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The recognition of letters in emergent literacy in German: evidence from a longitudinal study

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Background: German children do not formally learn letter-sounds before school entry. In this study, we evaluated kindergarten children's sensitivity to the frequency of letters and visually similar symbols in child-directed texts, how it develops and whether it predicts early reading abilities.
Method: In a longitudinal study from kindergarten to primary school, children were asked to judge whether a presented alphabetic (e.g., *A*) or non-alphabetic symbol (e.g., *#*) was a letter. High and low frequency was varied for both types of symbols. Furthermore, we analysed whether later reading abilities were predicted by this letter judgement ability.
Results: Before school entry, children had difficulties in distinguishing frequent non-alphabetic symbols from letters. Furthermore, letter judgement in kindergarten predicted reading abilities in first grade.
Conclusions: Children derive some knowledge about letters from the frequency of co-occurrence of letters and symbols in texts. The ability to distinguish letters from non-alphabetic symbols predicts early reading.

Highlights

What is already known about this topic

- Young nonreaders have knowledge about written language before school entry.
- Sensitivity to letter frequency predicts early spelling abilities.
- German children have little literacy stimulation before school entry.

What this paper adds

- Before school entry, children have difficulties in distinguishing frequent non-alphabetic symbols from letters.
- After school entry, children show less sensitivity to frequency of non-alphabetic symbols.
- Letter judgement ability, 10 months before school entry, predicts early reading abilities.

Implications for theory, policy or practice

- Early knowledge about letters and symbols is influenced by statistical learning.
- Letter judgement is an early indicator of reading.
- In countries with little literacy stimulation before school entry, children's literacy development can be predicted by studying their ability to distinguish letters and symbols.

The ability to recognise that letters represent phonemes (phonographic knowledge) is essential for the early acquisition of reading and writing abilities (Ehri, 1995; Ehri, 2005; Treiman & Kessler, 2014; Ziegler & Goswami, 2005). In addition, some studies have shown that the ability to recognise letters based on visual features also influences literacy development (Treiman & Kessler, 2014). For example, young children who are sensitive to the statistical distribution of letters in child-directed texts (e.g., bigram frequency) before school entry are better spellers after school entry (Kessler, Pollo, Treiman, & Cardoso-Martins, 2013; Pollo, Kessler, & Treiman, 2009). However, the influence of early sensitivity to the statistical distribution of letters on literacy development has not been studied for reading acquisition.

Studies that focus on the development of recognising letters based on their visual features are especially interesting for young children who grow up in an environment of education in which letter-sound correspondences are not taught before school entry. For example, in Germany, children receive little literacy stimulation before school entry (Kuger, Rossbach, & Weinert, 2013). They start learning about letter-to-sound relations and the alphabet only after entering school, at the age of 6 years. Nevertheless, the ability to recognise letters based on their visual features has not been studied in German children or in any other linguistically or pedagogically comparable environment.

To this end, we developed a letter judgement task in which young German speaking children were asked to judge whether a presented alphabetic or non-alphabetic symbol (e.g., *A*, *#*) was a letter or not. Both types of symbol were varied as a function of their frequency of appearance in child-directed texts. We evaluated the longitudinal development of this letter judgement ability starting 10 months before school entry until 2 months after school entry. We continued to analyse the contribution of letter judgement abilities at the first time point on early reading abilities at the beginning of first grade.

In theories of reading development, the component that describes the ability to link phonemes to graphemes plays an important role (Ehri, 2005; Ziegler & Goswami, 2005). Psycholinguistic grain size theory (Ziegler & Goswami, 2005) claims that the ability to map phonemes onto graphemes is a precondition for proceeding to word reading. Ehri (2005) notes that the ability to read words is enabled by phonemic awareness and knowledge about the alphabetic principle. The importance of phonological awareness and letter-sound-knowledge to reading development is, furthermore, well established across languages (Anthony & Lonigan, 2004; Caravolas, Lervag, Defior, Malkova, & Hulme, 2013). However, recognition of letters and words as a function of visual features as opposed to as a function of phonemes has not been studied as extensively in regard to early reading development.

