Max Planck Research Group

Reading Education and Development (REaD)

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The **Max Planck Research Group "Reading Education and Development" (REaD)** (Head: Sascha Schroeder) investigates the underlying structure of reading skills and their development across the lifespan. To this end, the Research Group assesses the component processes of reading longitudinally and analyzes their interactions. This approach will allow the researchers to provide a more detailed description of the various subprocesses of reading and to analyze their conditions and consequences. These insights, in turn, will enable the Research Group to identify the processes that should be targeted by effective remedial programs in reading education. The group started its work in July 2012.

Research Team 2012–2013

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Introductory Overview

Reading is one of the most important but also one of the most complex inventions in human history. In our modern, information-oriented society, it is vital to be able to read texts accurately and efficiently. People who lack these skills are at serious risk of marginalization: Adults with functional illiteracy often find themselves socially isolated; adolescents who are unable to write a letter of application fail to find a job.

In contrast to learning to talk, children do not learn to read spontaneously but need instructional help and support. Yet, many children have problems with reading acquisition and remain unable to understand even simple texts by the end of their compulsory education. How can we help these children?
Reading is a cognitive skill that involves a number of interacting component processes located at different levels within a general hierarchy. It is unclear which of these processes are important for children's reading development and how they interact. Furthermore, it is likely that different groups of struggling readers have different types of deficits and thus need different kinds of support.
The Max Planck Research Group "REaD" was launched in summer 2012 with the aim of investigating the underlying component processes of reading skills and their development over childhood and adolescence. This approach will provide a more detailed description of the various subprocesses of reading, their conditions, and consequences. These insights, in turn, will enable us to identify the processes to be targeted by effective remedial programs in reading education.
A distinctive characteristic of the "REaD" group is that it takes a holistic and integrative approach to the investigation of reading: Theoretically, we combine elements from linguistics, psychology, and education. Empirically, we are interested in the reading process as a whole—from lexical processes on the word level via syntactic processes on the sentence level up to discourse processes on the text level. Methodologically, we combine cross-sectional and longitudinal designs as well as corpus studies and experiments. In all of our studies, we are interested in connecting our data to computational models of reading.
The research agenda of the "REaD" group is structured around four main projects:

(1) In the *childLex* project, we have established a linguistic corpus of German-language writing for children. *childLex* is complemented by the *InLex* project *(Individual Lexicon in Reading Acquisition)*, which investigates interindividual differences in the size and quality of the mental lexicon. Establishing such norms is an essential basis for the design of experimental studies and training programs in German.
(2) In the *Developmental Lexicon Project (DeveL)* we are collecting behavioral data for a selected set of words from children at different stages of reading development as well as from adult samples across the lifespan. These data are urgently needed to create the next generation of computational models of visual word recognition.
(3) The *Developmental Eye-Tracking Study (DevTrack)* investigates reading processes using eye-tracking techniques. This approach allows us to analyze children's reading of connected text beyond the decoding of single words, as well as the associated syntactic and semantic processes, and the preprocessing of upcoming words.
(4) Two interconnected longitudinal studies will investigate interindividual differences in reading development. The *OPeRA* project *(Orthographic Processing in Reading Acquisition)* focuses on children's use of different orthographic grain sizes during reading development in school. The complementary *PLAiT* project *(Prerequisite Language Abilities in the Transitional Phase)* concentrates on the transition from kindergarten to grade 1 and investigates which precursor abilities predict children's later reading achievement.
At present, most projects are in the starting or data collection phase. In this report, we therefore demonstrate the general aims of the projects by providing results from pilot studies that are currently being published or from preliminary analyses of the main studies.

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Schroeder, S. (2011). What readers have and do: Effects of students' verbal ability and reading time components on comprehension with and without text availability. *Journal of Educational Psychology, 103,* 877–896. doi:10.1037/a0023731

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childLex: A Corpus of German Read by Children

childLex is a linguistic corpus that has been collected from a large number of children's books in order to investigate German-language writing for children. The project is being conducted in collaboration with the Berlin-Brandenburg Academy of Sciences and the University of Potsdam and was initiated in summer 2012. The complementary InLex project was launched in fall 2013 and will focus on interindividual differences in the structure of children's mental lexicon.

Key References

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Linguistic databases for children are important tools for developmental studies of reading and have a long history in educational psychology. They are important for selecting stimulus materials for experimental studies and for investigating children's written and spoken language skills. For adults, a wide selection of corpora is now available, such as the German *DWDS* corpus (Digital Dictionary of the German Language). Unfortunately, these databases may not be adequate for children.

In order to account for potential differences between adult and child print exposure, specialized corpora of writing for children have been collected in some languages. In English, for example, researchers can draw on *The Educator's Word Frequency Guide* or the *Children's Printed Word Database.* Similar databases have been collected for other European languages (e. g., French, Spanish, Italian). For German, however, there was previously no electronic database of materials intended to be read by children. Although some frequency counts for children have previously been published, they are based on small corpora and outdated materials. In addition, they provide no linguistic information beyond simple frequency counts and cannot be accessed electronically. To close this gap, we have compiled the *childLex* corpus to investigate German-language writing for children and to establish an online database that gives users access to a wide selection of linguistic variables.

A first version of the *childLex* database was made available to the scientific community in late 2013 (www.childlex.de). At present, we are working on several analyses investigating the differences between writing for children

What Do Children Actually Read?

The *childLex* corpus was compiled from books intended to be read by children by themselves. As a consequence, it mainly comprises narrative, informal texts but also some expository texts (science books, etc.). Books were selected from several sources: First, we analyzed children's self-reports (as published in newspapers, etc.) and the 2012 sales figures of online stores (as provided, e. g., by www.amazon.de). Second, a huge public library in Berlin provided us with the loan statistics for children's books for the years 2010 to 2012. Finally, responses to a teacher questionnaire implemented in a large educational study investigating reading in elementary schools were used to select school textbooks.

Three observations are immediately apparent from these materials: First, most of children's print exposure stems from informal settings outside school. For example, a typical grade 3 textbook comprises only 30,000 words—the approximate equivalent of one book in the *Diary of a Wimpy Kid* series, which children typically read within a week. Second, children like to read series of short books (such as the *Three Investigators* series). "Classic" children's books such as *Pippi Longstocking* or *The Neverending Story* are underrepresented in their self-directed reading. Third, children's books vary substantially with regard to content and genre ("horse books," "vampire books," etc.) as well as length and complexity (from short, easy books such as the *Beast Quest* series to elaborated text forms such as poems). Thus, huge differences in children's actual reading experience can be expected.

Box 1.

and adults and comparing German with other European languages. Further analyses will not only focus on theoretical questions, such as lexical development during childhood, but will also address more applied issues, such as how to assign text difficulty levels to books.

Establishing a Corpus

childLex provides separate norms for children aged 6 to 8 (beginning readers, grade 1 to grade 2), 9 to 10 (intermediate readers, grade 3 to grade 4), and 11 to 12 years (experienced readers, grade 5 to grade 6). The most recent version of *childLex* (0.08 January 2014) comprises 500 books that vary widely in terms of length and content (see Box 1). For example, a typical book for beginning readers comprises approximately 5,000 words, a book for intermediate readers 15,000 words, and a book for experienced readers 50,000 words. In order to maximize the number of words in each age group, we oversampled books for beginning and intermediate readers.

Books were scanned manually and converted into text using optical character recognition software. In addition, the corpus was processed and annotated using several algorithms: First, the text was divided into distinct words and sentences (tokenization). Next, the base form of each word was determined (lemmatization). Finally, words were assigned a syntactic category (noun, etc.).

childLex comprises approximately 11 million words (tokens). These are distributed over 170,000 different types (distinct word forms) and 110,000 lemmas (base forms). *childLex* distinguishes between variables from two levels of analysis: (1) lexical variables (e.g., frequency, length, and neighborhood size) and (2) sublexical variables (e.g., letter and syllable frequencies).

Differences Between Children and Adults

One of the most important questions is how the language of children's books differs from that of adult texts. *childLex* was deliberately designed to be comparable to the *DWDS* corpus, which comprises 120 million words (distributed over 1.8 million types and 1.3 million lemmas) and is the largest print corpus for adults in German.

Figure 1. childLex comprises 500 children's books.

Overall, *childLex* and the *DWDS* corpus share about 77,000 lemmas. This corresponds to 70 % of *childLex*, but only 6 % of *DWDS*. Thus, most words found in children's books are also found in texts for adults, but not vice versa. Words used only in children's books include verbs such as "pupsen" or "hicksen" (children's words meaning "to fart" and "to hiccup," respectively), while verbs such as "vereidigen" (to swear in) or "charakterisieren" (to characterize) are only used in texts for adults.

