.7	3.9	5.38**	1.44
Short-term memory[e]	−0.73	0.71	0	1	−2.98**	−.84
Reading[f]	6.5	4.7	62.0	26.9	−9.74**	−2.8
Spelling[f]	6.1	4.1	66.8	24.2	−10.09**	−3.5

RS-D reading and spelling disorder

* $p \leq .05$; ** $p \leq .01$

[a] IQ-scores ($M = 100$. $SD = 15$)

[b] T-values ($M = 50$. 1 $SD = 10$ T-values)

[c] Percentage correct

[d] Time in seconds

[e] z-scores

[f] Percentile scores

number of correctly written words. The test shows high reliability (split-half method: $r > .90$; internal consistency: Cronbach's $\alpha > .90$) and satisfactory validity (external criterion: $r > .60$; convergent validity: $r > .80$).

Nonverbal IQ

Children's nonverbal cognitive skills were assessed with the Culture Fair Intelligence Test Scale 2 (CFT-20-R, Scale 2; Weiß, 2006). The test consists of the subtests Sequence Completion, Classification, Matrices, and Topology. The CFT-20-R shows high reliability (internal consistency: $\alpha = .95$) and moderate validity (concurrent validity: $r > .64$).

Phonological awareness

The phonological awareness test consists of two subtests. The subtests were taken from a battery that was designed within our research group and was used in a previous study (Landerl et al., 2013). In each subtest, children receive practice items before starting the test. For the subtest Nonword Phoneme Segmentation the maximum score is ten. After hearing a nonword, children are asked to repeat the nonword and say each phoneme of the word (e.g., frap–f/r/a/p). In the subtest Phoneme Deletion, children hear a nonword and are asked to delete a specified phoneme from the nonword (e.g., "say tiek without /k/"). The maximum score for this subtest is 27. For both subtests, the percentage of correctly answered items is calculated separately. Subsequently, the mean percentage correct of the two subtests is calculated.

Verbal short-term memory

A conventional measure was used to assess verbal short-term memory. The Digit Span Task is a subtest of the Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV; German version: Petermann & Petermann, 2007). Children hear a series of digits at a rate of one digit per second and are asked to repeat the sequence immediately in order. The same procedure is used in the Digit Span Backward task, in which children are asked to repeat the series in reverse order. Each trial is scored as correct or incorrect. Z-Scores are calculated from the sum scores.

The second task used to assess verbal short-term memory is the One-Syllable Nonword Span Task, which was taken from a battery that was designed within our research group and was used in a previous study (Landerl et al., 2013). Items are presented in the same manner as in the Digit Span task. Children hear a series of one-syllable-nonwords and are asked to immediately repeat the sequence in order. The first sequence comprises two syllables. Sequence length then increases to up to six syllables. The task does not end until all sequences have been presented. Each sequence produces a binary score (correct/incorrect). Z-scores are calculated from the sum scores. For data analysis the mean z-score of the two tasks was calculated.

Rapid automatized naming (RAN)

This test was first introduced by Denckla and Rudel (1976a). Children are presented with four subtests of objects, colours, numbers, and letters. In each subtest children see 50 symbols in ten rows with either five objects, five colours, five numbers, or five letters that are repeated in a random order. Children are asked to name each item as quickly as possible. Accuracy and completion time are recorded for each subtest separately. Because rapid naming of letters is more closely related to orthographic processing than the other subtests, time (in seconds) for the subtest "letters" was used for data analysis.

Orthographic processing on the lexical level (Orthographic Choice Task)

Orthographic processing on the lexical level was operationalized by measuring word-specific knowledge with the Orthographic Choice Task. The task consists of 23 test items (chosen from Goswami, Ziegler, Dalton, & Schneider, 2001) and four practice items (self-developed). All items are listed in the "Appendix". Children see a correctly spelled word and a homophone with the same pronunciation (e.g., *Dorf–Dorv*). They are asked to identify the correctly spelled word and to indicate their answer by pressing a left or right button on a computer keyboard, corresponding to the position of the correctly spelled word. Children receive feedback after each item indicating whether their response was correct or incorrect. A time limit of 30 s for each test item is used. The test items are presented in random order. To control for response bias (left or right hand) half of the target words are presented on the right side of the screen and the other half are presented on the left side of the screen. The internal consistency of the task is good (Cronbach's $\alpha = .80$). The items were presented on a laptop with a 15-in. monitor on a white screen with black letters in font size 30. For data analysis, accuracy (the percentage of correct answers) was calculated.

