Understanding the influence of cognition and the home learning environment on early number skills

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Executive summary

1. This study examined the preschool predictors of three key early number skills (counting, number transcoding and calculation). The study had a particular focus on the influence of the home learning environment on the development of these skills.
2. The core aims are summarised in our three research questions:
    a. To what extent do preschool language and executive skills predict growth in early number skills?
    b. To what extent do number-oriented and language and literacy-oriented aspects of the home learning environment predict growth in early number skills?
    c. To what extent are the relationships between the quality of the home learning environment and early number skills direct and to what extent are they indirectly related via the promotion of language skills?
3. Children were recruited in their preschool year (the academic year in which they turned four years of age) from 40 Early Years settings. The participating settings were distributed across three counties in the North West of England and were broadly representative of the various types of preschool setting in England.
4. Parents were asked to complete a questionnaire that gathered information on a range of factors including the frequency of different types of home learning experiences. Three types of home learning experiences were indexed. Meaning-focused home literacy experiences (that focus on the meaning of written or oral language at the level of words, sentences or narratives), code-focused home literacy experiences (that focus on the phonological and orthographic structure of language) and home number experiences. Shared book reading was assessed using a book exposure measure where parents had to indicate which children's book titles they recognised.

5. The children were assessed on three separate occasions. In the spring term of their preschool year (time 1) their counting, number transcoding and calculation skills were assessed. In the summer term of their preschool year (time 2) their language and cognitive skills were assessed. Finally, in the summer term of their Reception year (time 3) their counting, number transcoding and calculation skills were re-assessed alongside the administration of standardised measures of reading and mathematics.
6. The language assessments covered both vocabulary and phonological awareness (the ability to identify speech sounds within words). The cognitive assessments covered both non-verbal reasoning and executive functioning.
7. A total of 274 children completed the number skills assessments at time 1 with 232 children being retained until time 3. Assessments of preschool quality were made for a sub-sample of the children using a standardised observation schedule. The sample was broadly representative in terms of national levels of deprivation.
8. Children's preschool language skills were related to counting, number transcoding and calculation skills at the end of Reception. Furthermore, preschool language skills predicted *growth* in their counting and number transcoding skills between preschool and the end of Reception.
9. Children's preschool non-verbal skills (executive functioning and non-verbal reasoning) were related to number skills at the end of Reception. However, these relationships were not significant once preschool language skills had been taken into account.
10. Preschool letter-sound interactions (an aspect of code-focused home literacy) predicted growth in counting and number transcoding skills between preschool and the end of Reception.
11. Direct relationships between preschool letter-sound interactions and counting and number transcoding at the end of Reception remained even when language skills were accounted for.

12. Calculation skills at the end of Reception were predicted by preschool letter-sound interactions. However, the relationship was not significant once initial calculation skills were taken into account. This indicates that letter-sound interactions could not predict growth in calculation between preschool and the end of Reception.

13. Preschool home number experiences were related to children's early number skills both in preschool and Reception. However, these relationships were not significant once letter-sound interactions were taken into account.

14. Neither the meaning-focused literacy experiences index nor the book exposure measure were consistently related to children's early number skills.

15. Alongside measures of phonological awareness and vocabulary, letter-sound interactions predicted word reading at the end of Reception.

16. Attending a preschool setting that was higher in quality was associated with more advanced preschool counting and number transcoding skills, but not with more advanced preschool calculation skills.

17. The findings underline the importance of children's preschool language skills in supporting the development of both early reading and early number skills. They suggest that preschool home learning experiences that focus on the sounds within words and the sounds that letters make, will be supportive both of preschoolers' developing language and their number skills.

18. The findings support the integration of interactions that focus on letters and letter sounds into pre-schoolers everyday experiences. Such interactions can be instigated by parents or early years practitioners and do not need to be 'formal'. Informal interactions could include talking about sounds at the start of words in rhymes or songs, identifying letters and the sounds they make in environmental print or talking about letter sounds when sharing books or toys.

Aims and context

The over-arching aim of the project was to analyse the preschool factors that influence children's number skills during preschool and once they have commenced their primary education. We had a particular focus on the influence of the home learning environment.