Children are surrounded by written language (e.g., picture books, text books, street signs and commercial advertisements) from birth. It was long assumed that young children treat words and letters as if they were pictures until they learn letter-sounds (*logographic stage*; Frith, 1985). However, an increasing number of studies suggest that children learn to use visual features of script to distinguish written language from pictures as early as 3 years of age (Bastien-Toniazzo, 1992; Ganapole, 1987; Gombert & Fayol, 1992; Robins & Treiman, 2009; Robins, Treiman, Rosales, Otake, 2012). For example, 3-year-old children produce far fewer iconic (picture like) drawings when they are asked to write as opposed to when they are asked to draw (Gombert & Fayol, 1992). A recent theoretical approach to writing development, the Integration of Multiple Patterns (IMP) model, takes the young children's sensitivity to visual features into account.

The IMP model (Treiman & Kessler, 2014) claims that young children use both probabilistic as well as deterministic patterns in learning about the visual form and the representative function of words and alphabetic symbols (letters). Children acquire these patterns either by using statistical information in their surroundings (e.g., Aslin & Newport, 2012; Newport & Aslin, 2004; Saffran, Newport, & Aslin, 1996) or by learning about them through statements from parents or teachers. In addition to reduced iconicity in writing (Gombert & Fayol, 1992), young children's description of written language indicates that they correctly identify script as an artificial tool (Robins et al., 2012), recognise that letters are visually less complex than other symbols (Bastien-Toniazzo, 1992; Ganapole, 1987) and know that letter strings (in most alphabetic languages) must be presented horizontally (Ganapole, 1987; Lavine, 1977; Puranik & Lonigan, 2011; Treiman, Cohen, Mulqueeny, Kessler, & Schechtman, 2007). These last two findings show that children are aware that script is sequential (written horizontally from left to right) and rectilinear (consists of lines, half circles and circles).

There is a growing body of research on children's use of visual properties in word recognition before they are formally introduced to reading (e.g., Puranik, Lonigan, & Kim, 2011). However, only a few studies have focused on the prediction of literacy development by children's ability to use visual and functional features to recognise written words and letters. For example, Kessler et al. (2013) analysed written letter strings of young children who were still unable to link letters to phonemes. They found out that Brazilian children, who wrote bigrams (two adjacent letters) that frequently occur in children's books, subsequently performed better at a spelling test in first grade. Therefore, children's sensitivity to the statistical distribution of bigrams was an indicator for their spelling development. Given these effects on spelling development, it is likely that children's sensitivity to the frequency distribution of letters in child-directed texts also predicts reading development. However, this has not yet been studied.

Treiman and Kessler (2014) have also pointed out that children need to acquire the ability to understand the symbolic function of letters. Previous work suggests that before the age of 6 years, children are likely to mismatch written names of objects and pictures of objects by overgeneralizing simple rules (e.g., size of object/length of word) to abstract representations (i.e., moving word task; Bialystok, 1992; Bialystok, 2000; Bialystok, Shenfield, & Codd, 2000; Uttal, Liu, & DeLoache, 2006). For example, the word *banana* is longer than the word *car*, and a car is bigger than a banana. Therefore, children incorrectly conclude, that the word *banana* must be the correct description for a car (Bialystok & Martin, 2003). However, in contrast, some recent evidence suggests that 3- to 5-year-olds understand that letters are a fixed representation of spoken words (Treiman, Hompluem, Gordon, Decker, & Markson, 2016).

Additional examinations of young children's use of visual and functional properties of letter strings focus on children's ability to determine whether strings with different types of symbols form words. For example, Bastien-Toniazzo (1992) found that some children accepted strings of symbols that contained letters and either numbers (e.g., *r4e*), geometrical symbols (e.g., *r*Δ*e*) or technological symbols (e.g., *r #e*) as words. However, this was not the case for letter strings that included iconic symbols (e.g., ♣). Ganapole (1987) found that school children had difficulties in rejecting letter strings that included numbers as ‘readable’, while younger children had difficulties with strings that contained either numbers or geometrical symbols. These results show that some children may have difficulties in distinguishing letters (phonographs) from symbols that share visual but not functional properties with letters (logograph). However, the results also show that children’s ability to distinguish logographs from letters increases with age. Nevertheless, neither study used these word awareness tasks to predict reading development.