Orthographic processing on the sublexical level

Orthographic processing on the sublexical level was measured with three different pseudoword tasks. The pseudowords used in these three tasks were composed of six letters and were pronounceable. They were presented on a laptop with a 15-in. monitor on a white screen with black letters in font size 30. For pseudoword construction, information about the statistical frequency of double consonants was used, which was kindly provided by the Institute for German Language in Mannheim (Institut für Deutsche Sprache, IDS; www.ids-mannheim.de). The IDS calculated the percentage of the occurrence of single letters, bigrams, and trigrams by analysing 5,963,546 texts with overall 1.5 billion words of contemporary written German (DeReKo; Deutscher Referenzkorpus [German reference base]). For each of the three general orthographic knowledge tasks, the percentage of correct answers was calculated for data analysis.

Knowledge of frequent double consonants (Freq-Choice-Task) Knowledge of double consonantal frequency was assessed using 36 pseudoword pairs. One pseudoword in each pair contains a double consonant that occurs frequently in German written words, whereas the other pseudoword contains a double consonant that occurs rarely (e.g., bossul–boddul). Children are asked to determine which pseudoword looks more like a real German word and to make their decision by pressing the corresponding button on a computer keyboard. Before starting the test, children complete three practice items. Children receive no feedback (neither for the 3 practice items nor for the 36 test items). There is a time limit of 30 s for each test item. The test items (listed in the "Appendix") are presented in random order. To control for a response bias (left or right hand) half of the target pseudowords are presented right and the other half are presented left. The task has good internal consistency (Cronbach's $\alpha = .86$). Detailed information on the pseudowords used in this task is given in Rothe et al. (2014). In short, we selected the consonants /s/, /l/ and /m/ because they occur frequently as single consonants (mean percentage of occurrence = 4.27 %) and as double consonants (mean percentage of occurrence = 0.41 %). They are contrasted with the letters /b/, /d/ and /g/, which occur frequently as single consonants (mean percentage of occurrence = 3.27 %) but not as double consonants (mean percentage of occurrence = 0.01 %). Each frequent double consonant (/ss/, /ll/, and /mm/) is paired with each infrequent double consonant (/bb/, /dd/, and /gg/). This results in nine different combinations (ss-bb, ss-dd, ss-gg, ll-bb, ll-dd, ll-gg, mm-bb, mm-dd, and mm-gg). For each combination, four pseudoword pairs are constructed. Two pseudoword pairs consist of pseudowords in which the double consonant appears in the middle of the word (e.g., kossur–koddur) and two pseudoword pairs consist of pseudowords in which the double consonant appears at the end of the word (e.g., koruss–korudd). In addition, the frequency of all bigrams and trigrams is controlled for. Therefore pseudoword pairs differ only in the frequency of the double consonant. For example, the frequencies of the bi- and trigrams that are comprised in the words *bossul* (/bos/, /os/, /su/, and /sul/) and *boddul* (/bod/, /od/, /du/, and /dul/) are very similar (mean percentage of occurrence: /bos/ = 0.02; /bod/ = 0.02; /os/ = 0.16; /od/ = 0.09; /su/ = 0.09; /du/ = 0.13; /sul/ = 0.0007; /dul/ = 0.0006). Accordingly, calculating the mean bi- and trigram frequencies of the pseudowords only bi- and trigrams without the double consonants were included. Mean bi- and trigram frequencies do not differ significantly between the two conditions (see "Appendix").

As a result, differences between pseudowords with frequently versus rare occurring double consonants (e.g. /ss/) cannot be explained by differences between overall frequency of the bi- and trigram frequencies.

