Article

How Cognitive Abilities May Support Children's Bilingual Literacy Development in a Multilingual Society

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Abstract: Underprivileged but highly multilingual Indian children often show low literacy performance. As a complicating factor, these children are often expected to develop literacy not just in the regionally dominant language but also in English. As good literacy skills are crucial for later academic development, it is important to identify factors that could support these children's literacy development. We, therefore, investigated whether cognitive abilities are associated with literacy development and whether they are so in the same way for both of these children's languages. In a longitudinal design (Std. 4 and Std. 5), literacy data in Hindi and English were collected from 336 children in Delhi, India. In addition, three cognitive tasks (Raven's, 2-back, Flanker) were performed. We found that bilingual literacy development is evident across children, although the starting point is low in some cases. Fluid intelligence (Raven's) and working memory capacity (2-back) significantly positively related to literacy performance in Std. 4 and Std. 5 in both Hindi and English. Literacy improvement from Std. 4 to Std. 5 also related to cognitive abilities—working memory capacity (2-back) for Hindi and inhibitory skills (Flanker) for English—but in the opposite direction: Children who had lower scores on these cognitive tasks show more improvement, indicating that they are in the process of catching up with their higher-performing peers—although they have not fully managed to do so by Std. 5.

Keywords: multilingualism; literacy; cognition; working memory; fluid intelligence; inhibition; disadvantaged contexts; generalized additive models

1. Introduction

Bilingualism or multilingualism, i.e., the ability to use multiple languages, is a frequent phenomenon in today's world. Although some research argues for cognitive benefits of bi- or multilingualism, underprivileged but highly multilingual children in linguistically diverse societies such as India often show low levels of school skills, raising the question of how generalizable or valid the cognitive benefits of multilingualism are and how cognition affects literacy development. In this context, underprivileged is taken to mean of low socio-economic status. While the underprivileged Indian context is generally understudied, it is known that literacy performance in Indian primary schools is often low (UNESCO 2015; Pratham 2014). Lower primary schools in India (age 6 to 10) are divided up into five grade levels called Standards (Std.). Results of the widely used Annual Status of Education Report literacy task (ASER task; Pratham 2017) show that letter, word, and sentence reading abilities are sub-par in underprivileged Indian primary school children; more than 50% of children in Std. 5 cannot read a text at Std. 2 level fluently. These findings were confirmed in a longitudinal study, which found that underprivileged Indian children in Std. 1 to 3 show substantial literacy difficulties (Menon et al. 2017). A clear and worrisome pattern thus emerges: disadvantaged Indian primary school children show sub-par literacy skills.

As a complicating factor, these children are often expected to develop literacy not just in the regionally dominant language but also in English, which is considered a language

of power and is an institutionalized language in India (Mohanty 2019a; Sharma 2006). Accordingly, reading (as well as writing and other modalities) is often taught in both English and in the regional language in Indian primary schools. In the population presented in this article, primary school children who live in Delhi, this means that both Hindi and English have to be learned. These languages do not belong to the same language family and use different writing systems, so, although some reading skills can transfer between languages (Bialystok 2001; Dressler and Kamil 2006; Durgunoğlu 2002), many aspects of each language will have to be learned separately. Nevertheless, many institutions, as well as parents, think it is important for children to learn English in addition to the regional language, as this language is seen as important for children's (academic) future.

Taking into consideration these children's (academic) future, it immediately becomes apparent why sub-par literacy outcomes are problematic. Early literacy skills are associated with academic success later in life (Duncan et al. 2007; Pluck 2019; Rabiner et al. 2016). In addition, language and reading skills are needed for children's learning in other subjects, their access to books and other forms of written knowledge, and their self-sustainability. As good literacy skills are crucial for later (academic) development, it is important to identify factors that could potentially support these children's literacy development. This study, therefore, investigates whether cognitive abilities are associated with literacy development and whether they are so in the same way for both of these children's languages.

The choice of examining cognitive abilities as potentially supporting children's bilingual literacy development is based on the context in which many underprivileged Indian children grow up. These children likely do not receive literacy support at home (Tsimpli et al. 2019), possibly due to the low literacy of the parents or guardians and/or absence of written materials in the home. However, these children often grow up in highly multilingual and sociolinguistically diverse societies, often speaking multiple languages (Tsimpli et al. 2020a; Mohanty 2010, 2019b). Crucially, bi- or multilingualism is frequently associated with enhanced cognitive abilities (Bialystok et al. 2004; Bialystok 2009, 2011; Costa et al. 2008; Soveri et al. 2011; Colzato et al. 2008; Costa et al. 2009; Lehtonen et al. 2018; Paap and Greenberg 2013; Samuel et al. 2018). At an older age, multilingualism could even delay cognitive decline (Alladi et al. 2013). Although it is difficult to demonstrate a causal link, it is often argued that bilingualism affects cognitive performance (Bialystok 2009). Much less research in bi- or multilingualism has argued for a potential relationship in the opposite direction and asked questions about the influence of cognitive abilities on aspects of children's language development, such as literacy.

In contrast, research on second language learning, acquisition, and processing has frequently examined the effects of cognitive abilities on language learning and development (e.g., Granena et al. 2016), which are generally positive. Such research has found associations of cognitive abilities with literacy performance (Kaufman et al. 2009; Kosmidis et al. 2011; Salthouse 1996; Ziegler and Goswami 2005) and specifically with literacy in primary school-aged children (Cain et al. 2004; Leather and Henry 1994), although the overwhelming majority of such research has been performed in Western (European or North American) societies. This study, therefore, aims to investigate whether cognitive abilities could also support the literacy development of children from underprivileged backgrounds in India.