The importance of Early Number Skills

Our study focused on three key formal early number skills:

- Counting (the ability to use the count-word sequence to enumerate sets)
- Number transcoding (the ability to read and recognise Arabic-Hindu digits)
- Calculation (the ability to add and subtract small quantities using concrete supports)

These skills were chosen because they relate to the number outcomes for the Early Year Foundation Stage in England (Department for Education, 2013; Testing and Standards Agency, 2017). They were thus relevant to the educational stage and age of the children in the sample. It is particularly important to understand the factors that influence the development of these skills because they are predictive of later mathematical achievement (*counting,* Jordan, Kaplan, Locuniak, & Raminni, 2007; Krajewski & Schneider, 2009ab; Moll, Snowling, Göbel, & Hulme, 2015; Nguyen et al., 2016; Passolunghi & Lanfranchi, 2012; Soto-Calvo, Simmons, Willis, & Adams, 2015; Stock, Desoete, & Roeyers, 2009; van Marle, Chu, Li, & Geary, 2014*; number transcoding*, Krajewski & Schneider, 2009b; Moll et al., 2015; van Marle et al., 2014; *calculation*, Jordan et al., 2007; Krajewski & Schneider, 2009b; Soto-Calvo et al., 2015).

The influence of within-child factors

In examining the influence of within-child factors, we built on existing research that has examined the influence of language (e. g. Moll et al., 2015) and executive functioning (e. g. Clements, Sarama, & Germeroth, 2016) on early mathematical development. Whilst research has highlighted the importance of all these skills, there has been limited *simultaneous* analysis of these factors within a

UK longitudinal study. Furthermore, our study allowed the analysis of the relative influence of these cognitive and language factors on *specific* number skills.

The influence of the home learning environment

Research from the UK, continental Europe and North America has associated a more enriched home learning environment with more advanced early number and literacy skills (e.g. Melhuish et al., 2008; Sammons, Toth, & Sylva, 2015). There is now increasing interest in identifying which aspects of the home learning environment underpin these associations. One area of particular focus is the relative influence of home number and home literacy experiences. Reports from North America and continental Europe have associated home number experiences with early mathematics attainment (Anders et al., 2012; Hart, Ganley, & Purpura, 2016; Skwarchuk, Sowinski, & LeFevre, 2014; Huntsinger, Jose, & Luo, 2016; Sonnenschein, Metzger, & Thompson, 2016; Zippert & Ramani, 2017). We have extended this research by examining this relationship in a UK preschool sample. The educational context is different in the UK with children starting their primary school education somewhat earlier than in many European and North American countries. Previous reports as to whether home literacy experiences are related to early numeracy are mixed (Anders et al., 2012; Baker, 2014; Huntsinger et al., 2016; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010; LeFevre et al., 2009; Napoli & Purpura, 2018). This may be because the home literacy indices employed vary in the extent to which they are code- or meaning-focused. Specifically we examined whether code-focused literacy experiences (that focus on the phonological and orthographic structure of language) and meaning-focused literacy experiences (that focus on the meaning of written or oral language at the level of words sentences or narratives) have differential relationships with children’s early number skills. There is some evidence that both phonological awareness (De Smedt, Taylor, Archibald, & Ansari, 2010; Krajewski & Schneider, 2009b; Koponen, Salmi, Eklund, & Aro, 2013; Purpura, Hume, Sims, & Lonigan, 2011; Soto-Calvo et al., 2015) and vocabulary (Moll et al., 2015; Romano, Babchishin, Pagani, & Kohen, 2010) may support the development of early number skills and that these language abilities are influenced by code- and meaning-focused home literacy experiences (Baker et al., 1998; Foy & Mann, 2003; Senechal & LeFevre, 2002). Consequently home literacy experiences may have indirect influence on early number skills via their support for early language skills. Alongside an indirect role it has been suggested that shared reading may have a direct influence on early number skills. Shared reading may have a more direct role as exposure to books may increase the likelihood of parents engaging in spontaneous exchanges of not only literacy-related discourse but also of numeracy-related discourse (see Vandermaas-Peeler, Nelson, Bumpass, & Sassine, 2009, and Barnes & Puccioni, 2017, for discussions of this issue). Our study was able to determine whether any influence of the home literacy environment on early number skills was direct or indirect and principally mediated by relationships between the home literacy environment and language skills.