Studying the influence of young children’s visual and functional perception of letters on reading development is particularly interesting for German children. In Germany, children enter school at the age of 6 years. Before school entry, they have very little literacy stimulation other than shared picture book reading sessions (Senatsverwaltung für Bildung, Jugend und Wissenschaft, 2014, pp. 102–103) in Early Childhood Education and Care (ECEC) institutions (Kuger et al., 2013). As a consequence, children in Germany have very little letter-sound knowledge before school entry (Hippmann, 2008; Mann & Wimmer, 2002; Goswami, Ziegler, & Richardson, 2005; Näslund & Schneider, 1996), while their ability to recognise letters based on visual and functional properties has not been previously investigated.

In this study, we evaluated the development of children’s sensitivity to letter and symbol frequency in child-directed texts and how this sensitivity influences children’s ability to distinguish letters from logographic symbols. We developed a letter judgement task, in which children were asked to judge whether a presented alphabetic (i.e., *M*) or non-alphabetic symbol (i.e., *&*) was a letter. For each group of symbol types, half of the presented symbols occurred very frequently, while the other half occurred infrequently in German child-directed literature. The same group of children was monitored at three time points, at 10 and 4 months before school entry and at 2 months after school entry. We hypothesised that children would be more likely to identify high than low frequent alphabetic symbols as letters and more likely to erroneously accept high than low frequent non-alphabetic symbols as letters. In addition, we predicted that the frequency effects would become smaller over time and vanish once children were introduced to the alphabet after school entry. Moreover, we assessed not only accuracy but also latency measures. Latency measures enabled us to look at the speed of the decision as an indicator of automaticity for lexical access in letter recognition.

In a subsequent analysis, we evaluated whether the letter judgement task was an early predictor of reading abilities. We also considered common reading predictors in the analysis (i.e., phonological awareness, phonological working memory and home literacy environment [HLE]). We hypothesised that children’s sensitivity to letter and symbol frequency 10 months before school entry would predict early word reading abilities at the beginning of first grade.

Method

Participants

Data were collected within the longitudinal project PLAiT (Prerequisite Language Abilities in the Transitional Phase), which explores the influence of early language processing skills on literacy development in German. Children were recruited from seven cooperating ECEC institutions in Berlin. The children were only able to participate with the consent of their parents. We present results from a task, which was administered 10 months (T1) and 4 months (T2) before school entry, and 2 months after school entry (T3). After school entry, children were taught letters with a phonics approach, which included the use of alphabet tables.

From the initial sample of 104 children, 78 children entered school and we collected full data sets from 73 children. From the base sample of 73 children, we excluded six children because their parents had reported that they did not speak German as a native language. The remaining 67 children (28 girls) were from middle to high socio-economic backgrounds (Highest value of the International Socio-Economic Index of Occupational Status: *M* = 67.74; *SD* = 11.24; Ganzeboom, De Graaf, & Treiman, 1992; Ganzeboom, 2010) and scored within normal range in standardised nonverbal intelligence, vocabulary and working memory assessments. Their mean age was 5 years, 4 months (*SD* = 3.04 months) at T1, 5 years, 10 months (*SD* = 3.14 months) at T2 and 6 years, 4 months (*SD* = 3.14 months) at T3. Testing took place in a quiet room in one of the seven participating kindergartens (T1 and T2) and at our research institute (T3). Children were tested in one-on-one sessions with an experimenter and received a small toy for their participation.

Letter judgement task

The letter judgement task was a computerised task, presented using INQUISIT (3.1.0.6.) with a DELL Latitude 520 laptop computer. The children were instructed to focus on a symbol that was presented in the middle of a white screen and were asked to decide whether it was a letter or not. The instruction was ‘Is this a letter?’. Children were asked to press a green key when they decided that the presented symbol was a letter or a red key if they decided that the symbol was not a letter. After finishing four practice trials with feedback, 32 test trials were presented without feedback in a randomized order. Both accuracy and latency measures were recorded.

Material. Stimuli of the letter judgement task consisted of 16 capital letters and 16 symbols. Letters were only chosen if they had a unique, or close to unique, grapheme to phoneme correspondence in German. The rationale behind this selection process was to include letters that have a unique phonemic representation, and thus, the symbolic function was unambiguous. For example, we excluded graphemes like <V> that can have a phonemic representation as either /f/ or /v/ (Costard, 2007 p.12). Selected consonants had one phonemic representation each. We included all vowels, which were each connected to two allophones (long and short).