The fact that the children in focus in this research are from underprivileged backgrounds is a crucial part of the present study. It is important to study the academic and cognitive development of children from disadvantaged socio-economic contexts more closely for several reasons. Firstly, most existing research looks at Western societies, most often studying children of middle-to-high social classes. Thus, children from non-Western societies and/or lower social classes are underrepresented in the current body of linguistic and cognitive research. Secondly, and most importantly, this is the case even though it is known that low socio-economic status negatively impacts learning outcomes, specifically in language skills (Burneo-Garcés et al. 2019; Pace et al. 2017) and cognitive skills (Alcott and Rose 2017; Arán-Filippetti 2013; Burneo-Garcés et al. 2019; Hackman and Farah 2009; Kelly

et al. 2011; Noble et al. 2005). What is more, any delay in the development of cognitive abilities due to social class could have a knock-on effect on language and literacy development, as cognitive abilities, too, relate to literacy development (Cain et al. 2004; Leather and Henry 1994). Specifically, socio-economic status has been suggested to moderate the influence of intelligence on reading development, with lower status having adverse effects, which could, however, be offset by education (Peng et al. 2019). In sum, children from lower social classes or underprivileged backgrounds are likely to underperform both in the language and in the cognitive domain compared to their peers of middle-to-high social class, and thus these children are the most pressing and the first to require additional support.

To answer the specific questions of whether cognitive abilities are associated with literacy development and whether they are so in the same way for both of these children's languages, we ran a longitudinal study measuring literacy in both the regional language Hindi and in English in a large sample of Indian primary school children. All literacy tasks were performed by the same children in both Std. 4 and Std. 5. In addition, three cognitive tasks were performed in Std. 4 to investigate whether these cognitive abilities support literacy development. The three cognitive domains covered by the tasks are fluid intelligence, working memory capacity, and inhibitory skills. Of these, working memory capacity has been found to relate to children's literacy skills in Western societies (Cain et al. 2004; Leather and Henry 1994; Vernucci et al. 2021). Fluid intelligence has been found to relate to adults' as well as children's literacy skills (adults: Peng et al. 2019; Scholz and Scheer 2020; children: Johann et al. 2019; Vernucci et al. 2021). In contrast, inhibitory skills are underexplored with respect to literacy development. Of the few studies that did examine this relation, Johann et al. (2019) found a positive relationship between children's inhibition skills and reading speed but not between inhibition skills and reading comprehension. In line with these previous findings, we predict that fluid intelligence, underlying processing speed and learning aptitude, and working memory capacity will be most relevant for literacy development.

2. Materials and Methods

2.1. Participants

The study tested 336 children (mean age 8.8; age range 8–12; 169 girls, 167 boys) from Delhi, India, at two time points. All children attended government (state) primary schools at the time of testing. Because the children all attended state schools instead of (more expensive) private schools, they are more likely to be from less affluent families with less-educated parents (Pratham 2017) and could be considered as coming from disadvantaged, underprivileged backgrounds. In Delhi, Hindi is the regionally dominant language and a language that is used in both the classroom and everyday life. The official language of instruction in the schools was either Hindi (for 64 children) or English (for 272 children), but in practice, the language used in the classroom was mixed (Lightfoot et al. 2021). None of the children reported having exposure to English in their home environment. The presented data are part of the MultiLila project (Tsimpli et al. 2019, 2020b), and in the context of this project, written consent was obtained from the schools as well as the children. The project was approved by the ethics committee of the University of Cambridge (RG83665).

2.2. Tasks

2.2.1. ASER Literacy Task

The Annual Status of Education Report (ASER; Pratham 2017) literacy task consists of letters, words, a paragraph, and a short story that the children were asked to read out loud. The task was applied both in Hindi (the regional language) and in English at two time points, with about a year in between (once in Std. 4 and once in Std. 5). The Hindi task was always applied first, with a session including the English task following on a different day.

The task was scored based on the percentage of letters, words, and sentences read correctly in each of the two languages at each of the two time points. Subsequently,

principal component analyses with the function *prcomp* in the statistical analysis software R (R Core Team 2019) were performed to calculate a composite score of overall literacy performance per language and time point. Principal component analysis is a technique that reduces the dimensionality of a dataset (such as a literacy task with several components, i.e., performance on letters, words, a paragraph, and a short story) while minimizing information loss. One principal component was found to explain a considerable amount of variance in literacy performance in each language at each time point in our dataset (see Appendix A). Based on these components, a composite score of overall literacy performance per language and time point could be calculated for every child. Finally, difference scores between performance in Std. 4 and Std. 5 were calculated to reflect children's improvement in the percentage of letters, words, and sentences read correctly in each language. These difference scores were again entered into principal component analyses (see Appendix B) to identify one dominant principal component and subsequently calculate composite scores of overall literacy improvement per language for each child.

2.2.2. Raven's Progressive Matrices Task

The Raven's colored progressive matrices task (Raven et al. 2008) is a task that measures fluid intelligence in a non-verbal way. The task consists of 36 visual patterns from which one piece is missing; the children had to select which of 6 pieces presented at the bottom would complete the pattern. The task was performed on a computer, but children could simply point to the correct piece or say its number, as the task was not timed. The Raven's task has been standardized (based on, e.g., age) for the Indian population (Raven's Educational CPM/CVS (India); Raven 2012). However, because previous research has argued that these standard scores are not representative of children from disadvantaged backgrounds (Tsimpli et al. 2020a), we used the percentage of correctly completed patterns as the children's final score on this task. Higher scores, therefore, indicate better fluid intelligence.

2.2.3. 2-Back Task

The 2-back task is a specific variation of the n-back task (Kirchner 1958), which measures working memory capacity, monitoring, and updating. The task consists of a series of 60 digits that were presented on a computer screen in turn, with the task of the children being to press a key when the current digit matches the one presented two digits back. The digits were presented for 500 ms each with 2500 ms in between. Out of the 60 digits, 20 required a response, whereas the remaining 40 digits did not match the digit presented two digits back and did not require a response. Performance on this task was calculated as a composite score based on the number of correct key presses and the number of incorrect key presses by means of an A-prime score (see Zhang and Mueller 2005 for details). Higher scores indicate better working memory capacity and monitoring and updating skills.