Wider environmental influences

Some existing research has established relationships between environmental factors beyond the home learning environment and early number skills. These have included socio-economic status (Anders, Grosse, Roßbach, Ebert, & Weinert, 2013; Krajewski & Schneider, 2009a; Sirin, 2005) and preschool hours and quality (Anders et al., 2013; Melhuish et al., 2013; Taggart, Sylva, Melhuish, Sammons, & Siraj, 2015; Sammons et al., 2014; Sammons, Toth, & Sylva, 2015). We gathered detailed information on demographic factors and completed observations of preschool quality so that we could examine the influence of these factors on early number skills.

The core aims are summarised in our three research questions:

1. To what extent do preschool language and executive skills predict growth in early number skills?
2. To what extent do number-oriented and language and literacy-oriented aspects of the home learning environment predict growth in early number skills?

3. To what extent are the relationships between the quality of the home learning environment and early number skills direct and to what extent are they indirectly related via the promotion of language skills?

Methodology

Design and procedure

The study had a longitudinal design following a sample of children from the spring term of preschool (the academic year that children turn 4 years of age) to the final term of Reception (the academic year that children turn 5 years of age). Table 1 summarises the data gathered and sample size at each time point. The questionnaire administered in the spring term of the preschool year (T_1) assessed the frequency of home number experiences, code-focused home literacy experiences and meaning-focused home literacy experiences. It also included a book exposure measure of shared reading as this has been hypothesised to have a direct impact on early number skills (see Vandermaas-Peeler, Nelson, Bumpass, & Sassine, 2009; Barnes & Puccioni, 2017). Alongside these indices of the home learning environment, it also included questions on demographic factors and parental attitudes towards mathematics.

Table 1: Data gathered, sample size and composition at each time point

	Spring Term Preschool		Summer Term Preschool		Summer Term Reception
Time point	T_{1a}	T_{1b}	T_{2a}	T_{2b}	T_3
Sample size[1]	274 (146)	274 (146)	266 (141)	199 (106)	232 (127)
Mean age[2]	3:11 (3.6)	4:0 (3.6)	4:3 (3.7)	-	5:3 (3.6)
Measures at this time point	Home learning environment questionnaire	Early number skills assessments	Language and cognitive assessments[3]	Preschool quality observations	Early number skills assessments Standardised mathematics and reading measures[3]

Notes. [1]Children with valid data at this time point. Number of females shown in brackets.

[2]Standard deviation shown in brackets.

[3]Includes children with full or partial data.

We contacted a range of preschool settings across the counties of Merseyside, Cheshire and Lancashire. A total of 41 settings responded and gave consent to participate in the study. We supplied copies of the home learning environment questionnaire directly to these preschools and asked them to distribute it to the parents of children born between the 1st of September 2012 and the 31st of August 2013 registered in their setting.

We received questionnaires relating to children within this age bracket from 40 settings. During the spring term of preschool (T_1) we assessed the early number skills of 274 children whose parents had returned completed questionnaires. We revisited these children in the summer term of preschool (T_2) to administer cognitive and language assessments and again in the summer term of Reception (T_3) to re-administer the early number skills assessments as well as to administer standardised measures of reading and mathematics. During the summer term of preschool (T_2) we also conducted standardised observations using the Early Childhood Environment Rating Scale-3 (Harms, Clifford, & Cryer, 2014) to assess the quality of the preschool settings of 199 children within the sample. The number of children retained at each time point is shown in Table 1.

Sample

The settings. The 40 participating settings were broadly representative of English Early Years provision, with 24 settings (60%) being private or voluntary nurseries or preschools (60% nationally), 12 (30%) being nursery classes within a maintained school (31% nationally), three (7.5%) being maintained nursery schools (4% nationally) and one (2.5%) being a nursery class within an independent school (2% nationally). When re-assessed at T_3 the children had transferred to 72 primary schools.