Knowledge of legal positions of double consonants (Pos-Choice-Task) Children's knowledge of legal positions of double consonants was assessed with a task consisting of 24 pseudoword pairs and three practice items. One pseudoword in each pair contains a double consonant in a legal position (medial or final position) and the other pseudoword contains a double consonant in the illegal word-initial position (e.g., sinnum–ssinum). Like in the Freq-Choice-Task children are asked to determine which pseudoword looks more like a real German word. The task follows the same procedure as the Freq-Choice-Task. The internal consistency of the task is moderate (Cronbach's $\alpha = .76$). The pseudoword pairs were composed by selecting two double consonants that occur equally often. Eight pseudoword pairs contain the double consonants ss and nn (e.g., *nissum–nnisum*; mean percentage of occurrence: ss = 0.42, nn = 0.41), eight pseudoword pairs contain the double consonants mm and tt (e.g., *tifumm–ttifum*; mean percentage of occurrence: tt = 0.28, mm = 0.22), and another eight pseudoword pairs contain the double consonants ff and rr (e.g., *rimeff–rrimef*; mean percentage of occurrence: ff = 0.12, rr = 0.11). Each double consonant occurs in four pseudowords in a legal position (two medial, two end) and in four pseudowords in an illegal position (beginning). The frequency of all trigrams is controlled for. It was not necessary to control for bigram frequency because the bigrams of each pseudoword pair are identically, except for double consonants (e.g. *rimeff–rrimef*, ri–im–me–ef). The mean trigram frequency for each pseudoword is displayed in the "Appendix". The mean trigram frequencies do not differ significantly between the two conditions (legal and illegal position).

Identification of legal positions of double consonants (Pos-Speed-Task) A pseudoword decision task was designed to measure children's ability to identify legal or illegal positions of double consonants. Since the focus of this task was to measure the child's ability to identify legal or illegal letter patterns spontaneously, limited word presentation duration was used. Van Doren et al. (2010) showed that for adult participants average word presentation duration of 35.5 ms was needed to identify a word. In the present study, the pseudowords were presented as single words for 50 ms due to the participants' young age (8–10 years). The short presentation (50 ms) makes it impossible to read the pseudoword using the nonlexical route (see DRC-Modell; Coltheart, Rastle, Parry, Langdon, & Ziegler, 2001). Using the lexical route is not possible because children do not have a representation of pseudowords in their mental lexicon. However, it remains possible to identify legal or illegal letter patterns.

The Pos-Speed-Task comprises 48 pseudowords. Target words contain a double consonant in a legal position (medial or final position; e.g., sinnum). Nontargets contain a double consonant in the illegal word-initial position (e.g., ssinum). Children are told that they will see pseudowords very briefly, that they will hardly be able to read the words, and that it will be enough just to "look" at the words and decide whether the pseudoword could be a real German word or not. Children are first presented with a fixation cross (150 ms) followed by a pseudoword (50 ms). Thereafter children see a blank screen until they respond (maximum 30 s). Children are asked to make their response by pressing the left or right button on a computer keyboard. To control for a response bias (left or right hand), half of the children are asked to press the right button if they think the word could be a real German word whereas the other half of the children are asked to press the left button if they think the word could be a real German word. Children receive no feedback (neither for the practice items nor for the test items). The test consists of four practice items and 48 test items (24 targets and 24 nontargets; see "Appendix"), which are presented in a random order. The number of correctly identified targets and nontargets is summed to yield a Pos-Speed-Task score. The internal consistency of the task is good (Cronbach's $\alpha = .85$). The same pseudowords are used as in the Pos-Choice-Task.

Data analysis

Two children were excluded from data analysis due to prolonged mean reaction times in the Pos-Speed-Task. Their mean reaction time deviated more than 2 standard deviations from the mean reaction time of the whole sample. In addition, children who pressed more than ten times in a row the same response button were excluded from the analyses (N = 2). We interpreted this either as a false understanding of the task instruction or as problems with attending to the task.