The distribution of different syntactic categories (noun, verb, adjective, etc.) provides further insights into the differences between writing for children and adults (Figure 2a). Both corpora show the typical distribution across syntactic categories; there are only few function words, most words are nouns, etc. However, there are also differences between the two corpora. For example, verbs are overrepresented and nouns are underrepresented in children's books. This is a typical indicator of spoken rather than written language and indicates that the language of the children's books represents a mixture of written and spoken language.

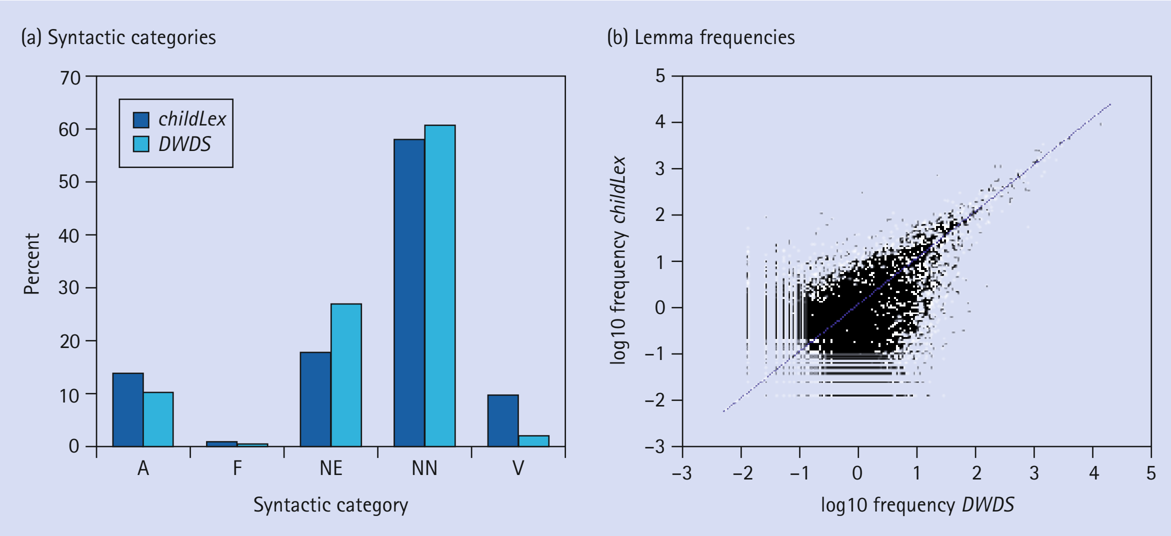

Figure 2. (a) Distribution of syntactic categories in *childLex* and *DWDS* (A = adjective, F = function word, NE = proper noun, NN = noun, V = verb); (b) correspondence of lemma frequencies in the two corpora.

Finally, we investigated whether the words featured in both *childLex* and *DWDS* are used with similar frequencies. Figure 2b shows the correspondence between the frequency measures of the two corpora. As can be seen, there are substantial discrepancies and the overall correlation is rather modest, at $r = .63$. Moreover, the strength of the association clearly depends on the overall level of frequency: For high-frequency words (e.g., "time"), children's and adults' frequency measures are well aligned with $r = .78$; for very low-frequency words (e.g., "jerkin"), this value declines to $r = .19$. Most of the differences between children's and adults' vocabularies are related to the use of specific words that are very infrequent in one corpus and modestly frequent in the other (see Box 2).

Comparing German With Other European Languages

Cross-linguistic comparisons—that is, studies that contrast reading development in different languages—constitute an emerging approach in developmental reading research. As languages differ substantially in their linguistic properties, it is unclear whether lexical norms are comparable across languages and how materials can be matched.

For example, German is a morphologically rich language. Relative to English, its inflectional system is quite sophisticated. For example, a regular verb such as "lachen" ("to laugh") has 13 different inflectional forms depending on the person, tense, and mode ("ich lache," "du lachst," "er lacht," etc.). In English, by contrast, there are only 4 distinct word forms ("laugh," "laughs," "laughed," and "laughing"). The same holds for nouns and adjectives, which are inflected according to number and case in German (resulting in 5 to 8 inflectional forms for nouns and 17 to 24 for adjectives).

Indeed, we have shown that lexical and morphological diversity is much higher in children's print language in German than in English, French, or Spanish. Figure 4a plots the number of types against the number of tokens in samples of 50,000 to 5 million words in four different child corpora. It is evident that the type/token ratio differs substantially between languages. English is the least diverse language and saturates very early: Once they have read approximately 1 million words, children are unlikely to encounter many new words. The type/token curve in German, by contrast, is rather steep: German children have to process a larger

Are "Child" and "Adult" Words Processed Differently by Children and Adults?

Do the differences in children's and adults' linguistic input affect their behavior in visual word recognition tasks? To investigate this issue, we chose 20 "child" words (that are frequent in *childLex* but infrequent in the *DWDS* corpus; e. g., "pirate," "fairy," etc.) and 20 "adult" words (that are frequent in the *DWDS* corpus, but not in *childLex*, e. g., "tax," "culture," etc.). Four age groups (children, adolescents, younger adults, older adults) with 50 participants each performed a lexical decision task involving these words. Their response accuracies are shown in Figure 3: Children showed a clear processing advantage for "child" words, adolescents performed similarly on both types of words, and adults showed a processing advantage for "adult" words. Importantly, the adults' processing advantage was driven not by decreasing performance on "child" words, but by increased accuracy on "adult" words.

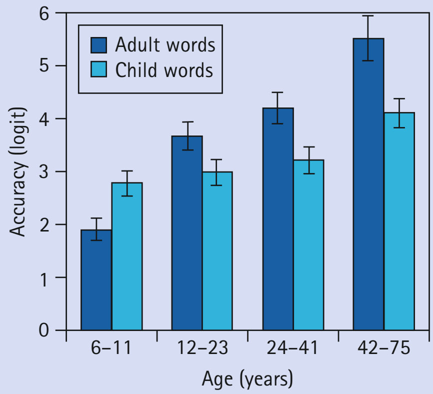

Figure 3. Response accuracy for "child" and "adult" words in different age groups.

Box 2.

number of different word forms when reading new materials and constantly encounter new words that have to be decoded. French and Spanish lie in between these two extremes. As Figure 4b shows, the same pattern can be observed for adults, but is less pronounced. For this reason, it is difficult to compare the lexical norms of German directly with those of other European languages. As words have more inflectional variations in German, each word form is used less often, is longer, and has more potential neighbors. This makes the analysis of a German linguistic corpus a particularly challenging task because it is necessary to derive frequency counts for the base forms of the words.

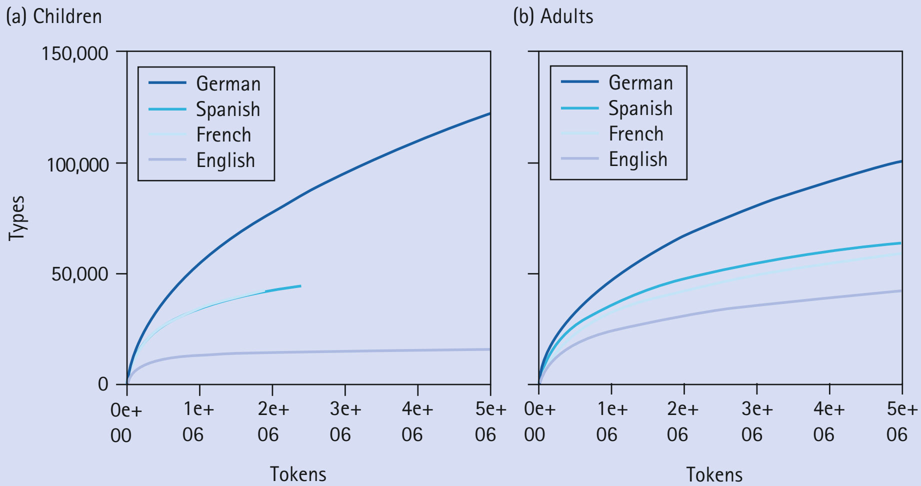

Figure 4. Type/token ratio in different (a) child and (b) adult corpora.

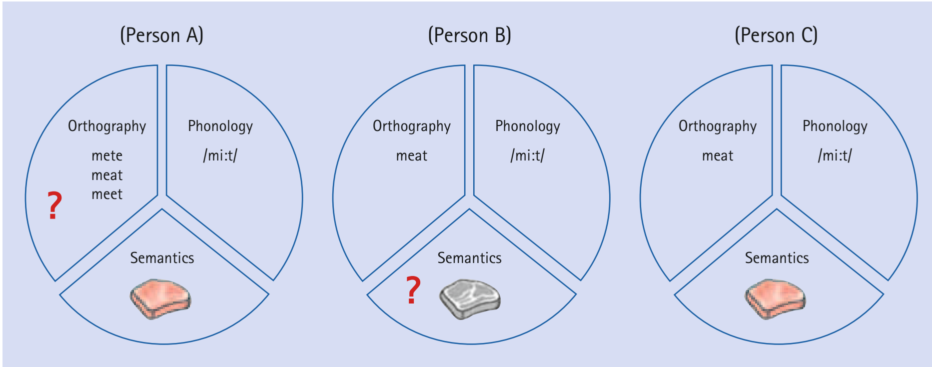

Figure 5. Lexical entries for the word "meat" for three different people.