2.2.4. Flanker Task

The Flanker task (based on Eriksen and Eriksen 1974) is a well-known non-verbal task for measuring inhibitory control. The task presents rows of five fish, with the task of the children being to indicate the direction of the fish in the center. They could indicate this direction, which could be either left or right, by pressing a left or right key on the keyboard. The five fish could all be pointing in the same direction (congruent condition), or the fish in the center could be pointing in the opposite direction compared to the fish surrounding it (incongruent condition). Trials were presented for 1000 ms each with 1500 ms in between. Two blocks of 100 trials each were used: one in which 50% congruent and 50% incongruent trials were used, and one in which 92% congruent and 8% incongruent trials were used. The order of these two blocks was counterbalanced across children. The block with 50% congruent and 50% incongruent trials requires high levels of conflict-monitoring from the children. The data from this block were therefore used in this article, with performance

on the task being calculated as the difference in response times to the incongruent trials and the congruent trials. Lower scores on this task indicate better conflict monitoring and inhibition skills.

For more details on all of these tasks, as well as some of the challenges encountered when administering them, we refer to Tsimpli et al. (2019).

2.3. Procedure

Each child was tested at two time points, once in Std. 4 and once in Std. 5[1]. The three cognitive tasks under investigation were performed at the first time point, in Std. 4. The ASER literacy task was performed in both Std. 4 and Std. 5 in both Hindi and in English. An overview of the different tasks at the different time points is presented in Figure 1. We set out to examine the relationship between cognitive abilities and bilingual literacy in three ways: At the first time point (Std. 4), at the second time point (Std. 5), and based on the improvement in literacy between the two time points (see Figure 1). This way, we can examine both whether cognitive abilities affect the initial performance on bilingual literacy and whether they affect subsequent improvements.
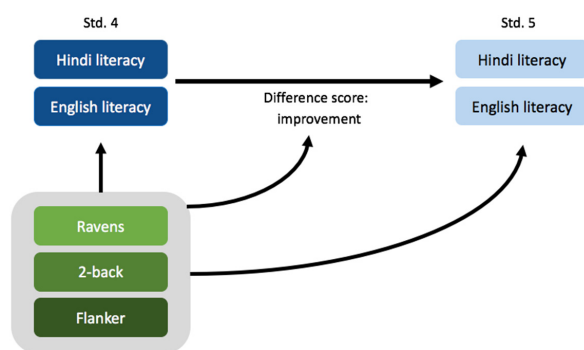

Figure 1. Setup of the study at two time points (Std. 4 and Std. 5), with the ASER literacy task as well as the three cognitive tasks being performed in Std. 4 and the ASER literacy task being performed in Std. 5.

3. Results

3.1. Bilingual Literacy Development

Overall, children scored 75% correct on reading in Hindi and 53% correct on reading in English in Std. 4. They subsequently improved to 86% correct in Hindi and 61% correct in English in Std. 5. So, although the children on average read better in Hindi than in English at both time points, reading performance increased in both languages. As can be seen in Figure 2, reading performance improved on all components of the ASER literacy task. As can be expected based on the nature of the components, children performed best on letter reading and were least proficient in story reading.
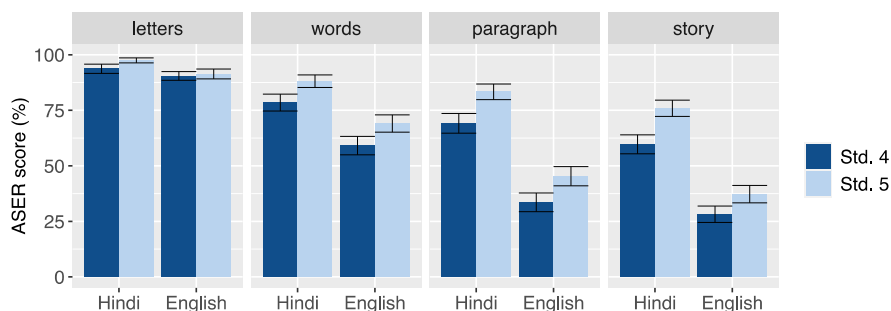

Figure 2. Children's performance on the different components of the ASER literacy task at the two time points (Std. 4 and Std. 5) and in the two languages (Hindi and English) depicted as the means and 95% confidence intervals.

3.2. Relation with Cognitive Abilities

We investigated how children's literacy relates to their cognitive abilities using generalized additive models (Wood 2006). These models were chosen because they are able to fit linear as well as non-linear relationships, and we suspected that some relations between literacy and cognitive abilities might be non-linear. The models investigated the relationship between the three cognitive measures (Ravens, 2-back, Flanker) on the one hand (independent variables) and literacy performance in Std. 4 and Std. 5 as well as the children's improvement from Std. 4 to Std. 5 on the other (dependent variables). Age was included as a covariate but did not show significant effects on literacy performance. The results of the models are graphically presented in Figures 3–5; The model output is presented in Appendix C.
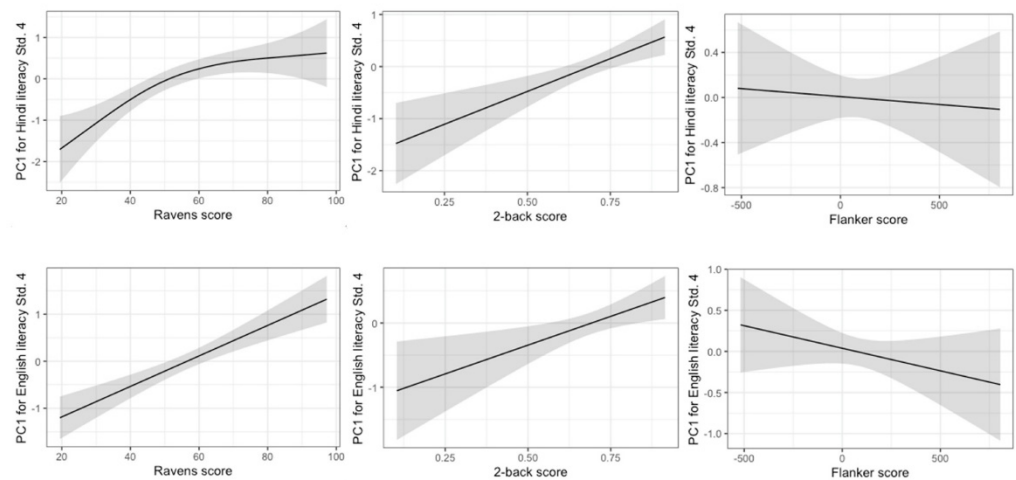