The distribution of scores in the Orthographic Choice Task and the Pos-Choice-Task in the control group differed significantly from normal distribution due to a ceiling effect (Orthographic Choice: $M = 98.8$ %-cor., $SD = 2.3$; Pos-Choice-Task: $M = 95.8$ %-cor., $SD = 7.0$). Therefore group differences for Orthographic Choice Task and the Pos-Choice-Task were investigated using Mann–Whitney *U* tests. Scores on the remaining tasks approximated a normal distribution. Group differences for these tasks were investigated using t-tests for independent samples. To identify group differences for the two conditions of the Pos-Speed-Task a repeated measures analysis of variance (ANOVA) with the two within-subjects variables “item-type” (targets/nontarget) and the between-subject variable “group” was carried out. The relationship between the orthographic knowledge tasks and reading and spelling skills were examined by correlations. For the Legal Position Choice Task and the Orthographic Choice Task Spearmans-Rho was calculated (because they differed significantly from normal distribution). For remaining variables bivariate Pearson correlations were carried out.

To examine the unique prediction of general and word specific orthographic knowledge for reading and spelling performance multiple hierarchical regression analysis were conducted. Firstly, known predictors of reading and spelling performance were entered into the regression model. Secondly, those orthographic knowledge tasks that correlate significant with reading and spelling development were entered into the regression model. To explore the impact of general orthographic knowledge and word specific orthographic knowledge independently of each other, separate regression models were calculated for general orthographic knowledge and word specific orthographic knowledge.

Results

Performance and group differences on the Orthographic Knowledge Tasks

Means, standard deviations, and effect sizes (Cohen’s d) for the orthographic knowledge tasks are shown in Table 2. Dyslexic children gave less correct answers (86.6 %) than controls (98.8 %) on the Orthographic Choice Task (word-specific knowledge, lexical level, $U(19,32) = 95.5$, $p < .05$).

Results on the tasks used to assess children’s general orthographic knowledge (sublexical level) were inconsistent. There was no significant group difference on

Table 2 Results of the word-specific and general orthographic knowledge tasks

Variable	Group				Group difference	Cohen’s d
	RS-D		Controls			
	M	*SD*	*M*	*SD*		
Word-specific orthographic knowledge (% correct)						
Orthographic Choice Task (% correct)[a]	86.3	12.8	98.8	2.3	95.5**	−1.36
General orthographic knowledge (% correct)						
Freq-Choice-Task	80.3	17.8	77.0	15.1	.70	.20
Pos-Choice-Task[a]	92.8	11.2	95.8	7.0	274.5	−0.32
Pos-Speed-Task	66.1	14.5	76.2	14.9	−2.21*	−.69

RS-D reading and spelling disorder

* $p \leq .05$; ** $p \leq .01$

[a] Due to a ceiling effect in the control group, group differences for Orthographic Choice Task and Pos-Choice-Task were calculated by using Mann–Whitney *U* tests

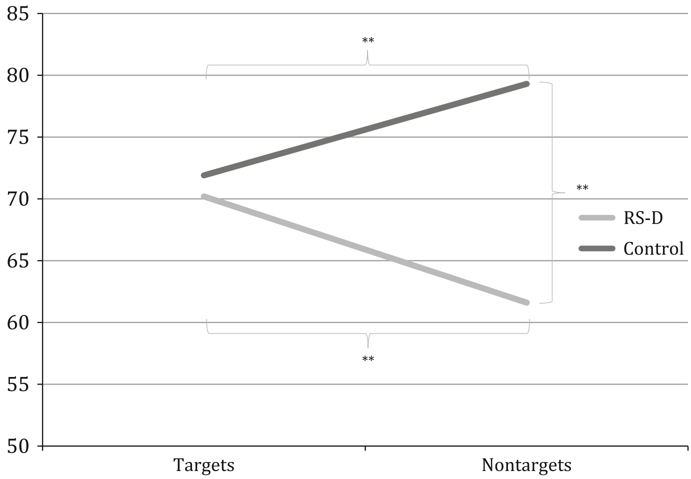

Fig. 1 Interaction between item-type and group in the Pos-Speed-Task

the Freq-Choice-Task ($p = .49$) and the Pos-Choice-Task ($p = .53$). However, on the Pos-Speed-Task, dyslexic children gave significantly less correct answers than controls, $t(49) = -2.21$, $p \leq .05$, $d = -.69$.