The parents. Of the 274 parents who completed the questionnaire 254 were female. The postcode deprivation decile for each household was obtained from the English indices of deprivation 2015 online open data of the United Kingdom (Department for Communities and Local Government, http://imd-by-postcode.opendatacommunities.org/). The mean deprivation level was close to the national average (M = 5.42, SD = 3.32). Three respondents did not supply their postcodes. Parental qualifications were coded according to the UK National Qualification framework (https://www.gov.uk/what-different-qualification-levels-mean/list-of-qualification-levels). This scale levels qualifications from 1 (qualifications equivalent to a lower grade GCSE, typically taken by 16-year-olds) to 8 (doctoral level qualifications). Parental highest level of education was diverse, with a mean which was broadly equivalent to two years of post-secondary education (M = 4.75, SD = 2.00). Four respondents did not report their qualifications.

The children. Parents were asked to report the ethnicity of their child, which was coded according to the categories used in the 2011 UK Census. A total of 249 (90.9%) of the children were white, 17 (6.2%) were of mixed/multiple ethnic heritage, four (1.5%) were Asian, three (1.1%) were Black and one (0.4) was classified as 'other' (a category that includes any ethnicity other than white, mixed/multiple, Asian or Black). Twenty-three children (8.4%) spoke a language in addition to English at home. A range of European, Asian and African languages were reported. Two children could use sign language in addition to spoken English to communicate.

A total of 15 children (5.5%) were described by their parents as having a special educational need or disability (SEND) or as being referred for or undergoing investigations because such a need was suspected. A range of needs were reported including speech and language impairments, autism and physical disabilities. These 15 children were included in the sample as they were judged able to comprehend the tasks and respond appropriately during the practice items. Inclusion of children with SEND in the sample is a more accurate reflection of the population of children attending mainstream preschools in the UK than excluding them.

The total number of preschool sessions per week was obtained by adding the number of sessions the child attended at the participating setting and an additional setting (where applicable) per week. A session equates to a half-day attendance (either morning or afternoon). On average children attended approximately six sessions a week (M = 5.74, SD = 1.65).

Measures

Home Learning Experiences. Parents were asked to report the frequency on a 6-point Likert scale ranging from *never* to *several times a day* that their child experienced 32 activities at home. There were eight number experiences, eight meaning-focused literacy experiences and seven code-focused literacy experiences. In addition, there were nine domain non-specific filler items that were not analysed (e.g. rides a scooter, balance bike or bike). The different types of items were randomly ordered within the questionnaire.

Book Exposure. This measure indexes parental familiarity with preschool book titles and is used as a measure of parent-child shared reading (see Dilnot, Hamilton, Maughan, & Snowling, 2017; Hamilton, Hayiou-Thomas, Hulme, & Snowling, 2016; Hume, Lonigan, & McQueen, 2015; Puglisi, Hulme, Hamilton, & Snowling, 2017; Skwarchuk et al., 2014; Sénéchal, Lefevre, Thomas, & Daley, 1998; Sénéchal, Pagan, Lever, & Ouellette, 2008). The book exposure scale consisted of a list of 21 book titles. Six titles were made-up and 15 were real. Each respondent was asked to indicate which book titles were real children's books. They were given three choices; 'real', 'made-up' and 'don't know'. The number of correctly identified real titles and falsely identified made-up titles was recorded. Responses to the book title checklist were then used to create a book exposure variable using the same formula as Skwarchuk et al. (2014), which corrects for guessing [(Story books titles correctly identified - Foils identified as real books) / total number of actual books] x 100). Six respondents did not complete this section.

Mathematical Attitudes. Parents indicated how much they agreed with 20 statements about their thoughts and feelings towards mathematics on a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*. The items were selected from the Attitudes to Mathematics Inventory (Tapia, 1996), excluding those relating to ongoing mathematics education. A higher score indicated more positive attitudes towards mathematics.