Figure 3. Relations between cognitive abilities and literacy performance in Std. 4 in Hindi and English. Shaded areas indicate 95% confidence interval. Positive relations were found between literacy and Ravens score and literacy and 2-back score in both languages. No significant relations were found between Flanker score and literacy in either of the languages.
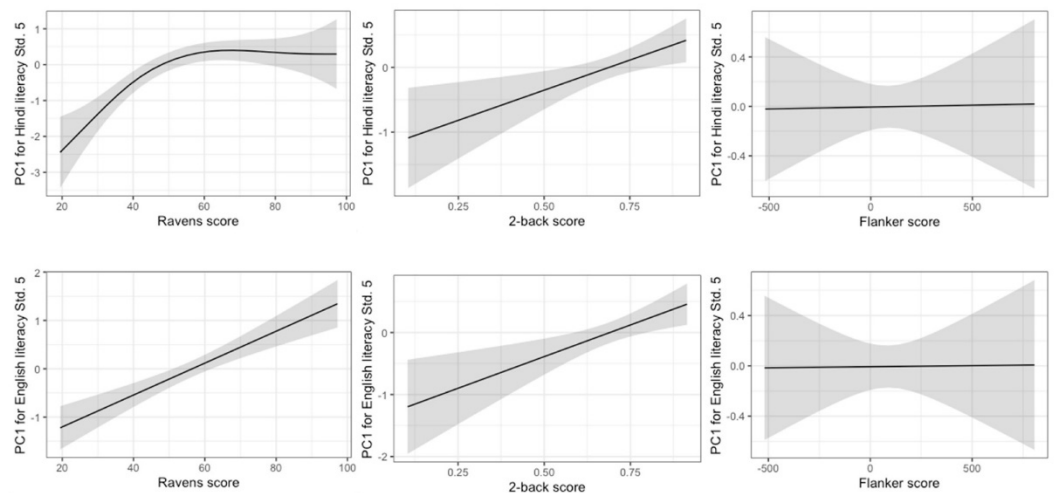

Figure 4. Relations between cognitive abilities and literacy performance in Std. 5 in Hindi and English. Shaded areas indicate 95% confidence interval. Positive relations were found between literacy and Ravens score and literacy and 2-back score in both languages. No significant relations were found between Flanker score and literacy in either of the languages.
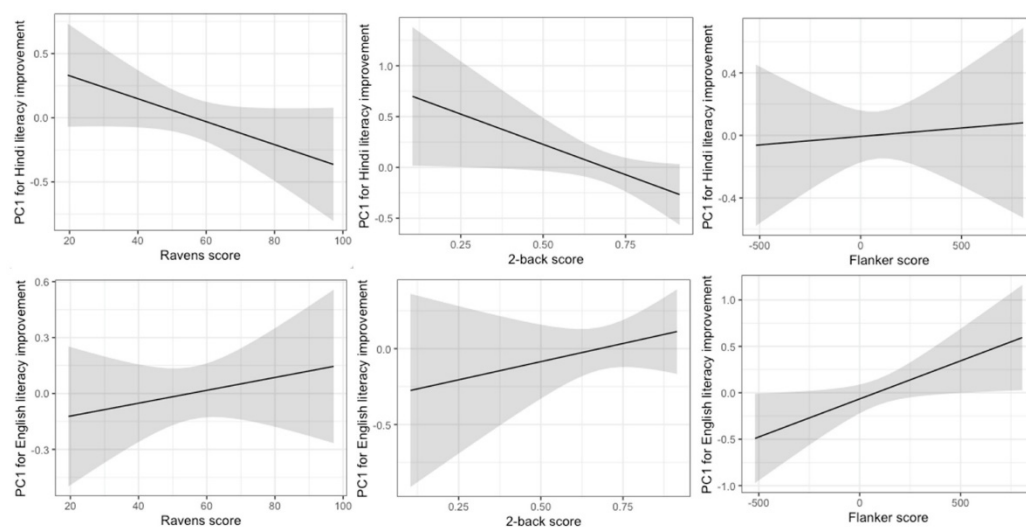
Figure 5. Relations between cognitive abilities and improvement in literacy performance from Std. 4 to Std. 5 in Hindi and English. Shaded areas indicate 95% confidence interval. A negative relation was found between improvement in Hindi literacy and 2-back score. A positive relation was found between improvement in English literacy and Flanker score (but note that lower scores on the Flanker task indicate better inhibitory skills).