On the Pos-Speed-Task, items were presented in isolation rather than in pairs. It was therefore possible to differentiate between target words, which contain a double consonant in a legal position, and nontargets, which contain a double consonant in an illegal position. Repeated measures ANOVA showed a significant main effect of group, $F(1,49) = 4.87$, $p \leq .05$, no significant main effect of item-type, $F(1,49) = .09$, $p = .77$ but a significant interaction between item-type and group, $F(1,49) = 18.1$, $p \leq .001$. The interaction is displayed in Fig. 1. Results indicate that dyslexic children have problems to identify nontargets correctly but they identify as many targets correctly as the control group. Children of the control group identify more nontargets correct than targets, whereas dyslexic children identify more targets correct than nontargets.

Relationship between orthographic knowledge and reading and spelling performance

Correlations between performance on the orthographic knowledge tasks and reading and spelling skills are shown in Table 3. There is only a minor difference between Spearmans Rho and Pearson's r of the correct identified nontargets of the Pos-Speed Task and the Orthographic Choice Task. Therefore in Table 4 only Pearson correlations are reported. In line with the significant group differences on the Orthographic Choice Task and the correctly identified nontargets in the Pos-Speed-Task these tasks correlate significantly with reading and spelling performance.

Table 3 Intercorrelations among reading, spelling and the orthographic knowledge tasks

	1	2	3	4	5	6	7	8
Reading	–							
Spelling	.84**	–						
Frequent double consonant choice task	−.08	−.09	–					
Legal position speed task	.30*	.26	.25	–				
Legal position speed task—targets	.13	.06	.36**	.89**				
Legal position speed task—nontargets	.38**	.39**	.11	.92**	.64**	–		
Legal position choice task	.10	.09	.14	.46**	.38**	.45**	–	
Orthographic Choice Task	.53**	.53**	−.17	.38**	.19	.48**	.40*	–

* $p < .05$; ** $p < .01$

Table 4 Hierarchical multiple regression analyses predicting reading and spelling performance

Model	Step	Predictor	Reading			Spelling		
			β	R^2	ΔR^2	β	R^2	ΔR^2
1				.50**			.44**	
	1							
		Phonological awareness	.15			.27*		
		RAN letters	−.52**			−.40**		
		Short-term memory	.20			.19		
	2	Phonological awareness	.14			.26*		
		RAN letters	−.43**			−.30*		
		Short-term memory	.17			.15		
		Orthographic Choice	.33**	.60**	.10**	.36**	.56**	.12**
2								
	2	Phonological awareness	.08			.19		
		RAN letters	−.45**			−.32**		
		Short-term memory	.30**			.29*		
		Correctly identified nontargets in Pos-Speed-Task	.32**	.59**	.09**	.33**	.53**	.09**

* $p \leq .05$; ** $p \leq .01$

Predictive patterns of orthographic knowledge for reading and spelling performance

Multiple hierarchical regression analyses were conducted to explore whether orthographic processing at the lexical and sublexical level explains unique variance in reading and spelling performance. To examine if there were significant differences between the two groups (dyslexics and controls) regarding the correlation coefficients of reading, spelling and the predictor variables, Fisher's z were calculated. Results show that there are no significant differences between the correlation coefficients (correlation for the correlation pairs; rapid automatized naming: reading $p = .78$, spelling $p = .91$; phonological awareness: reading $p = .57$, spelling $p = .33$; verbal short term memory: reading $p = .29$, spelling $p = .66$). Therefore the regression analyses were calculated for both groups together.

Separate regression models were calculated for general orthographic knowledge and word specific orthographic knowledge. In both regression models known predictors of reading and spelling disorder (phonological awareness, rapid automatized naming, and verbal short term memory) were entered first (step 1). At step 2 those variables that correlated significantly with reading and spelling performance (for general orthographic knowledge: correctly identified nontargets in the Pos-Speed-Task; for word specific orthographic knowledge: Orthographic Choice Task) were entered. Results of the regression analysis are displayed in Table 4.