InLex: The Individual Lexicon in Reading Acquisition

How many words has a child actually read? And how many are stored in his or her mental lexicon? What do these lexical representations contain and how are they connected? Based on the *childLex* corpus, the *InLex* project will address these issues and their impact on children's word recognition. The size and structure of the mental lexicon varies between individuals. However, it is difficult to obtain reliable estimates of a single person's vocabulary. This is unfortunate because both the quantity of entries in the lexicon and their quality (i. e., their composition and connections) are important factors in reading acquisition.

A person's mental lexicon consists of lexical representations of every word that person knows. According to the Lexical Quality Hypothesis, each representation contains information about three different aspects of a word: phonological knowledge about its pronunciation, orthographic knowledge about its spelling, and semantic knowledge about its meaning. The amount and specificity of the knowledge within these three areas varies between individuals. Figure 5 shows the lexical entry for the word "meat" for three different people. For person A, the phonological and semantic knowledge is fully specified: He or she knows how to pronounce the word (/mi:t/) and understands its meaning (e. g., "something to eat, flesh of an animal …"). The orthographic domain is underspecified, as indicated by different spellings of the word ("meet," "mete"). That is, person A is not sure how the word "meat" is spelled correctly. Person B, in contrast, has fully specified phonological and orthographic knowledge of the word "meat," but his or her semantic knowledge of the word is incomplete; that is, person B is not aware of the correct meaning of the word. This may cause problems in understanding the word when hearing or reading it. For person C, the entry is fully defined in all three areas; this person has a clear idea of the phonology, orthography, and semantics of "meat."

During language development, children build up word representations, initially consisting of mostly phonological and semantic information. As they learn to read and write at school, they add orthographic knowledge as well. But how do interindividual differences in lexical quality affect word recognition? The first aim of the *InLex* project is to measure children's phonological, orthographic, and semantic knowledge of a specific set of words and to assess their performance in different word recognition tasks. This will allow us to investigate the impact of lexical quantity and quality on word recognition performance.

Another question is how these interindividual differences in lexical quality can be explained. Several internal and external factors may impact the individual lexicon. One is children's print exposure, that is, the time they spend reading outside school. Previous studies

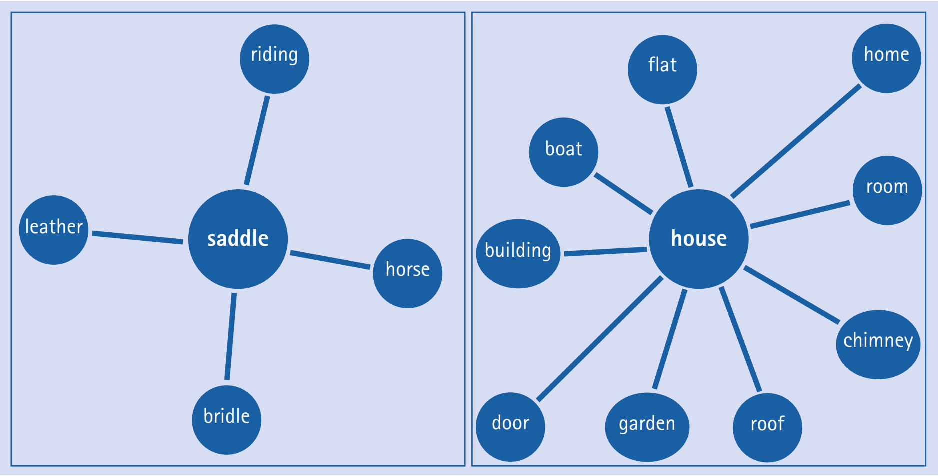

Figure 6. Lexical networks for "saddle" (low diversity) and "house" (high diversity).

have shown that the amount of reading influences reading ability in children and adults. These effects are presumably mediated by print-related differences in the quantity and quality of lexical entries. Apart from spoken language, reading is an important source for children to learn new words and to expand their knowledge of familiar words. This is particularly true in later childhood, at which stage new words are increasingly unlikely to occur in spoken language. Another aim of this project is therefore to measure the influence of children's print exposure on their lexical quantity and quality and thereby its influence on word recognition.

Investigating children's exposure to specific words in print raises further issues: In which semantic contexts did a child read a certain word and does this affect the quality and connections of the lexical entry? Contextual diversity is a linguistic variable that has been proposed as an important factor for lexicon development. It has been hypothesized that words encountered in more contexts and in more diverse contexts exhibit higher connectivity, especially in the semantic domain (Figure 6).

A word with low contextual diversity such as "saddle" is associated with only a small set of other words; its occurrence is generally limited to contexts involving horses and riding. A word with high contextual diversity such as "house," in contrast, has more links to other words as it occurs in print in many different contexts. Higher connectivity is thought to be associated with faster and more robust lexical retrieval. This prediction will be tested empirically in the *InLex* project using association tasks and contextual diversity measures derived from *childLex.*

In summary, in a series of studies, the *InLex* project will investigate the interrelationships between the quality and quantity of the individual lexicon and its impact on word recognition performance. Furthermore, it will explore the impact of children's print exposure and contextual diversity on the size and structure of the lexicon. Findings will inform theories of reading acquisition by shedding light on the relationship between reading and the mental lexicon and thus help to explain interindividual differences in reading. First results will be published in summer 2014.

DeveL: The Developmental Lexicon Project

The *Developmental Lexicon Project (DeveL)* was launched in spring 2013 to provide new data on how visual word recognition processes change during reading development and across the lifespan. These data will be used to extend existing computational models of visual word recognition.

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The process of word recognition, in which print is converted into linguistic information, is fundamental for reading. The impact of most word characteristics (length, frequency, etc.) on this decoding process is likely to change over time. However, none of the current models of visual word recognition explicitly includes a developmental dimension. One reason is that few studies have systematically compared the impact of linguistic variables on word processing across different age groups. For example, the *English Lexicon Project,* which was a multi-university effort to provide a database for the processing of 50,000 English words, investigated only adult readers. The aim of the *DeveL* project is to close this gap by providing first data on word recognition in German for the same words across the lifespan.

To this end, we selected 1,152 German words according to specific linguistic characteristics that are considered crucial in developmental theories of written language acquisition. In a cross-sectional study, these words were presented to participants of different age groups, including children at different stages of reading acquisition, younger adults, and older adults. In a first phase of data collection, data from 430 students (grade 2, 4, and 6) were collected in computerized single sessions. In a second phase, which is scheduled for winter 2013/14, younger (20–30 years) and older adults (65–75 years) will be assessed. Word recognition performance was measured using lexical decision and naming paradigms, which are commonly used in psycholinguistic research to assess lexical processing. To further investigate the impact of different reader variables on processing, we implemented measures of reading speed, vocabulary knowledge, and nonverbal intelligence. The study's central questions are (1) which linguistic features affect German word recognition, (2) how their influence changes over time, and (3) whether these developmental patterns show interindividual differences.

To illustrate the aims of the project, in the following we focus on the impact of word length (number of letters), which is especially prone to developmental changes.

According to the Dual-Route Model (see Box 3), length effects vary depending on how much the sublexical route, which operates serially, is involved in processing. The amount of sublexical processing, in turn, depends on several factors.

First, the impact of word length can be expected to vary with the transparency of a

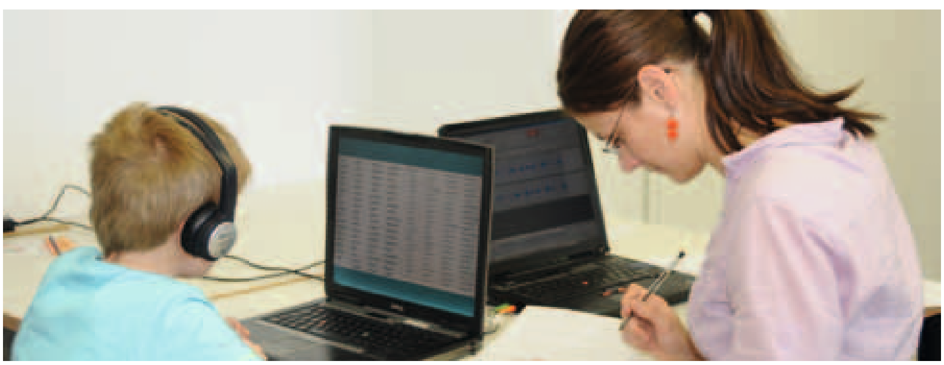


Figure 7. Reading speed and accuracy improve considerably across the lifespan.