The results indicate that cognitive abilities support children's literacy in both Std. 4 and Std. 5. Specifically, positive relations were found between literacy performance in Hindi and both fluid intelligence (Raven's) and working memory capacity (2-back) in both Std. 4 and Std. 5. Positive relations were also found between literacy performance in English and fluid intelligence (Raven's) and working memory capacity (2-back) in both Std. 4 and Std. 5. Thus, better cognitive abilities are related to better bilingual literacy outcomes. Interestingly, the relations between cognitive abilities and literacy were not all linear. In particular, the relation between Hindi literacy (both in Std. 4 and in Std. 5) and Raven's score shows what looks like a ceiling effect, with better performance on Raven's relating to better Hindi literacy, but only up to a Raven's score of about 60%; after that, a higher Raven's score does not relate clearly to better Hindi literacy outcome. No influence of inhibition (Flanker) was found for Hindi or English in Std. 4 or Std. 5.

The relations between cognitive abilities and improvement in literacy performance from Std. 4 to Std. 5 in Hindi and English look notably different from the relations between cognitive abilities and literacy performance at single time points. No significant effects of Raven's were found. A negative relation was found between the 2-back score and improvement in Hindi literacy, indicating that children with higher (i.e., better) working memory capacity improve less. This indicates that children with lower 2-back scores are improving more than children with higher 2-back scores. Since the 2-back score correlated positively with literacy in Std. 4, this indicates that children with lower scores on literacy and cognition in Std. 4 are now in the process of catching up with their peers, even though they have not managed to catch up fully by Std. 5. Finally, a positive relation was found between improvement in English literacy and Flanker score. Recall that lower scores on the Flanker task indicate better inhibitory skills. Thus, this result can be interpreted as indicating that children with lower inhibitory skills improve more.

4. Discussion

The aim of this study was to investigate whether cognitive abilities are associated with literacy development and whether they are so in the same way for both of these children's languages. We investigated these questions in a large group of Indian children from disadvantaged backgrounds using a longitudinal design. Our findings show that bilingual literacy development and learning are evident across children, although the

starting point is low in some cases. Particularly in English, an institutionalized language that the children reported not speaking at home, performance on paragraph and story reading was low (<50%).

Furthermore, the results show that cognitive abilities are associated with these children's literacy: Fluid intelligence (Raven's progressive matrices task; Raven et al. 2008) and working memory capacity (2-back task; Kirchner 1958) positively related to literacy in both the regional language Hindi and the institutionalized language English. Children with better performance on these cognitive tasks also showed better literacy performance. Thus, we can confidently claim that the overall literacy performance of Indian children from disadvantaged backgrounds is related to their cognitive abilities.

But do cognitive abilities support literacy performance, or does literacy performance support performance on cognitive tasks? Correlation is not causation (Conn 2017), and causality is difficult to prove here, but we can nevertheless speculate about the most likely directionality of the effect. Since all children were from similar backgrounds and received similar education (i.e., they attended the same schools and classes), it is unlikely that differences in (literacy) education can explain why some children perform above and some below average on the applied literacy task. Literacy is a skill that is explicitly taught, whereas cognition is generally not. Cognitive abilities rather are expected to naturally vary amongst children based on both genetic and environmental factors. For example, sociolinguistic diversity (Tsimpli et al. 2020a), socio-economic background (e.g., Alcott and Rose 2017), sleep (e.g., Chen et al. 2021), and nutrition (e.g., Nyaradi et al. 2013) are all factors that can affect cognition or cognitive development in children. For this reason, we argue that it is most likely that our results indicate that cognitive abilities support bilingual literacy performance. This would be in line with previous research that has made this connection (Cain et al. 2004; Leather and Henry 1994).

However, it is possible that a third construct, not included in our study, affects both cognitive and literacy performance. The most likely candidate for this might be social class or socio-economic status. Social class is known to affect both language skills (Burneo-Garcés et al. 2019; Pace et al. 2017) and cognitive skills (Alcott and Rose 2017; Arán-Filippetti 2013; Burneo-Garcés et al. 2019; Hackman and Farah 2009; Kelly et al. 2011; Noble et al. 2005). It is thus possible that the link between literacy development and cognitive skills is mediated by socio-economic status. We recommend future studies to examine this interplay more closely in cohorts of disadvantaged children. Finally, it is possible that cognition and language abilities develop simultaneously but separately as children grow older. In this case, maturation would be the common denominator, and no other causal link would be present. This hypothesis could be tested in a (longitudinal) intervention study that trains children's cognitive skills and examines whether those skills transfer to their literacy performance.

The improvement in literacy that children exhibit from Std. 4 to Std. 5 was also found to be related to their cognitive abilities. Working memory capacity and updating (2-back) showed an effect in Hindi but in the opposite direction of the effects in Std. 4 and Std. 5: Children who had lower scores on this cognitive task show more improvement in literacy performance, indicating that they are in the process of catching up with their higher-performing peers. We tentatively interpret this as good news, as this shows that the literacy gaps, at least in Hindi, are decreasing between Std. 4 and Std. 5. However, the children with lower cognitive and literacy performance have not fully managed to catch up by Std. 5, as evinced by the persisting effect of cognitive abilities in this grade. Thus, the lower-scoring children would require additional literacy support to fully catch up unless the effect persists over time, further narrowing the gap with higher-performing peers in subsequent school years. A more longitudinal study (also looking at children in higher grades) and/or an intervention study offering literacy support to the children who lag behind are some possible ways forward.

In addition, a relation was found between inhibitory skills (Flanker; Eriksen and Eriksen 1974) and literacy improvement in English. More precisely, children that showed

lower levels of inhibition improved more in English literacy. This is an interesting effect, as it was not found in Hindi literacy development, and the effect of inhibitory skills did not reach significance in Std. 4 and Std. 5. This effect may be interpreted on the basis of the fact that the children who participated in our study did not speak English at home and consistently performed better in Hindi than in English literacy. Because of this, it is likely that children would try to scaffold their English literacy with their Hindi literacy and/or knowledge of other languages. Since the Hindi and English language are from different language families and use different writing systems, it is possible that high levels of inhibition prevented children from transferring their knowledge successfully. As a result, children with lower inhibitory control may have been less resistant to the new script and reading system. Counterevidence to this explanation, however, is provided by results from Pulido (2021), who found that adults with better inhibitory skills are better at second language learning. In children, better inhibitory skills have been associated with a higher reading speed (Johann et al. 2019). Therefore, the nature of the relationship between inhibitory skills and literacy development remains to be investigated further.