As expected, control variables (phonological awareness, rapid automatized naming, and verbal short term memory) explained a large amount of variance (50 %) in reading performance, $F(3, 47) = 15.9$, $p < .001$. Orthographic Choice can explain an additional amount of 10 % of reading performance $F(1, 46) = 11.4$, $p < .01$). The correctly identified nontargets in the Pos-Speed-Task explained an additional amount of 9 % in reading performance $F(1, 46) = 10.2$, $p < .01$. The increase in the proportion of explained variance was significant for both orthographically predictors.

For spelling performance the control variables explained 44 % of variance $F(3, 47) = 12.3$, $p < .001$. Orthographic Choice can explain an additional amount of 12 % of spelling performance $F(1, 46) = 12.1$, $p = .001$. The correctly identified nontargets in the Pos-Speed-Task explained an additional amount of 9 % in spelling performance $F(1, 46) = 9.2$, $p < .01$. The increase in the proportion of explained variance was significant for both orthographically predictors.

Discussion

The main goal of the present study was to investigate different aspects of orthographic processing (processing on the lexical and sublexical level) in children with dyslexia compared to typically developing controls and to identify the impact of lexical and sublexical orthographic processing on reading and spelling performance in the two groups. In line with our expectation, children with dyslexia were significantly less accurate than control children (86.6 vs. 98.8 %) in the Orthographic Choice Task, indicating poorer word-specific orthographic knowledge. The control group showed a ceiling effect on this task. Previous studies reported ceiling effects on Orthographic Choice Tasks mainly in older children aged 12 years and older (Bekebrede et al., 2009; Georgiou et al., 2012). One explanation for the unexpected ceiling effect found in children aged 8–10 years in the current study is that reading and spelling development advances rapidly in regular orthographies (such as German; Aro & Wimmer, 2003; Seymour et al., 2003). Future studies should therefore increase the difficulty of the Orthographic Choice

Task by constructing more complex items (e.g., by using infrequent words or increasing syllable length). However, the result supports the hypothesis that for dyslexic children, compared to normal reading children, it is hard to store and access orthographic representations when they are lexical. Still, it must be noted that also dyslexic children show a high accuracy in the Orthographic Choice Task. The present study also shows that normal reading children as well as dyslexic children are able to distinguish legal and illegal letter patterns in pseudowords if they have the possibility to choose between two alternatives (e.g., sinnum vs. ssinum).

As dyslexic children seem to have problems in lexical decision even for very short words (three letters, therefore trigrams) we hypothesized that dyslexic children might have a general deficit to build up representations of letter patterns and therefore will show impaired orthographic processing on the sublexical level (measured with general orthographic knowledge tasks). Contrary to our expectations, dyslexic children showed similar performance on two of three general orthographic knowledge tasks (Freq-Choice-Task and Pos-Choice-Task) compared to the control group. Two aspects might be relevant for understanding this finding. First we investigated third and fourth graders. Due to implicit learning of bigram and trigram frequencies in words by word reading also dyslexic third graders might develop a bigram and trigram representation in the brain that is sufficient to solve the orthographic knowledge task on the sublexical level. Therefore investigating this paradigm with first or second graders or better in a longitudinal study can help to better understand the development of sublexical orthographic representations in dyslexic children. Second as we found a significant group difference in children's performance on the Pos-Speed-Task the different task difficulties and requests of the sublexical orthographic knowledge task seem to be relevant. On a closer examination the two groups did not differ in terms of their performance on target words (pseudowords with a legal letter pattern; e.g., sinnum), but differed on nontargets (pseudoword with an illegal letter pattern, e.g. ssinum). The control children performed significantly better than children with dyslexia. The dyslexic children were more likely to accept a nontarget as a real word than the controls. Since there is no group difference on target words, the speed component of the Pos-Speed-Task (i.e. 50 ms presentation time of the pseudoword) cannot explain the group difference observed for nontargets. Instead we suggest, that the group difference is likely to reflect poorer position representation of the bigrams in children with dyslexia that might disturb their word identification. Comparable results were reported by Bergmann and Wimmer (2008) for word-specific orthographic knowledge.