Early Number Skills. All number skills tasks were completed in one-to-one sessions in a quiet area of the child's preschool (T_1) or school (T_3). There was one sequential counting measure, two measures of counting (*give me x* and *counting objects*), two measures of number transcoding (*numeral reading* and *numeral recognition*) and two measures of calculation (*addition* and *subtraction*). In the *sequential counting* task children were asked to count out loud to a cuddly toy starting from one to as high as they could. The highest number recited in the correct order was recorded. In the *give me X* task the child was asked to place a specific number of toy animals (that they had to select from a larger set) on a drawing of a farm and in a house (e.g. "Can you put two ducks in the pond?"). In the *counting objects* task the children were asked to count animal pictures presented on a card (e.g. "How many bears are there?"). There were 20 cards with pseudo-randomly distributed pictures of animals on each card. The cards were grouped into four blocks each consisting of five items. In the *numeral recognition* task the researcher asked the child to point at a specific number (e.g. "Can you point to number five?"). In the *numeral reading* task children were asked to name the printed numerals that the researcher pointed at on a sheet of card. Each card displayed five numerals. In the *addition* and *subtraction* tasks the experimenter presented each problem to the child in the form of story (e.g. “If you put two horses on the path and you add one more, how many horses would there be?”). Animal toys and a drawing of a farm or a house were available to help the child complete the calculation. The child was asked to provide a verbal response.

Cognition and language assessments. Two subtests from the Preschool and Primary Inventory of Phonological Awareness (PIPA, Dodd, Crosbie, MacIntosh, Teitzel, & Ozanne, 2000) were administered to assess children’s phonological awareness. In the *Alliteration Awareness* subtest children had to identify the word (from a choice of four) that did not start with the same sound as the others. In the *Rhyme Awareness* subtest children had to identify the word (from a choice of four) that did not rhyme with the others. Both of these tests consisted of two practice items and 12 experimental items. Vocabulary was assessed with two standardised measures. In the *Naming Vocabulary* subtest from the British Ability Scales III (BAS-3, Elliott & Smith, 2011) children had to name a picture presented to them. In the *Receptive Vocabulary* subtest from the Wechsler Preschool and Primary Scale of Intelligence - Fourth UK Edition (WIPPSI-IV-UK, Wechsler, 2013) children had to point at the picture (from a choice of four) that best matched the word said by the researcher. Non-verbal reasoning was assessed with two standardised measures. In the *Matrices* subtest from the British Ability Scales III (BAS-3, Elliott & Smith, 2011) the child had to choose the shape that best completes the pattern (from a choice of 4). In the *Picture Similarities* subtest from the British Ability Scales III (BAS-3, Elliott & Smith, 2011) the child had to place a card under the picture (from a choice of 4) that best fitted with the picture on the card. Executive functioning was assessed with two experimental measures, which had been used previously with preschool children. The *Fish/Shark task* (Wiebe, Sheffield, & Espy, 2012) task was a response inhibition task presented on a laptop computer. The children had to press a key when they saw a fish (to catch it), but inhibit this response when they saw a shark. The *d’* index was calculated (this is a sensitivity index, which represents how accurately the child detects the fish and rejects the sharks). The *Big-Little* stroop (Kochanska, Murray, & Harlan, 2000) was a verbal inhibition task. The child was shown the large outline of an animal with smaller animal outlines presented within it. The large outline appeared briefly first (priming effect). The child's task was to inhibit naming the larger animal and state what the smaller animals within the outline were. Children's performance was indexed by the percentage of incongruent trials (where the larger outline differed from the smaller ones within it) responded to correctly.

Standardised measures of mathematics and reading. Standardised measure of mathematics (*BAS-3 Early number concepts*, Elliot & Smith, 2011) and reading (*YARC Early word recognition*, Hulme et al., 2009) were administered. The mathematics measure covered a broad range of mathematical concepts that were relevant to the age of the children. The reading measure required children to read aloud regular and irregular words. Children's performance on the key measures is shown in Table 2.