Selection of symbols was based on visual and functional features. All non-alphabetic symbols were chosen to match visual features of letters. All non-alphabetic symbols were indexing semasiographic symbols (= symbols with a referential function, e.g., #; Haas, 1976; Treiman & Kessler, 2014). Like letters, they were artificial (no real objects), sequential (written horizontally from left to right), rectilinear (consisted only of lines, half circles and circles) and non-iconic (did not depict real objects). In contrast to letters, all non-alphabetic symbols were logographic, rather than phonographic. Numbers were not included as non-alphabetic symbols, because their representation in spoken German is complex. For example, in German, the number 45 literally translates to *five and forty*, rather than *forty-five*. Therefore, sequentiality for numbers is not clear.

Frequency of symbols was selected from a corpus for German child-directed literature (childLex; v.16.0.3; Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015) on the basis of their absolute unigram type frequency. High frequent letters (i.e., A, E, G, S, F, B, M and K) had a significantly higher mean type frequency *(M* = 8,464, *SD* = 3,333) than low frequent letters (i.e., D, O, R, N, P, L, I and U; *M* = 3,920, *SD* = 1,629)1, $t(15) > 31.62$, $p < .001$. The group of high frequent symbols (i.e., #, &, $, §, @, €, = and £; *M* = 3.51, *SD* = 3.06) appeared less frequently in child-directed texts than low and high frequent letters, both *t*s > 200, both *p*s < .001. Frequent symbols primarily consisted of technological and financial signs. Finally, the group of low frequent symbols, which consisted of zodiac signs (i.e., ♎, ♐, ♑, ♒, ♍, ♌, ♏ and ♓), did not appear in children's literature.

Reading and predictors of reading

In an additional analysis, it was assessed whether letter judgement abilities predicted word reading abilities. Previous literature shows that German children do not have reading abilities before school entry (Goswami et al., 2005; Hippmann, 2008; Mann & Wimmer, 2002). Therefore, our first assessment of reading abilities was administered at the beginning of first grade. Furthermore, measures of phonological awareness, phonological working memory and HLE were also included as reading predictors. Moreover, children's nonverbal intelligence was assessed as a control measure of general cognitive abilities.

Mean scores, standard deviations and reliabilities of the tasks are reported in Table 3. Except for HLE, the dependent measure for all variables was the number of correct responses. Task difficulties were age appropriate, and reliabilities were good to very good.

Reading. At the beginning of first grade, after 2 months of schooling, children participated in a standardised word reading task (WLLP; Würzburger Leise Lese Probe; Küspert & Schneider, 1998). In this task, children were shown five pictures and within 5 minutes were asked to assign as many words as possible to the corresponding picture. The WLLP has been standardised for first grade. However, because the participating children had only spent a small amount of time in school, it was anticipated that not all children would be able to achieve age-appropriate results. Twenty-three of the 67 participating children did not complete the task and were credited with 0 points.

Phonological awareness. Children's ability to perceive and manipulate phonemes was tested with a standardised rhyme judgement and vowel substitution task (PITPA; Esser & Wyschkon, 2001) at the beginning of first grade. In the rhyme judgement task, children were shown four pictures of objects and were asked to find the picture whose depiction rhymed with a target word. In the vowel substitution task, children were asked to form a new word by substituting one vowel in a presented word with another vowel and to name the newly formed word (e.g., b*a*d becomes b*e*d).

Phonological working memory. The ability to store and retrieve phonological information during a cognitively demanding task was assessed with a standardised digit recall task at the beginning of preschool (BUEVA; Esser & Wyschkon, 2002).

Home literacy environment. Home literacy environment was assessed 6 months prior to the beginning of preschool with a parental questionnaire (Niklas & Schneider, 2013). It included questions about the number of books at home and the amount of time spent in literacy-related parent–child interactions. The dependent measure was the sum of scores of 11 Likert-scale questions. Results indicated that children had a rich HLE.

Nonverbal intelligence. The ability to solve logical problems that without verbal processing was assessed with a standardised odd-one-out task (BUEVA-III; Esser & Wyschkon, 2016). Children were asked to find the odd picture in a matrix of five pictures.