The Dual-Route Model of Visual Word Recognition

A widely accepted computational model of visual word recognition is the Dual-Route Model. It postulates two ways by which print can be converted into meaning (see Figure 8). First, words can be decoded via a sublexical route using grapheme–phoneme rules that are applied serially from left to right, letter by letter. Second, words can be processed via a lexical route. Here, the meaning and pronunciation of a word as a whole are retrieved from the mental lexicon. This process is assumed to happen quickly and in parallel.

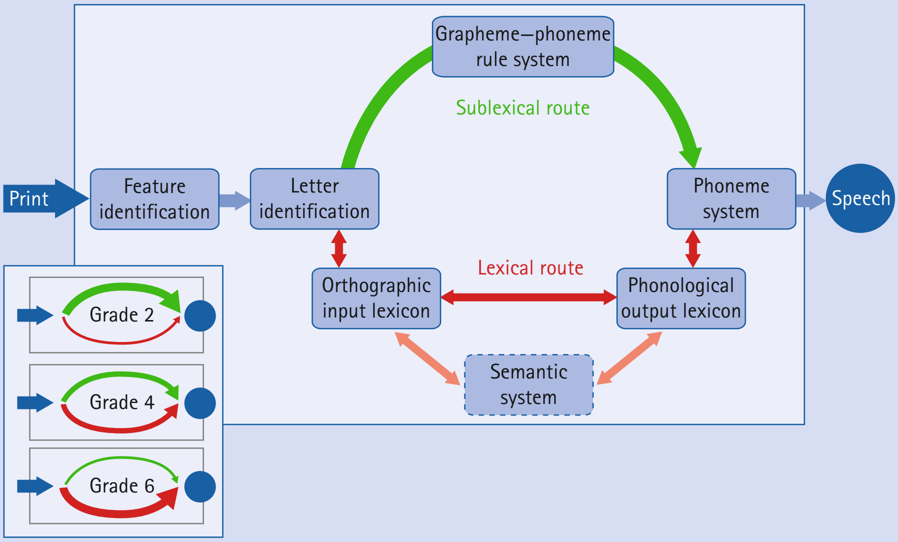


Figure 8. The Dual-Route Model of visual word recognition, extended to include a developmental trajectory for the transition from sublexical to lexical processing (adapted from Coltheart et al., 2001).

Box 3.

language. Orthographically transparent languages, such as German, are characterized by relatively consistent mappings between single letters and sounds. In contrast, in orthographically intransparent languages, such as English, the same letter usually has multiple pronunciations (see Figure 9).

Grapheme	Phoneme	
a	German	English
Park	[paʁk]	[pa:(ɹ)k]
Ball	[bal]	[bɔ:l]
Band	[bant]	[bænd]

Figure 9. The correspondence between letters and sounds in orthographically transparent (German) and intransparent (English) languages.

Because grapheme–phoneme conversion is more reliable in transparent orthographies, German words are more likely to be processed sublexically, whereas English words typically require processing via the lexical route. As a consequence, results of studies on English cannot be directly compared with those of studies on German, and it can be assumed that length effects are generally stronger in German. Second, the impact of word length can be expected to vary as a function of lexicality (word vs. nonword). By definition, nonwords (such as "hurk") have no entry in the mental lexicon and thus require serial processing via the sublexical route. Words (especially high-frequency words), in contrast, are likely to be processed lexically and in parallel. As a consequence, length effects should be more pronounced for nonwords than for words.

Figure 10. A 12-year-old performing the naming task.

Third, and most importantly, the effect of word length can be expected to vary with lexical development. For beginning readers, all words are functionally nonwords and thus have to be decoded using the sublexical route. Once children become acquainted with a specific word, however, it can be processed via the fast-track lexical route as its representation in memory becomes increasingly elaborated and accessible. Thus, fading susceptibility to word length is evidence for a gradual shift from sublexical to lexical processing throughout reading development (see Figure 8).
Taken together, the Dual-Route Model predicts a rather complex pattern of results: In a transparent orthography, such as German, length is generally expected to be a strong predictor of reading time. However, length effects should be more pronounced for nonwords than for words. Furthermore, length effects for words should decrease slowly during reading development as words are increasingly processed via the lexical route. In contrast, length effects for nonwords should not benefit from increased reading experience.
In order to demonstrate how such complex predictions can be investigated, Figure 11 presents some preliminary data from the *DevelL* project. The plots show lexical decision latencies as a function of stimulus length separately for words and nonwords and for children in grade 2 (beginning readers), grade 4 (intermediate readers), and grade 6 (experienced readers). Overall, the pattern is in line with the predictions made by the Dual-Route Model: In German elementary school children, word length generally had a strong and linear impact on word recognition latency. As expected, nonwords needed more time to be processed and revealed a stronger length effect than words. Ultimately, there was a clear developmental pattern: In grade 2, children showed similar length effects for words and nonwords. For words, length effects declined gradually across grades (by 41 % from grade 2 to grade 4 and by an additional 18 % from grade 4 to grade 6). Length effects for nonwords, in contrast, decreased only minimally during reading development (28 % overall).

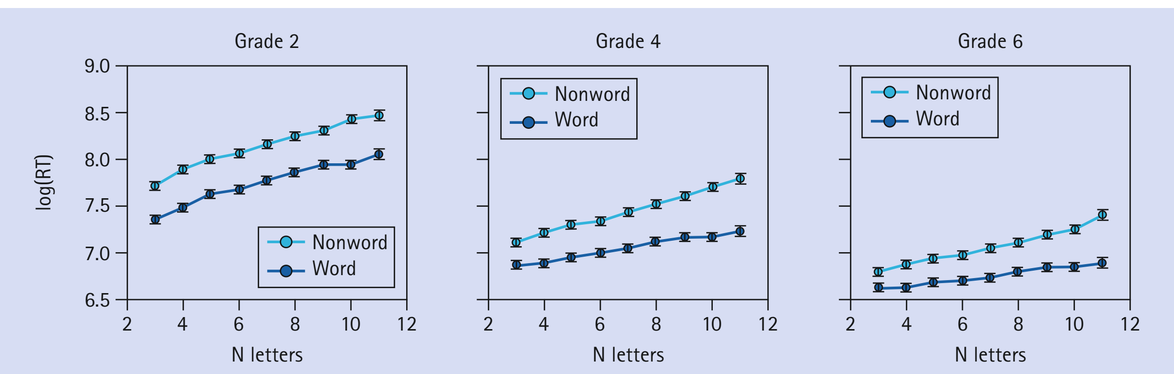


Figure 11. Length effects for words and nonwords at different grade levels.

Similar analyses will be carried out for the effects of other linguistic variables (e. g., word frequency, orthographic neighbors). We will also investigate whether the effects observed generalize to paradigms such as naming. As we assessed large samples of children in each age group, we are able to dissociate the impact of age from the impact of lexical development. Findings such as these not only provide further knowledge on reading development in German but are needed to expand existing models of visual word recognition in general. At present, for example, it is unclear whether and how computational models such as the Dual-Route Model can accommodate developmental changes in marker effects. One particular question is whether various effects observed in different age groups can be explained on the basis of a shared mental architecture—for example, by changing parameter settings. Alternatively, structural changes may be necessary in order to fit the developmental patterns observed. To foster the development of new computational models, we will make data from the *DeveL* project available to the scientific community through an online platform. Future research can then be conducted by means of virtual experiments, enabling international scientists to perform investigations directed at refining current models. In the long term, such explanatory approaches are needed to address the problems of beginning readers more specifically and to further improve the design of reading training programs.

Decomposing the Lexical Decision Task

Most tasks used to investigate visual word recognition, such as the lexical decision task, are cognitively complex. Apart from lexical processing, they afford attention, perceptual processing, and some form of motor response. In a separate set of studies, we investigated which processing components are involved in these tasks and whether they develop differentially across the lifespan.

In one of the studies, for example, children and adults performed a lexical decision task and a naming task using the same set of words. Their task performance was decomposed using the Diffusion Model. In this model, separate parameters represent different cognitive processes such as speed of information uptake *(v)*, response caution *(a)*, and time for response execution (T_{er}). The results of fitting this model to children's and adults' lexical decision data revealed that children had deficits in all processing components (Figure 12a). However, in the naming task (Figure 12b), children showed deficits only in lexical processing, but not in any of the nonlexical processing components. This indicates that different tasks afford a different mixture of cognitive processes, which develop differentially over time. The same deficit observed in overt task behavior might therefore be driven by different cognitive processes in different age groups.