As a final note, it should be mentioned that even though the children reported having no exposure to English in their home environment, code-switching or code-mixing is a natural phenomenon and part of the everyday reality in large parts of the world, at least in oral language use. Very generally speaking, code-mixing describes the practice of mixing multiple languages within a sentence or within a conversation or classroom. Within the context of the project that the data described in this article were taken from, we have found that language use of both children and teachers in Delhi classrooms was largely mixed, not just between Hindi and English but also Urdu (Lightfoot et al. 2021). Such language mixing or translanguaging practices (see, e.g., García and Wei 2014) have not been sufficiently mapped out, and their influence on language learning and literacy development in a second, mixed, language is as yet largely unknown.

In sum, based on the empirical results from the presented study, we argue that cognitive abilities support literacy development but that they do not necessarily do so in the same way for Hindi and English. Fluid intelligence and working memory capacity were associated with literacy performance in similar ways in Hindi and English, showing that these aspects of cognition may support language development in the broad sense and potentially development in other school skills (e.g., maths, Formoso et al. 2018) as well. In contrast, inhibition was only relevant to English literacy, suggesting that it is a separate type of cognitive skill that is related to different underlying (cognitive) processes than memory and intelligence. Specifically, we speculated that high levels of inhibition might prevent skill transfer. We recommend schools and teachers take into account individual differences in cognitive skills to optimally support literacy development. At the same time, this recommendation shows that the job of primary schools and their teachers is harder with children who are from disadvantaged backgrounds. These schools are often hosting a diverse student population with limited resources, highlighting the need for targeted and efficient intervention strategies and teaching methods.

Appendix A

Outcomes of the principal component analyses for literacy performance at each time point for each language.

Figure A1. Scree plots of the principal components analyses for the literacy data.

Figure A2. Contribution of variable to each of the first principal components for the literacy data. The order of the contribution of components is the same for both time points and both languages.