Results

In the following, we present the results of two analyses. First, we assess children's sensitivity to frequency of symbol distribution in a letter judgement task across development. Second, we analyse the contribution of letter judgement abilities 10 months before school entry to early reading abilities at the beginning of first grade. The analyses were computed with R, an open source software for statistical analysis and mathematical computing (R version 3.3.2; R-Core-Team, 2008, RStudio Team, 2015).

In the first analysis, we used a (generalised) linear mixed-effects approach, because we were interested in participant-driven (letter perception) and item-driven (frequency) effects. Mixed-effects models allow us to take the variances of both participants and items into account simultaneously and offer the most reliable and powerful analysis for this kind of research question (Baayen, Davidson, & Bates, 2008). In the second analysis, we used a multiple regression analysis to evaluate whether early letter judgement abilities contributed significantly to the prediction of early reading abilities in addition to common reading precursors.

Development of sensitivity to frequency in letter judgement abilities

In the first analysis, response accuracy and latency served as outcome variables. Response accuracy was defined as the percentage of correctly identified letters and correctly rejected symbols in the letter judgement task. In latencies, only accurate responses were included to control for speed–accuracy trade-offs. Furthermore, latencies below 300 and above 7,000 ms were excluded prior to the analysis. Moreover, latencies that deviated more than 2.5 *SD*s from the log-transformed participant or item mean were discarded to control for accidental responses or unintentional interruptions. Overall, 4.6% of latencies were excluded. Descriptive statistics for all three measurement points are provided in Table 1.

Table 1. Descriptive statistics for letter judgement task across all three time points.

	Accuracy			Latency		
	Start of preschool	End of preschool	Start of school	Start of preschool	End of preschool	Start of school
Familiar letters	97.6 (0.7)	97.3 (0.7)	98.4 (0.5)	1,657 (52)	1,287 (41)	1,039 (33)
Unfamiliar letters	95.5 (1.1)	96.8 (0.8)	97.8 (0.6)	1,722 (55)	1,310 (41)	1,047 (33)
Familiar symbols	88.4 (2.4)	92.9 (1.6)	95.6 (1.1)	2,297 (74)	1,690 (54)	1,287 (41)
Unfamiliar symbols	94.4 (1.3)	97.0 (0.8)	98.0 (0.6)	2,053 (65)	1,521 (48)	1,238 (39)

Note. Standard errors are provided in parentheses.

Raw accuracy responses were analysed with a generalised linear mixed-effects model using a logit link and a binomial error distribution (*glmer* function). Raw latency responses were log transformed and analysed with a linear mixed-effects model using a Gaussian distribution (*lmer* function; both functions from R-package *lme4*; Bates et al., 2015). In these models, participants and items were treated as crossed random effects. In addition, the factors Time (3: T1, T2, T3), Symbol Type (2: letters vs symbols) and Frequency (2: high frequent vs low frequent) and their interaction served as within-participant fixed-effects. Omnibus effects were calculated based on Type III model comparisons (using the ANOVA function in the R-package *car*; Fox & Weisberg, 2011). Main and interaction effects are presented in Table 2. Post hoc analyses were carried out using single-degree-of-freedom contrasts based on the cell mean estimates in separate models with the same parameters.

Response accuracy. Although accuracy responses were near ceiling (>90%), results showed a significant main effect of Time. Overall, performance improved significantly with $M = 94.0\%$ ($SE = 1.4$), at T1, $M = 96.0\%$ ($SE = 1.0$), at T2, and $M = 97.4\%$ ($SE = 0.7$), at T3. The improvement from T1 to T2, $\Delta = 2.0\%$, $t > 2$, $p < .01$, and from T2 to T3, $\Delta = 1.4\%$, $t > 2$, $p < .01$, was significant. Second, a main effect for Symbol Type was explained by more accurate responses for letters, $M = 97.2\%$ ($SE = 0.7$), than for symbols, $M = 94.4\%$ ($SE = 1.3$). Thus, children were better at identifying letters than rejecting symbols. The Symbol Type effect could have partly been driven by an affirmation bias. Therefore, letter and symbol effects are interpreted separately in the following.

Finally, the analysis showed a significant Symbol Type × Frequency interaction. The interaction effect was driven by the fact that the difference between high and low frequent items was not significant in letters, $\Delta = 1.0$, $t < 2$, $p > .05$, but in symbols. Here, performance on high frequent symbols, $M = 92.3\%$ ($SE = 1.7$), was lower than that on low frequent symbols, $M = 96.5\%$ ($SE = 0.9$), $\Delta = 4.1$, $t > 2$, $p < .01$.