Together the group differences on the orthographic knowledge tasks show that children with dyslexia are able to discriminate letter patterns that they never/or rarely have seen before, from letter patterns that they frequently see (Freq-Choice and Pos-Choice). They also show a high accuracy in identifying correct spelling for words if they see two phonologically plausible alternatives (Orthographic Choice Tasks). Seeing either a pseudoword with legal or illegal letter patterns singly and for a short time (Pos-Speed-Task), dyslexic children show deficits in identifying illegal letter pattern as incorrect, whereas they have no problems to identify legal letter pattern as correct. This indicates that children of the dyslexic group have no general problem in identifying letter patterns in separately and shortly represented pseudowords. In summary, the findings of the present study together with earlier findings suggest that dyslexic children are able to recognize frequent/legal letter patterns. But it seems to be hard for dyslexics to access orthographic representations of words in the mental lexicon to identify incorrect spellings or infrequent/illegal letter patterns. This could be an explanation for their difficulties in producing correct word spellings. As this is the first investigation of general orthographic knowledge together with word specific orthographic knowledge in dyslexic children, further research is needed to understand the difference between children's ability to recognize letter patterns and words, to identify correctness of orthographic spellings and to produce correct spellings.

The second aim was to investigate the predictive patterns of lexical and sublexical orthographic processing for reading and spelling performance. As reviewed above we hypothesized that word-specific representations as well as representations of letter patterns are crucial for reading fluency as well as for orthographically correct spellings. In line with our expectation the amount of unique variance that could be explained by Orthographic Choice was comparable for both, reading (10 %) and spelling (12 %). The results suggest that word specific orthographic knowledge is necessary in a similar manner for reading as well as for spelling performance. Also in line with our expectation the impact of general orthographic knowledge to reading and spelling performance was comparable (9 % for both, reading and spelling performance). These results indicate that general orthographic knowledge is also critical for both reading and spelling performance. Results also shows that the amount of variance, explained by word specific orthographic knowledge is comparable to the amount explained by general orthographic knowledge. Further research can help to understand more precisely how sublexical orthographic knowledge and word specific orthographic knowledge are causally related.

There are two limitations to the present study that are worth noting. First, the sample size is small. As the participants were initially recruited for an MRI study it was difficult to recruit children who fulfil all inclusion criteria. A larger sample size would allow examining the predictive patterns for children with and without dyslexia separately. Secondly, there were ceiling effects in two of the orthographic knowledge tasks (Pos-Choice and Orthographic-Choice Task). Additionally, future studies should improve the Orthographic-Choice Task by controlling for bi- and trigram frequencies. This might help to further differentiate between deficient word representations and poor knowledge of bi- and trigram frequencies.

In conclusion, the present study shows that for dyslexic children, compared to normal reading children, it is hard to store and access orthographic representations when they are lexical. However dyslexic children have no deficit to access the representations of orthographic letter patterns that are characteristic for their language, i.e. a language with a high grapheme-phoneme correspondence. The results support further the hypothesis that there is a difference between recognising frequent (orthographically correct) letter patterns (Freq-Choice and Pos-Choice Task) and identifying infrequent (orthographically incorrect) letter patterns

(Nontargets of the Pos-Speed Task). Dyslexic children have difficulties identifying orthographically incorrect letter patterns, but they do not show a deficit when asked to identity orthographically correct letter patterns.

Appendix

See Tables 5, 6 and 7.

Table 5 Nonwords included in the Pos-Choice-Task and the Pos-Speed-Task

Legal position		Illegal position	
Stimuli	Trigramfreq.	Stimuli	Trigramfreq.
sinnum	0.05	ssinum	0.05
mottin	0.02	mmotin	0.02
mettus	0.02	mmetus	0.05
ferrab	0.05	fferab	0.07
rimeff	0.01	rrimef	0.01
ruffis	0.01	rrufis	0.009
sedann	0.07	ssedan	0.08
nabess	0.12	nnabes	0.10
fimerr	0.06	ffimer	0.04
nissum	0.05	nnisum	0.04
sannit	0.07	ssanit	0.03
tifumm	0.005	ttifum	0.004
rokuff	0.004	rrokuf	0.004
furris	0.03	ffuris	0.03
sabenn	0.16	ssaben	0.13
nedass	0.12	nnedas	0.12
torumm	0.03	ttorum	0.03
morutt	0.01	mmorut	0.008
temmus	0.03	ttemus	0.07
reffab	0.01	rrefab	0.03
nassit	0.07	nnasit	0.02
mifutt	0.004	mmifut	0.003
tommin	0.05	ttomin	0.03
fokurr	0.01	ffokur	0.01
Mean	0.04	*Mean*	0.04