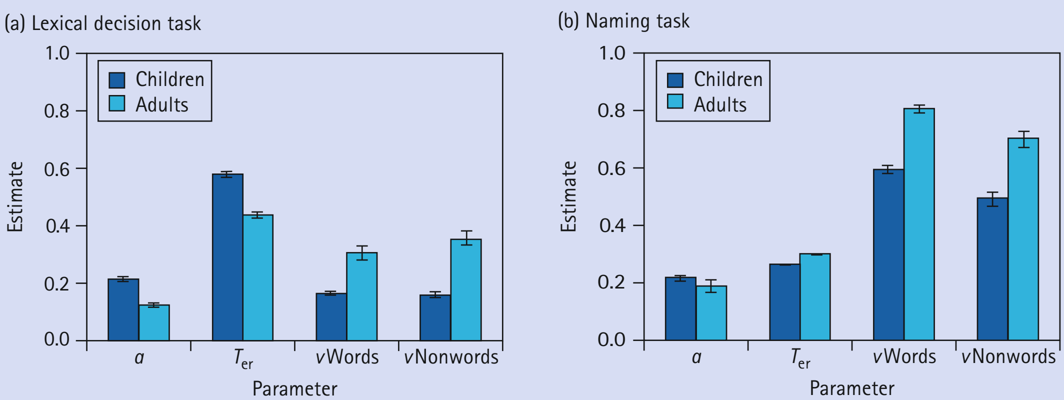
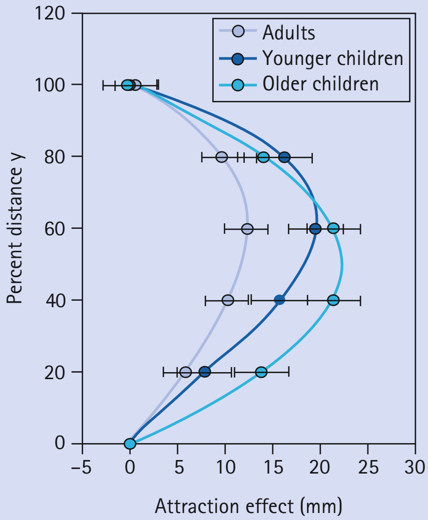


Figure 12. Diffusion model parameters for children and adults in (a) the lexical decision task and (b) the naming task.

Box 4 (continued on next page).



In another study, we investigated children's and adults' response behavior more closely using a motion capture system. Children and adults performed a simple pointing task and a lexical decision task by pressing a response button 30 cm in front of them while their hand movements were recorded. Compared with their performance in the pointing task, children's movements in the lexical decision task were slower and more hesitant. In addition, they showed substantial attraction effects, that is their movements to the correct response were "attracted" by the other response option (see Figure 13). This indicates that lexical decision and response movement processes might be more intertwined in children than in adults.

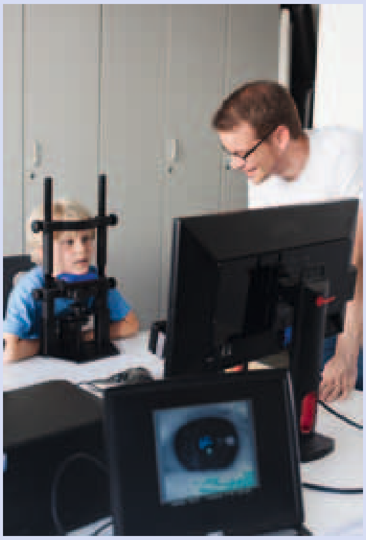
Figure 13. Attraction effects in lexical decision movements in younger children, older children, and adults (adapted from Schroeder & Verrel, in press).

Box 4 (continued).

DevTrack: The Developmental Eye-Tracking Study

Reading is more than decoding single words. With the *Developmental Eye-Tracking Study (DevTrack),* which started in fall 2012, we aim to add depth to our understanding of children's natural reading processes by tracking their eye movements as they read continuous texts.

Eye movements have long been used to track cognitive processes during complex tasks such as visual search, scene perception, and reading (Box 5). The eye-tracking research of the early 20th century established much of what we know today about typical eye movements;



How Do We Know Where Someone Is Looking?
Modern eye-tracking methods use an infrared light source to shine light off of the reader's eye. A small camera is used to pick up two areas of the eye: the center of the pupil (in blue) and a reflection off the surface of the eye (the light dot immediately below the pupil). These two points are used to calculate where a participant is looking on the screen. A chin rest helps to steady the participant's head while reading. The high spatial (1 letter) and temporal (1 ms) resolution of such techniques is critical for this kind of research.

Figure 14. A typical setup for an eye-tracking study.

Box 5.

What Do Readers' Eye Movements Look Like?
The eye movements of beginning readers differ markedly from those of skilled adult readers. Children typically show shorter saccade lengths and refixate the same word multiple times before moving on to the next word. In contrast to adults' reading, words are not skipped and there are more saccades back to earlier parts of a text (regressions), which suggest rereading of passages that were not completely understood. Figure 15 illustrates the differences in the typical eye movements of beginning and skilled adult readers.

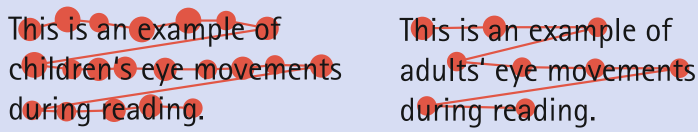


Figure 15. Eye movements of a beginning reader (left) and a skilled adult reader (right).

Box 6.

for instance, that the eyes move in a series of jumps (saccades) and pauses (fixations) and that information is processed only during fixation periods. Reading is a particularly complex task in which words must be decoded, their meaning extracted, and inferences generated to connect words, phrases, and sentences. During reading, adult eye movements generally consist of saccades of 7 to 9 characters and fixations of 200 to 250 milliseconds. The characteristics of eye movements are also subject to developmental changes, however, and the efficiency of eye movements during reading has been shown to be strongly related to the skill of the reader. Skilled adult readers generally make long saccades, fixate words for short durations, and skip over short, predictable words. For children, however, we find a different pattern (Box 6).

We know that the eye movements of skilled adult readers and beginning readers differ substantially. We also know that individuals differ in their reading skill. Longitudinal designs, as employed in *DevTrack*, are therefore vital to capture both individual differences in the reading skill of beginning readers

Foveal Versus Parafoveal Processing
The center of a reader's field of vision, the foveal region corresponding to the central 2° of the visual field, is where visual acuity is highest. The acuity of the fovea is essential for the processing of letter features. However, readers can also make use of information in the parafovea, which extends out to about 5° to either side of the point of fixation. Little can be derived from the outermost peripheral region. In writing systems that are read from left to right, the parafoveal and peripheral visual fields develop a skew to the right in the direction of reading. Conversely, in scripts such as Hebrew and Arabic they develop a skew to the left.

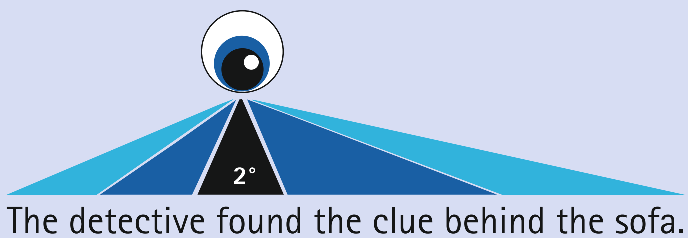


Figure 16. Foveal, parafoveal, and peripheral visual fields during reading.

Box 7.

and the development of reading skill over time. *DevTrack* will be one of the very few longitudinal studies that have attempted to tease apart the individual and developmental aspects of reading acquisition at the German elementary school level.

Two mechanisms are known to drive the efficiency and development of eye movements. Foveal reading processes are involved when a word is focused directly; parafoveal processes are relevant when information about letters and words to the right of the fovea is extracted (see Box 7). *DevTrack* will focus on the development of foveal and parafoveal processes in reading using eye-tracking paradigms specifically developed to tap into these processes.

Foveal Processes in Reading

DevTrack will investigate the development of children's foveal processes by analyzing their reading behavior as they read age-appropriate short stories and sentences that have been developed to create a natural reading setting. Materials will contain embedded target words that are systematically manipulated on characteristics that are known to reliably affect word recognition time: word length and word frequency (see Figure 18). Preliminary study results suggest that effects of frequency and length can be found in the fixation duration measures of elementary school children at the end of grade 3. The main study will examine how these two variables and their interaction affect children's eye movements during read-

Comparing Eye Movements Across Orthographies

In a separate study, conducted in cooperation with the University of Southampton, UK, and the University of Turku, Finland, we investigate whether children's eye movements are influenced by the transparency of the orthography in which they are reading. To this end, we have translated 48 sentences from German (which has an intermediate level of transparency) into English (which is very intransparent) and Finnish (which is very transparent).

English	The trip	to the zoo	was	funny	because	the **goat**	had	run into	the teacher.
German	Der Ausflug	in den Zoo	war	lustig,	denn	die **Ziege**	hatte	den Lehrer	umgerannt.
Finnish	Retki	eläintarhaan	oli	hauska	koska	**vuohi**	oli	juossut	opettajaa päin.