Appendix B

Outcomes of the principal component analyses for the difference scores between Std. 4 and Std. 5 for each language.
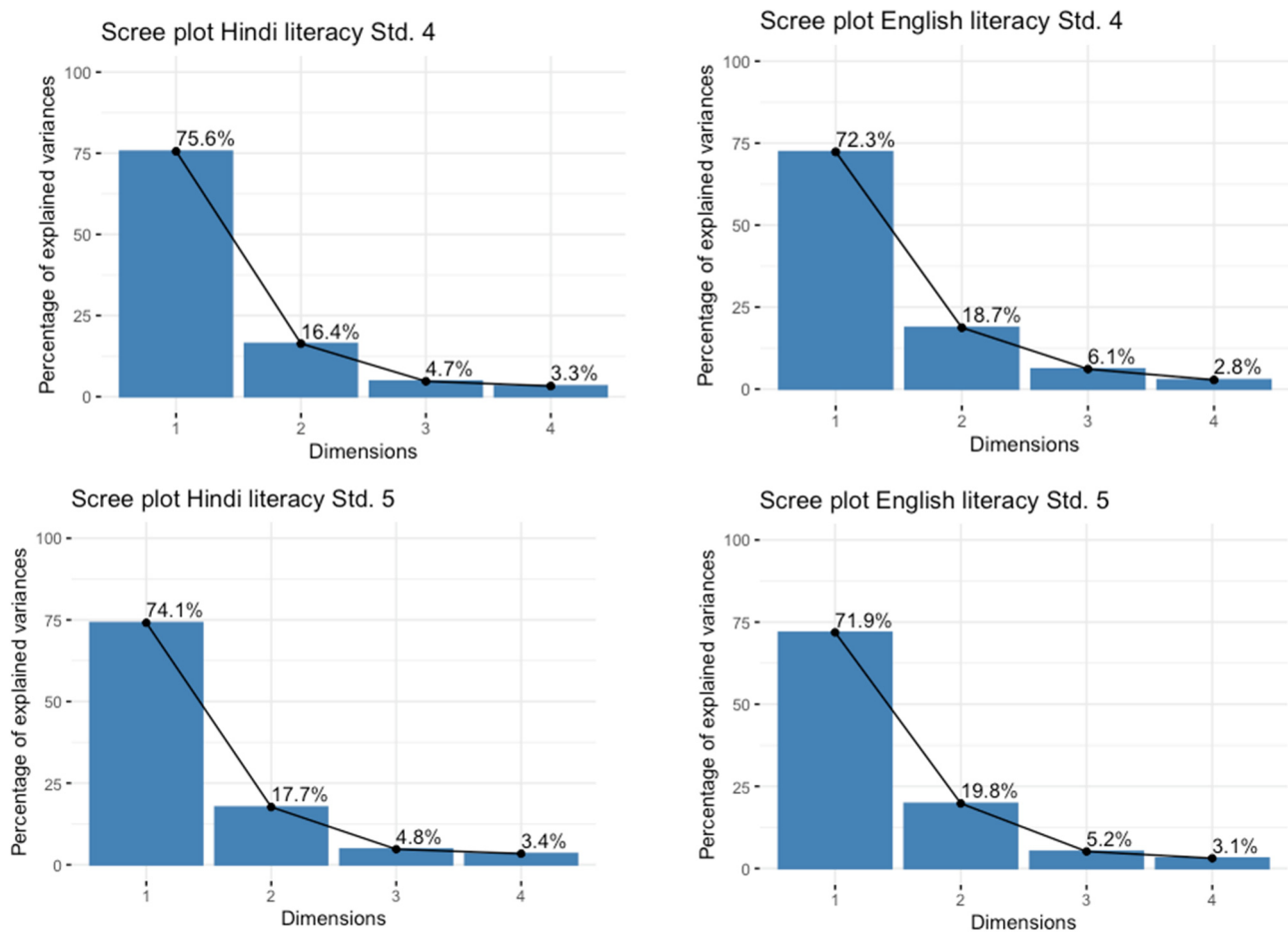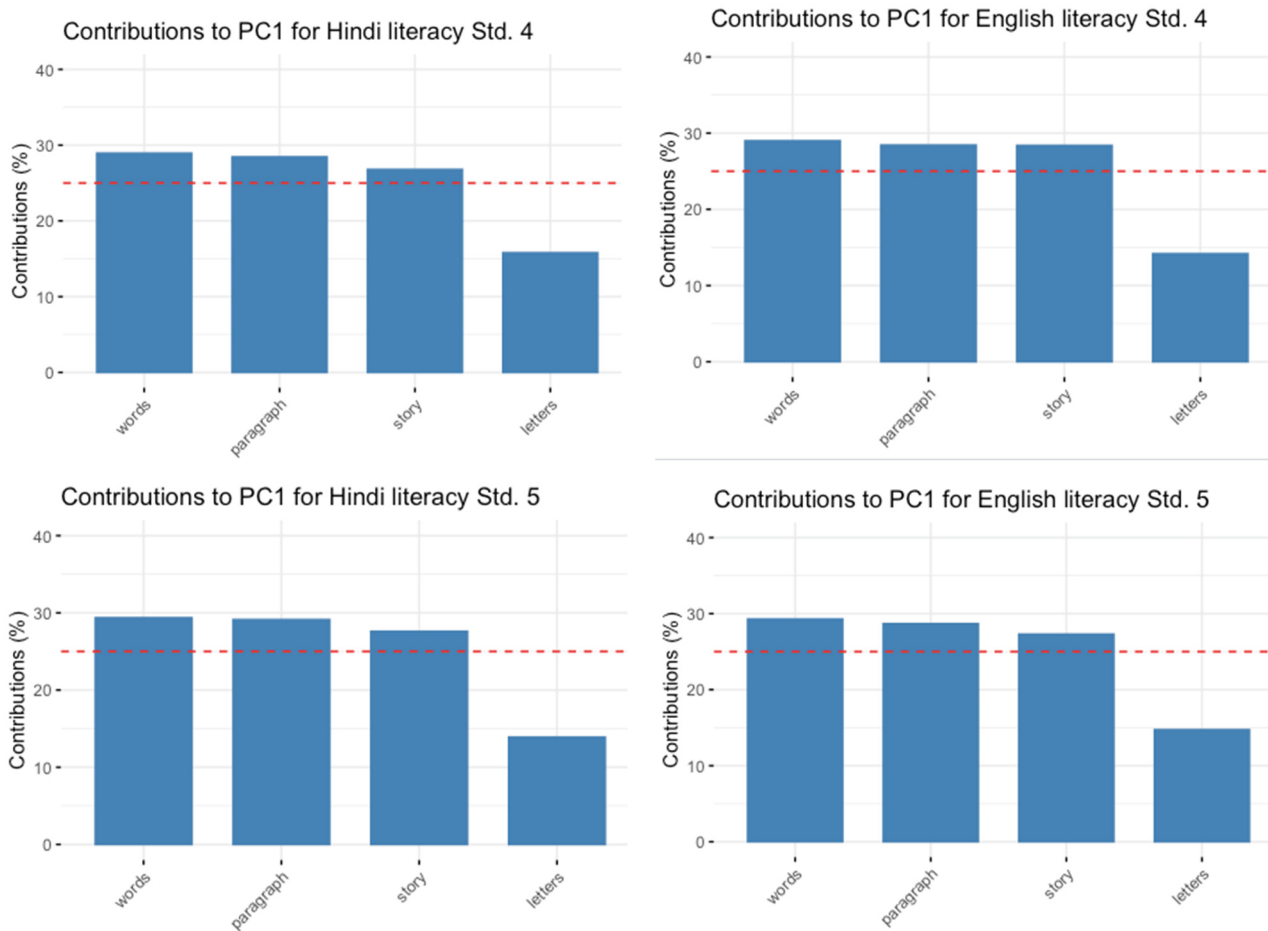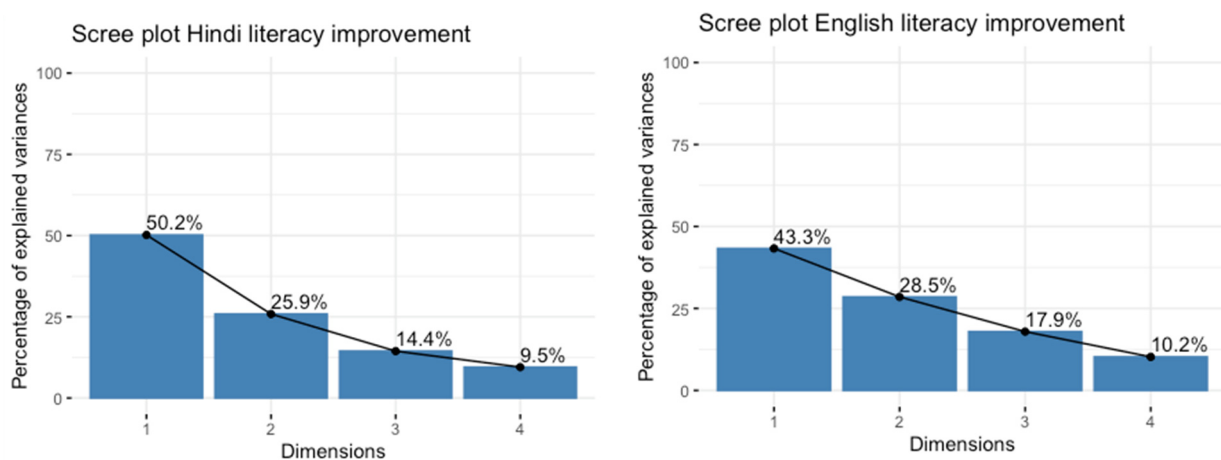