Response latency. First, there was a main effect for Time. Children's response latency became smaller with $M = 1{,}932$ ms ($SE = 62$), at T1, $M = 1{,}452$ ms ($SE = 46$), at T2, and $M = 1{,}153$ ms ($SE = 36$), at T3. Both the difference between T1 and T2,

Table 2. ANOVA results for (generalised) linear mixed-effect models of longitudinal analysis for the letter judgement task.

	Accuracy		Latency	
Effect	$\chi^2(df)$	p	$F(df, df_{res})$	p
Intercept	443.5(1)	<.001	87,221.7(1, 77)	<.001
Symbol Type	7.5(1)	<.01	155.1(1, 28)	<.001
Frequency	1.0(1)	>.05	3.3(1, 28)	>.05
Time	27.7(2)	<.001	1247.5(2, 5681)	<.001
Symbol Type × Frequency	6.2 (1)	<.01	9.4(1, 28)	<.01
Symbol Type × Time	3.8(2)	>.05	4.5(2, 5680)	<.05
Frequency × Time	1.0(2)	>.05	1.07(2, 5680)	>.05
Symbol Type × Frequency × Time	0.5(2)	>.05	3.5(2, 5680)	<.05

Note. χ^2 (accuracy) and F values (latency) for effects using Type III sum of squares.

$\Delta = 480$ ms, $t > 20$, $p < .001$, and the difference between T2 and T3, $\Delta = 299$ ms, $t > 20$, $p < .001$, were significant.

Second, the main effect for Symbol Type was significant: Children's responses for letters were faster, $M = 1{,}344$ ms ($SE = 42$), than for symbols, $M = 1{,}681$ ms ($SE = 54$). In addition, the interaction effect of Time and Symbol Type was significant: The Symbol Type effect was larger at the beginning of preschool (T1), $\Delta = 485$ ms, $t > 10$, $p < .001$, compared with at the end of preschool, $\Delta = 308$ ms, $t > 10$, $p < .001$ (T2), and did not differ in size between the end of preschool and the beginning of first grade, $\Delta = 219$ ms, $t > 9$, $p < .001$; T1 vs T2: $\Delta = 177$ ms, $t = 2$, $p < .05$; T2 vs T3: $\Delta = 89$ ms, $t < 1$, $p > .05$. Children improved more in their speed of symbol type decision during the last year of kindergarten compared with the transitional period to school. Again, this result must be interpreted with caution, because of possible influences by an affirmation bias.

In line with the accuracy analysis, the interaction effect of Symbol Type and Frequency was significant. Contrasts revealed that children showed no Frequency effect in letter responses, $t < 2$, $p > .05$ but in symbols, $t > 2$, $p < .001$. Children were slower in their responses to non-alphabetic symbols that frequently appeared in child-directed texts. Finally, we also observed a significant three-way interaction of Time, Symbol Type and Frequency. Children did not show Frequency effects at any time point for letters, all *t*s < 2, all *p*s $> .05$. For symbols, the simple interaction effect between Frequency and Time was significant, $\chi^2 = 7.7$, $p < .05$. This interaction was driven by the fact that children needed significantly more time to reject high frequent symbols than low frequent symbols at both T1, $\Delta = 244$ ms, $t > 3$, $p < .001$, and T2, $\Delta = 169$ ms, $t > 3$, $p < .001$, but not at T3, $\Delta = 49$ ms, $t < 1.5$, $p > .09$.

Letter judgement as a precursor of reading

In the second analysis, we evaluated whether early letter judgement made a unique contribution to the prediction of word reading abilities, in addition to common precursors of reading. In a multiple regression model, letter judgement at T1 was used to predict word reading abilities at the beginning of first grade. To account for both accuracy and speed of the decisions in the letter judgement task, a ratio value was calculated. The value represented the number of correct answers per second. The following variables were also added to the model as reading precursors: standardised assessment of phonological awareness as assessed at the beginning of first grade; phonological working memory as assessed 10 months before school entry; and HLE as assessed 16 months before school entry. Finally, nonverbal intelligence as assessed 6 months before school entry was entered to control for general cognitive abilities (Table 3). Correlations of all measures are displayed in Table 4. Variables were *z*-transformed before they were added to the model.