In each sentence, there was one target word that was long or short and either frequent or infrequent. We expected to find that frequent words can be processed in parallel, whereas infrequent words have to be decoded sequentially. However, this pattern was expected to be moderated by reading skill. Indeed, this is the pattern we found in our German data (see Figure 17).

We are currently collecting data in the United Kingdom and Finland to test whether this interaction varies with the transparency of the language that children are learning: We expect the observed pattern to be more pronounced for English children, but less pronounced for Finnish children, as the orthographic characteristics of their languages foster more lexical versus sublexical processing, respectively.

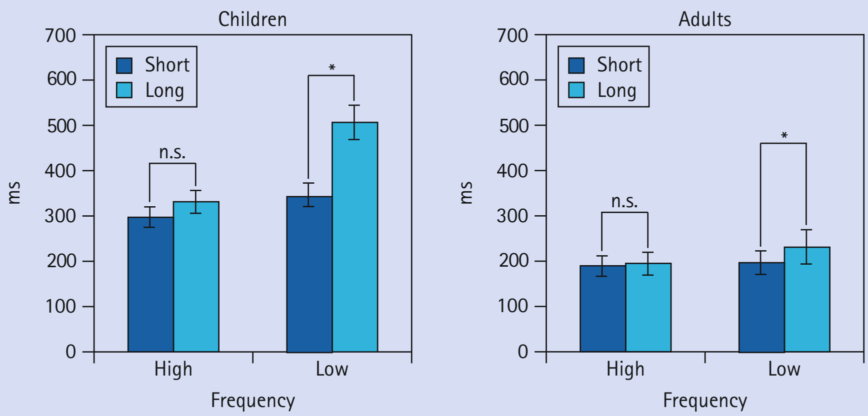


Figure 17. Mean gaze duration for long versus short high- versus low-frequency words for children and adults reading German.

Box 8.

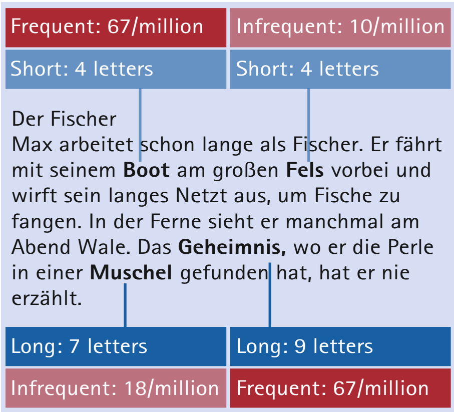


Figure 18. Example story: The fisherman.

ing and how their influence changes over the elementary school years.
In addition, *DevTrack* will investigate children's higher level processing of connected discourse, which is important in many educational settings. For example, we will analyze how inferences are generated during reading and how relationships between elements of the text are processed by the reader. In Figure 18, for instance, the pronoun "er" in the second sentence has to be connected to its antecedent "Max" in the first sentence, who is also the "Fischer" referred to in the title. Children who do not make these connections will have difficulty understanding the story.

In addition to assessing children's comprehension of the story, we will track their eye movements to investigate the underlying online processes.

Parafoveal Processes in Reading
In a different line of research, the *DevTrack* project will investigate how children's processing of information in the parafovea changes during reading development. Studies have found that adults extract different types of linguistic information (orthographical, phonological, morphological, semantic) from the parafovea. This information can then be integrated when the word is fixated foveally, facilitating the word recognition process. This facilitation has been shown to manifest itself in shorter fixation durations. How much and what kinds of information can be processed parafoveally by beginning readers remains unclear, however. This question can be addressed using the boundary paradigm illustrated in Box 9, which is a technique specifically developed to assess parafoveal processes.
In *DevTrack*, we will concentrate on two marker effects that are particularly disposed to show developmental effects. According to the Dual-Route Model (see Box 3 above), words are processed both via a sublexical and a lexical route. During sublexical processing, grapheme—phoneme correspondence rules are

Investigating Parafoveal Processing: The Boundary Paradigm
In the boundary paradigm, sentences are presented as a single line of text, each with an embedded target word. These targets are presented as manipulated previews until the reader's eyes move to bring them into focus. An invisible boundary directly before the target word triggers when the first saccade crosses it. At this point, the preview is exchanged with the target word (see Figure 19). As the display change happens during the saccade onto the target word, the reader never actually sees the preview other than in his or her parafovea. By manipulating the preview, we can assess whether fixation durations on the target word differ, depending on whether the target word or a similar sounding nonword was present in the parafovea. In the example above, the preview "clew" is a phonologically similar nonword (pseudohomophone) to the target word "clue."

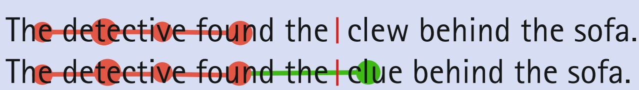


Figure 19. Preview and display change to target word after the reader's gaze crosses the invisible boundary in the boundary paradigm.

Box 9.

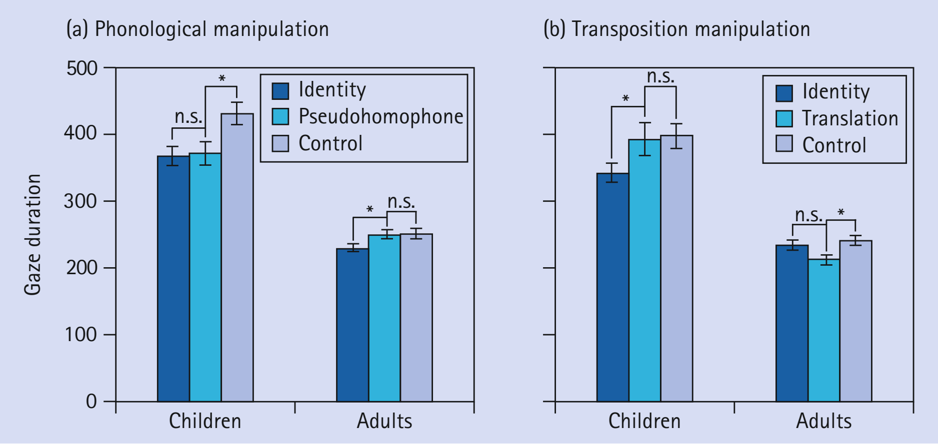


Figure 20. Findings on the parafoveal preview benefit.

used to convert print into sound. This process may be facilitated by phonological information extracted from the parafovea, which can be investigated using pseudohomophone previews. Here, either a nonword that is pronounced similarly to the target word (e.g., "cl**ew**" for the target word "cl**ue**") or an orthographically matched control word (e.g., "cl**on**") is shown in the parafovea. If the target word is processed faster in the pseudohomophone condition than in the control condition, this indicates that phonological information has been accessed. By a similar logic, transposition preview effects can be used to quantify the amount of lexical processing in the parafovea. As lexical processing becomes more parallel during reading development, the encoding of the exact position of a letter becomes less important, and words with transposed letters (e.g., "b**na**d") are frequently mistaken for the real target word (e.g., "b**an**d"). Again, by comparing the parafoveal preview benefit of transposed letter primes with orthographically matched control words (e.g., "b**or**d"), we can assess the amount of lexical preprocessing in the parafovea. As an extensive amount of research suggests that children are initially more reliant on sublexical processing, we might expect greater phonological preview effects and weaker transposition benefit effects for children than for skilled adult readers.

To test these assumptions, we conducted a pilot experiment in which children and adults read single sentences with embedded target words in three different preview conditions (identity vs. pseudohomophone/transposition vs. control). First results indicate that children, but not adults, showed phonological preview benefit effects (Figure 20a). This suggests that children rely more on phonological decoding processes during parafoveal processing than adults. By contrast, adults, but not children, showed transposition preview benefit effects (Figure 20b). This indicates that children do rely more on the exact position of letters within a word than adults. Taken together, both findings are consistent with a developmental trend from sublexical to lexical processing during parafoveal preview.

In the *DevTrack* project, we will investigate how foveal and parafoveal processes develop by following 100 children from grade 2 to grade 4. This will allow us to describe developmental changes in eye-movement behavior over the first years of elementary school and their relation to other skills such as lexical access, phonological ability, and oculormotor efficiency. Combining controlled experimental manipulations and natural reading of age-appropriate texts, *DevTrack* will investigate the interactions between foveal and parafoveal processes, which are as yet largely unexplored in children. The first round of data collection will be conducted in spring 2014; first results from the main study will be published in summer 2014.

Investigating Reading Longitudinally: OPeRA and PLAiT

What are the developmental mechanisms underlying reading acquisition and which precursor abilities are needed? Two interconnected longitudinal studies initiated in 2013 will investigate the preconditions and consequences of children's initial reading ability.