Trigramfrequency shows the mean percentage of occurrence within the DeReKO corpora (based on the number of all bi-/trigrams)

Table 6 Nonwords included in the Freq-Choice-Task

Frequently occurring			Rarely occurring		
Stimuli	Bigramfreq.	Trigramfreq.	Stimuli	Bigramfreq.	Trigramfreq.
nilemm	0.47	0.038	nilebb	0.25	0.045
weremm	0.47	0.043	weredd	0.23	0.028
vonass	0.51	0.008	vonabb	0.34	0.009
geross	0.16	0.025	gerodd	0.09	0.016
defiss	0.85	0.010	defigg	0.44	0.010
renamm	0.35	0.015	renabb	0.34	0.009
sejamm	0.35	0.002	sejagg	0.32	0.003
wihall	0.74	0.103	wihabb	0.34	0.096
wiromm	0.19	0.021	wirodd	0.09	0.016
behass	0.51	0.008	behadd	0.14	0.007
sohimm	0.34	0.007	sohigg	0.44	0.012
zuhoss	0.34	0.007	zuhobb	0.10	0.007
havill	0.34	0.008	havidd	0.13	0.007
dilass	0.51	0.063	dilagg	0.32	0.072
sibull	0.11	0.004	sibudd	0.14	0.005
dafull	0.11	0.0009	dafugg	0.10	0.0008
wesull	0.11	0.004	wesubb	0.07	0.004
erfill	0.34	0.019	erfigg	0.44	0.010
massun	0.30	0.026	maggun	0.209	0.02
dissan	0.56	0.033	diggan	0.317	0.03
bossul	0.13	0.01	boddul	0.114	0.01
gasset	0.71	0.023	gabbet	0.809	0.03
tallus	0.44	0.015	tabbus	0.231	0.02
rassin	0.56	0.018	raddin	0.582	0.03
lommun	0.15	0.0007	loddun	0.114	0.0008
dullen	0.48	0.370	dubben	0.674	0.42
simmap	0.39	0.003	siggap	0.317	0.007
zullot	0.12	0.016	zuddot	0.085	0.01
hemmos	0.29	0.005	heddos	0.176	0.004
jammuz	0.23	0.003	jagguz	0.209	0.004
gemmun	0.29	0.092	gebbun	0.184	0.10
zammor	0.23	0.003	zabbor	0.204	0.002
silluw	0.24	0.010	sigguw	0.267	0.007
tuller	0.48	0.222	tugger	0.905	0.25
nillun	0.24	0.0009	niddun	0.132	0.001
lossat	0.22	0.011	lobbat	0.157	0.007
Mean	0.36	0.035	*Mean*	0.28	0.036

Bigramfreuquency and trigramfrequency shows the mean percentage of occurrence within the DeReKO corpora (based on the number of all bi-/trigrams)

Table 7 Words and pseudohomophones included in the Orthographic Choice Task

Word	Pseudohomophone
stimuli	stimuli
Haus (*house*)	Hauss
Banane (*banana*)	Bannaane
Dorf (*village*)	Dorv
September (*september*)	Sebtämber
Berg (*mountain*)	Bärg
verlieren (*to lose*)	värlihren
Vater (*father*)	Vahter
Mond (*moon*)	Moond
Karamell (*caramel*)	Karramäll
Blume (*flower*)	Bluume
Hund (*dog*)	Hunt
Tomate (*tomato*)	Tohmahte
rot (*red*)	rodt
Bruder (*brother*)	Bruhder
Fenster (*window*)	Fänster
lesen (*reading*)	leesen
Besenstiel (*broomstick*)	Beesenstihl
Kind (*child*)	Kindt
fünf (*five*)	fünv
Spiegelei (*fried egg*)	Spigelai
Braten (*roast*)	Braaten
Messer (*knife*)	Mässer
Nase (*nose*)	Nahse

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