The multiple regression model contributed significantly to explaining variance in the data, $R^2 = 0.36$, $F(5,61) = 6.71$, $p < .001$. The effects are displayed in Table 5. Phonological awareness had the strongest effect on word reading ability in first grade. Moreover, letter judgement made a significant contribution as well. Neither phonological working memory nor HLE made an additional contribution. Word reading ability was also not explained by nonverbal intelligence. The analysis, thus, supports the hypothesis that letter judgement abilities as measured in the letter judgement task are an early indicator of literacy development.

Table 3. Descriptive statistics and reliabilities of reading predictors, nonverbal intelligence and reading at first grade.

Task	*M*	*SD*	Range	Max	α
Reading	8.31	10.73	0–49	--	.97
Phonological awareness	18.61	7.26	6–38	38	.93
Letter judgement task	0.46	0.14	0.13–0.87	--	.85
Phonological short term memory	20.81	4.53	11–30	52	.80
Nonverbal intelligence	21.87	4.54	6–29	31	.82
Home literacy environment	42.96	2.72	35–48	51	.86

Note. For letter judgement, a ratio value is reported that describes the number of correct answers per second.

Table 4. Correlations of reading predictors, nonverbal intelligence and reading at first grade.

Measures	1	2	3	4	5	6
1. Reading	—					
2. Phonological awareness	0.53***	—				
3. Letter judgement	0.24*	0.03	—			
4. Phonological short term memory	0.10	0.41***	0.08	—		
5. Nonverbal intelligence	0.02	0.01	0.11	0.05	—	
6. Home literacy environment	0.08	0.08	0.14	0.30**	0.01	—

Note.
*$p < .05$, ***$p < .001$

Table 5. Multiple regression analysis predicting reading abilities at the beginning of first grade by letter judgement, common predictors and after controlling for nonverbal intelligence.

Variables	*B*	*SE B*	*t*	*p*
Letter judgement	0.23	0.11	2.20	<.05
Phonological awareness	0.59	0.11	5.25	<.001
Phonological working memory	−0.18	0.12	−1.54	>.05
Nonverbal intelligence	−0.02	0.11	−0.14	>.05
Home literacy environment	0.06	0.11	0.52	>.05

Note. Variables were *z*-transformed before they were added to the model.

Discussion

Children in Germany receive very little literacy stimulation in ECEC institutions (Kuger et al., 2013). In consequence, letter-sound knowledge cannot be presumed before school entry (e.g., Goswami et al., 2005; Mann & Wimmer, 2002). Recent studies in American and Brazilian children suggest that children recognise visual and functional features of letters from a very early age and are sensitive to the frequency with which letters appear in child-directed texts (Kessler et al., 2013; Puranik et al., 2011; Robins et al., 2012; Treiman & Kessler, 2014; Treiman et al., 2016). However, it is unclear whether this sensitivity to visual features, functional features and frequency of letters is a precursor of reading. In the present study, children's sensitivity to letter frequency was studied in a letter judgement task. The task was administered to German speaking children 10 and 4 months before school entry and 2 months after school entry. Furthermore, it was evaluated whether responses in the letter judgement task were an early predictor of reading abilities.

Development of sensitivity to frequency in letter judgement abilities

Children's ability to distinguish between letters and non-alphabetic symbols was studied through a task that required children to judge whether high or low frequent alphabetic (e.g., *A*) or non-alphabetic symbols (e.g., *#*) were letters. The results showed that children were very good at identifying letters already 10 months before school entry and that they improved significantly from one time point to another. There were no significant differences between the recognition of high and low frequent letters in terms of accuracy or latency at any of the time points. This indicates that children at different points of development are able to recognise high and low frequent letters equally well.

In the following, we discuss now two possible explanations for the lack of frequency effects in responses to letters. First, children in our study were likely to be in regular contact with written language and letters, as they came from middle to high SES families with high quality HLE environments. Second, we presented the children with letters that had unique letter-sound correspondences. Thus, it might have been easier to memorise these symbols as letters after a limited number of exposures. Our study is the first to consider letter complexity as an influence on letter recognition.