The *OPeRA* project *(Orthographic Processing in Reading Acquisition)* focuses on children's use of different orthographic grain sizes (see Box 10) during reading development in school from grade 1 to grade 4. The complementary *PLAiT* project *(Prerequisite Language Abilities in the Transitional Phase)* concentrates on the transition from kindergarten to school and investigates which precursor abilities are linked to children's later reading acquisition. By using a similar theoretical framework and identical outcome measures, *OPeRA* and *PLAiT* will be able to provide a unified picture of the processes needed in the initial steps of reading acquisition and their consequences for children's later development in school (see Figure 21).

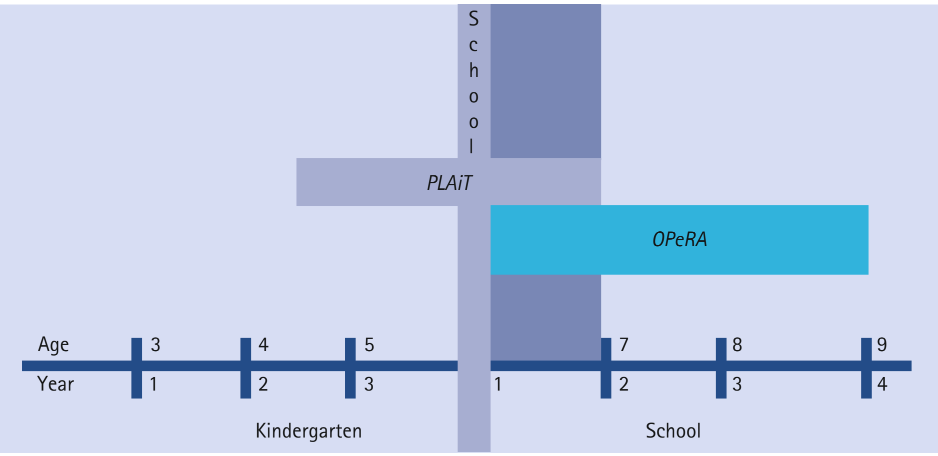


Figure 21. Time frame and overlap of the *PLAiT* and *OPeRA* projects.

Fine- and Coarse-Grained Orthographic Processing

After initial perception of the visual input, readers can process orthographic information by using location-specific coding of letters, namely fine-grained processing. This mode makes information about the neighbors of letters and their sequence necessary. It is thus especially useful for recognizing co-occurring letter combinations. However, it is more demanding with regard to spatial attention. Alternatively, letters can be processed in a coarse-grained mode, independent of specific letter position information. Due to its holistic nature, this processing mode is assumed to be faster in accessing whole word representations.

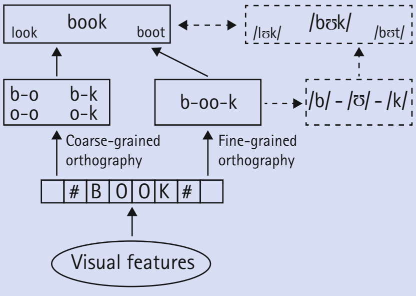


Figure 22. A model of reading incorporating two different modes of orthographic coding: coarse-grained and fine-grained.

Box 10.

OPeRA: Orthographic Processing in Reading Acquisition

Modern theoretical models of reading assume a distinction in the mode of coding relevant orthographic features, namely, between fine- and coarse-grained orthographic processing (Box 10).

Fine-grained orthographic processing operates using orthographic units of different sizes, referred to as grain sizes (Box 11). Which grain sizes readers rely on is believed to vary across languages as well as individuals. In general, it is thought that beginning readers start with smaller grain sizes such as single phonemes and, by means of chunking, proceed to use increasingly bigger units such as syllables or morphemes.

Language-specific characteristics impose special constraints on the units of analysis used in reading. One such specific characteristic of German is its morphological richness. Many German words are composed by systematically concatenating morphemes (e.g., "blau-es," "Fahr-er," "Krank-heit," "glück-lich," "Tee-tasse"). Thus, using morphemes as a grain size may be especially useful for German readers. From a developmental perspective, it is theorized that, after an initial stage of phonology-based, sequential decoding, readers adopt a more parallel, fine-grained decoding strategy.

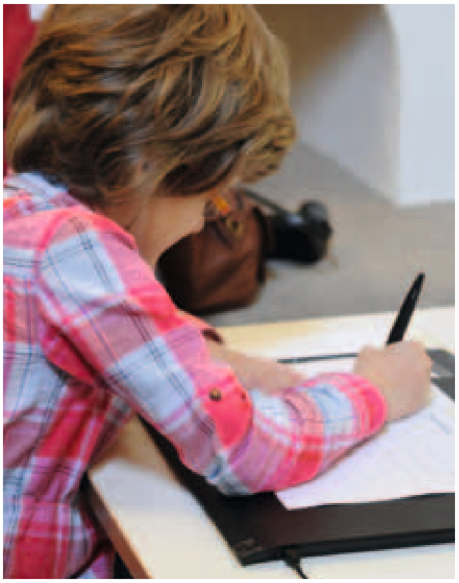


Figure 24. Children use different grain sizes in reading and writing.

This is attained by chunking letters into increasingly larger units such as multiletter graphemes (e.g., "ch") or morphemes (e.g., plural "-s," suffix "-er"). Fine-grained processing, using morphological units as a grain size, allows children with a small lexicon to access complex words more efficiently. The coarse-grained lexical route makes fewer demands

Orthographic Grain Sizes in Reading

Grain sizes are linguistic units with correspondences in orthography. Various grain sizes are hypothesized to be used in reading, depending on the individual and the language. Figure 23 depicts the word "BOOKS" divided into units of different sizes, namely, morphemes, syllables, onset and rime, nucleus and coda, and phonemes. Morphemes are the smallest units of meaning. In this case, "BOOK" refers to the object, while the "S" indicates the plural. Syllables divide words into sequences of sounds. The onset–rime distinction further subdivides a syllable into the consonant at the word beginning and the cluster of vowels and consonants at the end of the syllable. The rime is the element that is usually similar-sounding when rhyming (e.g., "BOOKS"–"LOOKS"). The nucleus is the vowel of a syllable which, together with the coda, makes up the rime. Phonemes are the different sounds that make up a word.

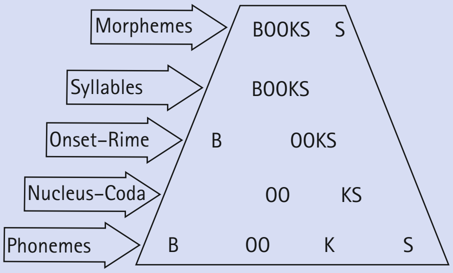


Figure 23. The word "BOOKS" divided into units of different grain sizes.

Box 11.

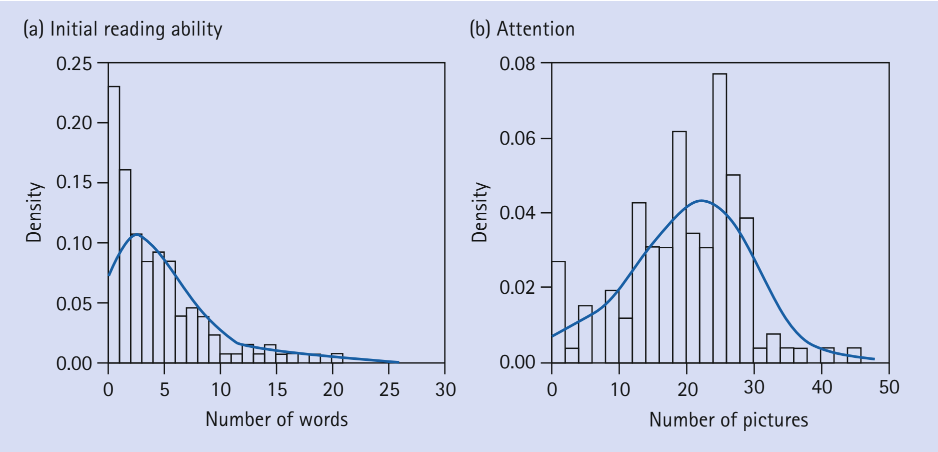


Figure 25. Interindividual differences at the beginning of grade 1.

on spatial attention and may thus benefit reading. Due to the morphological richness of the language, however, it may not be as crucial for reading in German.

The *OPeRA* project aims to track the development of orthographic processing in German and to identify the grain sizes used by children at different developmental stages. To this end, we recruited 120 grade 1 students from elementary schools in Berlin. Assessments of precursor skills such as general motoric and cognitive abilities as well as specific linguistic competencies began in October 2013. Although most children at the beginning of grade 1 were not yet able to decode simple words (Figure 25a), there were remarkable interindividual differences in children's cognitive abilities at school entrance (Figure 25b).