Figure A3. Scree plots of the principal components analysis for the literacy data.
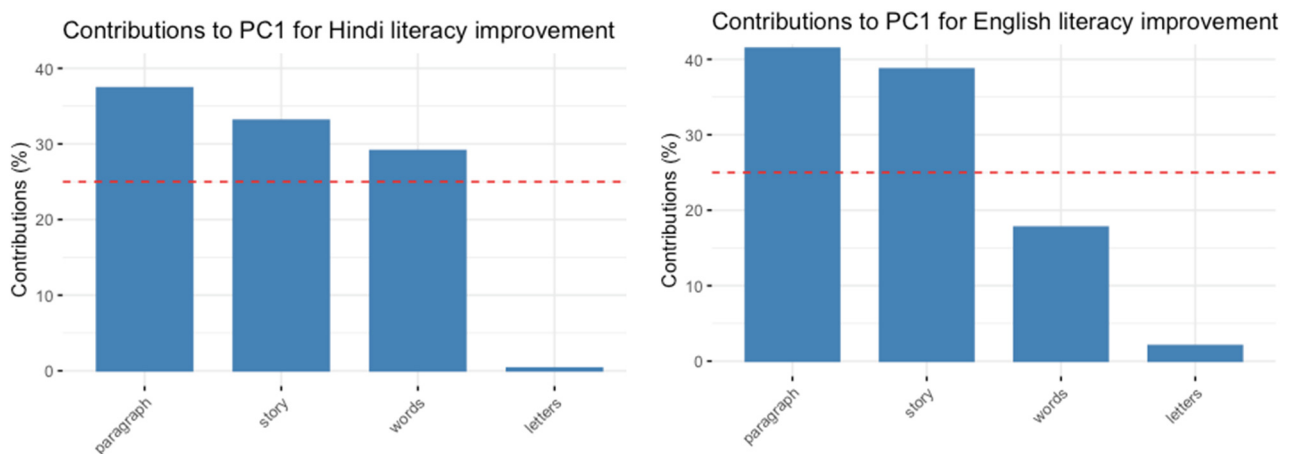
Figure A4. Contribution of variable to each of the first principal components for the literacy data.

Appendix C

Output of the generalized additive models. Effects are marked as significant when their *p*-value is below 0.05 (*), 0.01 (**), or 0.001 (***).

Table A1. Output of the generalized additive model for the Hindi literacy in Std. 4.

Formula: PC1 Hindi Std. 4~s(Ravens) + s(2-Back) + s(Flanker) + s(Age, bs = 're')			
	Edf	**F-Value**	***p*-Value**
s(Ravens)	2.15	10.63	<0.001 ***
s(2-back)	1.00	14.43	<0.001 ***
s(Flanker)	1.00	0.09	0.77
s(Age)	<0.01	<0.01	0.84

Table A2. Output of the generalized additive model for the English literacy in Std. 4.

Formula: PC1 English Std. 4~s(Ravens) + s(2-Back) + s(Flanker) + s(Age, bs = 're').			
	Edf	**F-Value**	***p*-Value**
s(Ravens)	1.00	31.16	<0.001 ***
s(2-back)	1.00	7.53	0.006 **
s(Flanker)	1.00	1.37	0.24
s(Age)	0.39	0.65	0.20

Table A3. Output of the generalized additive model for the Hindi literacy in Std. 5.

Formula: PC1 Hindi Std. 5~s(Ravens) + s(2-Back) + s(Flanker) + s(Age, bs = 're')			
	Edf	**F-Value**	***p*-Value**
s(Ravens)	2.93	10.56	<0.001 ***
s(2-back)	1.00	7.96	0.005 **
s(Flanker)	1.00	1.00	0.95
s(Age)	<0.01	1.00	0.86

Table A4. Output of the generalized additive model for the English literacy in Std. 5.

Formula: PC1 English Std. 5~s(Ravens) + s(2-Back) + s(Flanker) + s(Age, bs = 're').			
	Edf	F-Value	*p*-Value
s(Ravens)	1.00	32.93	<0.001 ***
s(2-back)	1.00	9.97	0.002 **
s(Flanker)	1.00	<0.01	0.97
s(Age)	0.07	0.07	0.30

Table A5. Output of the generalized additive model for the Hindi literacy improvement.

Formula: PC1 Hindi Improvement~s(Ravens) + s(2-Back) + s(Flanker) + s(Age, bs = 're')			
	Edf	F-Value	*p*-Value
s(Ravens)	1.00	3.00	0.08
s(2-back)	1.00	4.21	0.04 *
s(Flanker)	1.00	0.07	0.80
s(Age)	<0.01	<0.01	0.54

Table A6. Output of the generalized additive model for the English literacy improvement.

Formula: PC1 English Improvement~s(Ravens) + s(2-Back) + s(Flanker) + s(Age, bs = 're')			
	Edf	F-Value	*p*-Value
s(Ravens)	1.00	0.51	0.47
s(2-back)	1.00	0.78	0.38
s(Flanker)	1.00	4.45	0.04 *
s(Age)	<0.01	<0.01	0.73

Note

[1]   In total, 336 children participated at both time points. Several additional children only participated at one of these time points, but since we were interested in literacy development, which requires measures as both time points, we did not take the data of these additional children into account.

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