While children did not show sensitivity to letter frequency in letter responses, children showed significantly less accurate and slower decisions when they were asked to reject high frequent symbols (i.e., *#*) than low frequent symbols (i.e., ♎). Given that children did not show frequency effects for letters, children's sensitivity to high frequent symbols cannot be explained by a sensitivity to the unigram frequency of appearance of letters and symbols in child-directed texts. It is more likely that children's sensitivity to high frequent, non-alphabetic symbols is explained by the frequency of co-occurrence of letters and non-alphabetic symbols in child-directed texts. Nevertheless, children's sensitivity to co-occurrence shows that children are sensitive to the statistical distribution of these symbols in their environment. This observation is in line with the IMP approach (Treiman & Kessler, 2014), which supports the assumption that young children learn about properties of written language via statistical learning (Aslin & Newport, 2012; Newport & Aslin, 2004; Saffran et al., 1996).

The development of responses in the letter judgement task indicated that children became more accurate and faster in their decisions about whether a presented symbol was a letter or not. However, in respect to frequency effects, high frequent, non-alphabetic symbols were mistaken more often than low frequent, non-alphabetic symbols for letters, even after school entry (i.e., response accuracy). Regarding latency, children showed the expected effect, namely, that the frequency effect in non-alphabetic symbols was not significant after school entry. Thus, even after school entry, children were not certain about which high frequent, non-alphabetic symbols they needed to reject. However, in decisions about high frequent, non-alphabetic symbols that they were sure about, their decisions became more automatized.

Regarding children's sensitivity to the functional properties of letters and symbols, these results suggest that children, even after school entry, did not make their decision based on the referential function of symbols. If children would have based their decisions on the phonographic function of letters, they could have rejected all logographic symbols. However, the introduction to the alphabet might have helped them to reject faster non-alphabetic symbols that they were certain about.

Letter judgement as a precursor of reading

In the second analysis, it was evaluated whether letter judgement abilities predicted word reading. In addition to letter judgement abilities, the analysis included phonological awareness, phonological working memory, HLE and nonverbal intelligence. Both phonological awareness and letter judgement predicted word reading at the beginning of first grade. Phonological awareness was the strongest predictor of reading abilities, which stands in line with previous research (e.g., Anthony & Lonigan, 2004; Caravolas et al., 2013). Letter judgement at T1 also predicted word reading abilities significantly. Therefore, children who achieved high accuracy and low decision speed rates (i.e., ratio value) in the letter judgement task 10 months before school entry were also better readers at the beginning of first grade.

The ability to recognise that non-alphabetic symbols that share visual features and text environments with letters were not letters explained much of the variance of responses in the letter judgement task. Thus, the ability to distinguish visually similar symbolic subtypes that appear together in child-directed text environments is an early indicator for literacy development. Moreover, the ability to distinguish letters from symbols can be easily assessed in children who do not have letter-sound knowledge.

In the following, we want to point out three environmental factors, which might help explain why children have difficulties to distinguish non-alphabetic symbols and co-occurring letters. First, symbols appear less frequently than letters. Thus, children might be less familiar with symbols. Second, non-alphabetic symbols are displayed together with letters on keyboards, tablets and smartphones. Thus, the increasing influence of digital media might make it difficult to distinguish the set of symbols in the alphabet from the set of symbols that is displayed on keyboards. Finally, some studies suggest that in child–caregiver conversations, functional representations of letters are often falsely assigned to real-life objects (i.e., '*L like lemon*'; Robins et al., 2012; Robins, Treiman, & Rosales, 2014). Therefore, the inconsistency of letter's referential assignment might be confusing.

Conclusions

In this study, we aimed to evaluate whether children's sensitivity to statistical distributions of letters and symbols in child-directed texts was an early indicator of literacy development. Our results show that children misjudged non-alphabetic symbols as letters if the symbols shared visual features with letters and co-occurred with letters in child-directed texts. Children did not base their decisions on functional differences between alphabetic and non-alphabetic symbols. Thus, we concluded that children were sensitive to the frequency of co-occurrence of non-alphabetic symbols and letters. In addition to phonological awareness, the ability to judge whether a presented symbol was a letter was an early predictor of word reading. Finally, our study also evokes possible directions for new research questions, such as the role of letter complexity in letter recognition across languages or the role of digital media and child–caregiver communication in the acquisition of the referential function of letters.

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