How will these initial differences in reading skill develop over time? Are they related to the use of different grain sizes and decoding strategies? To address these questions, we will track students' development through extensive individualized test sessions implemented at the end of each grade. Specifically, we will examine the effects of marker variables such as length and frequency. Furthermore, effects

Figure 26. Most processes involved in reading are influenced by the amount of children's reading behavior.

The Masked Priming Paradigm

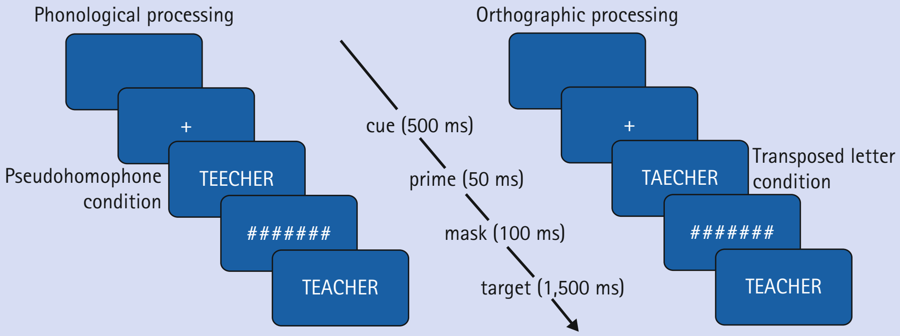


Figure 27. Schematic depiction of the sequence of a trial in the masked priming paradigm with a pseudohomophone and a transposed letter manipulation.

Masked priming is a well-established paradigm for distinguishing fine-grained, phonology-based processing from coarse-grained, holistic processing in visual word recognition. It uses manipulations that comply with either fine- or coarse-grained processing to prime a target word (Figure 27). In the pseudohomophone condition, the prime is phonologically similar to the target, but does not conform to the standard spelling. In the transposed letter condition, two letters in the prime are interchanged. Participants are required to decide whether or not the target is a word. The priming benefit relative to a control condition indicates the mode of processing.

Box 12.

of different reading strategies will be investigated to discern fine-grained phonology-based from coarse-grained holistic processing. Younger readers are expected to show effects based on fine-grained decoding, as the coarse-grained route is not yet established at this stage of development. With increased reading experience, the pattern is expected to reverse, with children showing less marker effects of phonology-based processing and more marker effects of holistic processing. These questions will be addressed using the masked priming paradigm (Box 12). The same paradigm can be applied to examine the use of other grain sizes such as morphemes. First results from this study are expected to be published in summer 2014.

Figure 28. Masked priming in the lexical decision task.

PLAiT: Prerequisite Language Abilities in the Transitional Phase

The longitudinal *PLAiT* project aims at closing the gap between language acquisition studies in early childhood and reading research at school age. *PLAiT* will investigate the cognitive development of children in the transitional phase between kindergarten and school. This will allow us to relate the development of orthographic representations to the general dynamics of language acquisition. The project will track 50 children from the 2nd year of kindergarten until the end of grade 1 of elementary school (4–7 years of age). We will closely monitor the children's linguistic abilities by testing them in individual sessions at equal time intervals of 6 months.

The main focus of *PLAiT* lies on the lexical quality of word representations at different developmental stages. The Lexical Quality Hypothesis claims that the speed of retrieval of a lexical entry, that is, the mental representation of a word, depends on the quality of various linguistic dimensions: orthography, semantics, phonology, and (although not explicitly mentioned) morphosyntax.

The hypothesis assumes that children with detailed representations of words on different linguistic dimensions are able to access words in the lexicon faster than children with underspecified or missing representations. In addition, more elaborated lexical representations are assumed to foster the acquisition of new words. Thus, children with better and interconnected representations are expected to be more successful in the acquisition of reading and writing.

The Lexical Quality Hypothesis was derived on the basis of studies of participants who were already able to read and write. The *PLAiT* project, in contrast, will focus on the development of phonological and semantic representations that are fundamental for later orthographic processes. To this end, the project will examine the development and interrelations of phonological, semantic, and morphosyntactic skills in the kindergarten years. Furthermore, it will explore their impact

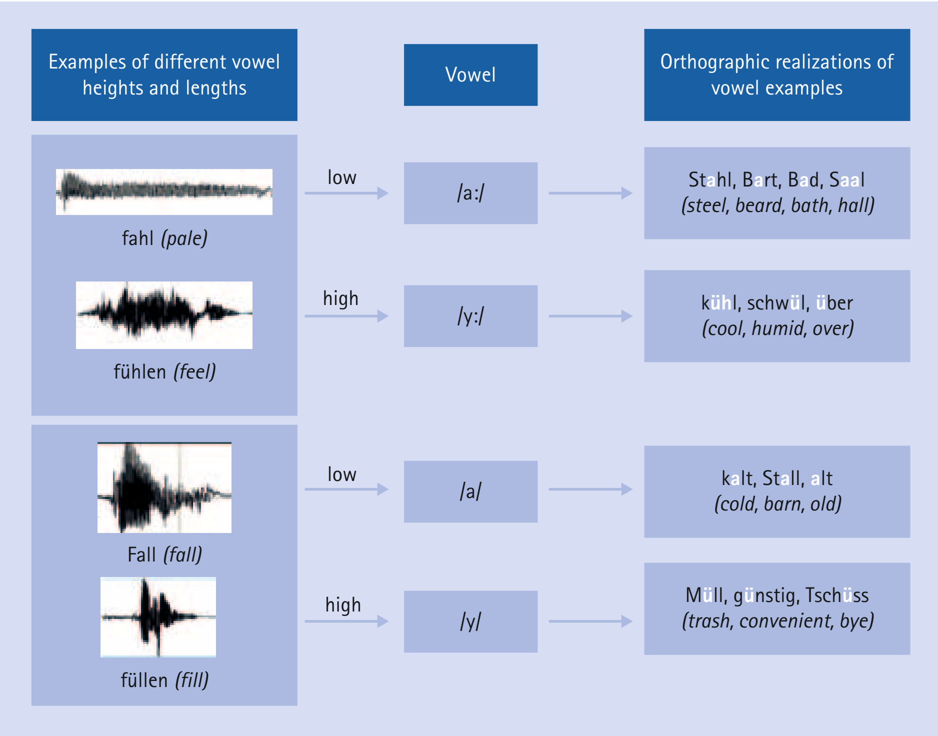


Figure 29. Examples of different vowel length realizations in German.

Figure 30. The acquisition of linguistic abilities before school is important for later reading development.

on the orthographic lexicon at school entry and investigate the differential effects of distinct precursor abilities on children's reading fluency or comprehension. By combining reaction time and accuracy measures, *PLAiT* will be able to provide a detailed picture of children's lexical retrieval.

PLAiT will also pay particular attention to the language-specific challenges of German, such as the perception of vowel lengths in phonology and irregularities in morphosyntax. To give an example from phonology, one way to measure phonological perception is to look at children's ability to identify different vowel lengths. In German, the correct perception of vowel lengths is crucial to successfully activate semantic information (Figure 29). A child who cannot differentiate between "fahl" (pale) and "Fall" (fall) will misunderstand the meaning of the word and will not be able to identify its function within a sentence (adjective vs. noun). Furthermore, words with the same vowel length can be realized using different spellings. Without the ability to distinguish between vowel lengths, children will find the decoding and writing of similar words difficult. Vowel length perception is therefore an important prerequisite skill for reading and writing acquisition. Phonetically, both words in the example ("fahl" and "Fall") contain vowels with similar spectral profiles (low frequency), which are perceptually more salient than high-frequency vowels (such as the /y/ in "füllen" and "fühlen"). Vowel length discrimination may thus be easier for low than for high vowels. At the same time, there may be substantial interindividual differences. For children with better phonological representations, it should be easier to distinguish between different vowel lengths independently of their spectral features.

Phonology, or more precisely phonological awareness, has been identified as an important predictor of reading and writing. It can be measured using various operationalizations. Vowel length discrimination or rhyming tasks, which are primarily perceptual tasks, are one possibility. Alternative options are productive tasks (e.g., nonword repetition) or transfer tasks (e.g., sound deletion tasks, which involve perception, transformation, and production of stimuli). However, it is unclear whether the nature of the task (e.g., cognitively more vs. less demanding) impacts the predictive power of these measures. Children, as investigated in the initial stages of the *PLAiT* project, are not yet proficient language producers, but proficient language perceivers. Against this background, *PLAiT* will investigate whether the type of task (perceptual, productive, transfer) impacts the predictive power of these measures at different stages of reading development.

In summary, the general aim of *PLAiT* is to identify valid predictors of reading acquisition. Additionally, the project seeks to provide information about which types of phonological tasks are best suited to identify children at risk of becoming poor readers at an early stage of development. The project thus focuses on the typical development of young children, while monitoring potential risk factors. *PLAiT* was launched in August 2013; data collection will begin in spring 2014. First results are expected in summer 2014.

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(last update: January 2014)

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