Table 2: Performance across the key measures at the different time points

	Maximum[1]	T_1	T_2	T_3
Sequential counting		16.57 (14.23)		56.91 (38.43)
Counting objects	20	5.14 (2.72)		9.78 (4.08)
Give me x	15	3.17 (2.47)		8.29 (3.53)
Numeral recognition	20	6.41 (5.32)		17.57 (6.00)
Numeral reading	20	5.07 (3.99)		13.39 (4.93)
Addition	12	1.69 (2.25)		5.83 (3.40)
Subtraction	12	2.23 (2.23)		5.37 (3.41)
Alliteration[2]			9.79 (2.93)	
Rhyming[2]			9.72 (2.76)	
Receptive vocabulary[1]			10.02 (3.07)	
Expressive vocabulary[3]			52.27 (9.80)	
Big/Little Stroop			75.70 (26.71)	
Fish/Shark			1.74 (1.12)	
Picture similarities[3]			47.01 (9.60)	
Matrices[3]			43.10 (9.48)	
BAS Number concepts[3]				49.80 (11.67)
YARC Word decoding[4]				115.87 (12.92)

Notes. Age standardised scores given for all standardised measures. [1]Maximum possible score. [2]Standardised mean of 10. [3]Standardised mean of 50. Examination of the children's performance on the early number skills tasks demonstrates clear growth from T_1 to T_3. [4]Standardised mean of 100. Performance on the standardised measures is broadly comparable to that of the standardisation samples with the exception of word decoding where they are performing somewhat above average. We believe that the elevated word reading score is likely the result of two factors. First, the increase in young children's word decoding skills in recent years (Department for Education, 2018) and second the fact that all of our children had commenced their formal reading education whereas a proportion of the standardisation sample were still attending preschool.

Analysis Strategy and Key findings

Data Reduction

Home Experiences and Mathematical Attitudes. Prior to subsequent analyses we created scales for the number, code-focused literacy and meaning-focused literacy experiences. First, we removed items with limited variability then we conducted a Principal Axis Factoring (PAF) analysis on each scale separately. Whilst the home number experiences and the meaning-focused home literacy experiences formed a single scale, the code-focused home literacy experiences fractionated into two scales. One contained activities that were more interactive and focused on sounds or the links between letters and sounds. We therefore labelled this scale *Letter-sound interactions*. The second contained activities that were less interactive and focused less on sounds. We therefore labelled this scale *Letter activities*. The final items that were contained in these scales are shown in Table 3. The mathematics attitudes items fractionated into two scales one that was labelled *Mathematics feelings and competence* and one that was labelled *Mathematics interest and satisfaction*.

Table 3: Items within the final home experiences scales

		Code-focused literacy	
Number	Meaning-focused literacy	Letter-sound interactions	Letter activities
Is encouraged to point out or identify numbers in books or the environment (e.g. "What number is on the bus? Can you see a number 8?")	Discusses stories with an adult (e.g. "What do you think happens next? Do you think the bunny is frightened?")	Talks about letter sounds with an adult (e.g. "What sound does snake start with?", "Can you think of any other words starting with 's'"?	Plays with puzzles or games involving letters
Is taught the names of numbers (e.g. "This is number 8")	Is encouraged to point out or identify pictures in books (e.g. "Can you point to the elephant?")	Is taught the names or sounds of letters or how to 'sound out' words	Sings or recites the alphabet
Writes or traces numbers	Is encouraged to choose books that interest them to look at with an adult	Forms or traces letters or writes their name	Completes activities involving letters or sounds in magazines or workbooks
Completes number activities in magazines or workbooks	Is encouraged to use books to follow-up interests or experiences they have (e.g. looking at a space book because that had talked about space at preschool)	Is prompted to identify letters in books or the environment (e.g. "Can you see a's' on the sign?", "What letter does the word cat begin with?")	
Plays games that involve number cards, dice or a number spinner	Discusses with an adult how things work or what they mean (e.g. "Why do you think the ice lolly is melting?", "Nocturnal animals sleep in the day")		
Discusses numbers or quantity with an adult (e.g. "How many blocks are there?", "Who has more sandwiches?")	Looks at factual books (e.g. books about animals, space or transport)		

Early number skills. Prior to subsequent analyses we used confirmatory factor analysis (CFA) to confirm that our number skills measures loaded onto the three factors we hypothesized (counting, number transcoding and calculation). This three-factor structure was a good fit for the data at both T_1 and T_3 for the six core tests. However, sequential counting could not be accommodated in the model either as a single observed measure or as part of the counting factor since it reduced the fit of the model. Consequently, it was dropped from subsequent analyses. The preferred model of early number skills at T_1 and T_3 is shown in Figures 1 and 2.

Figure 1. Relationships between the number skills measures and number factors at time 1

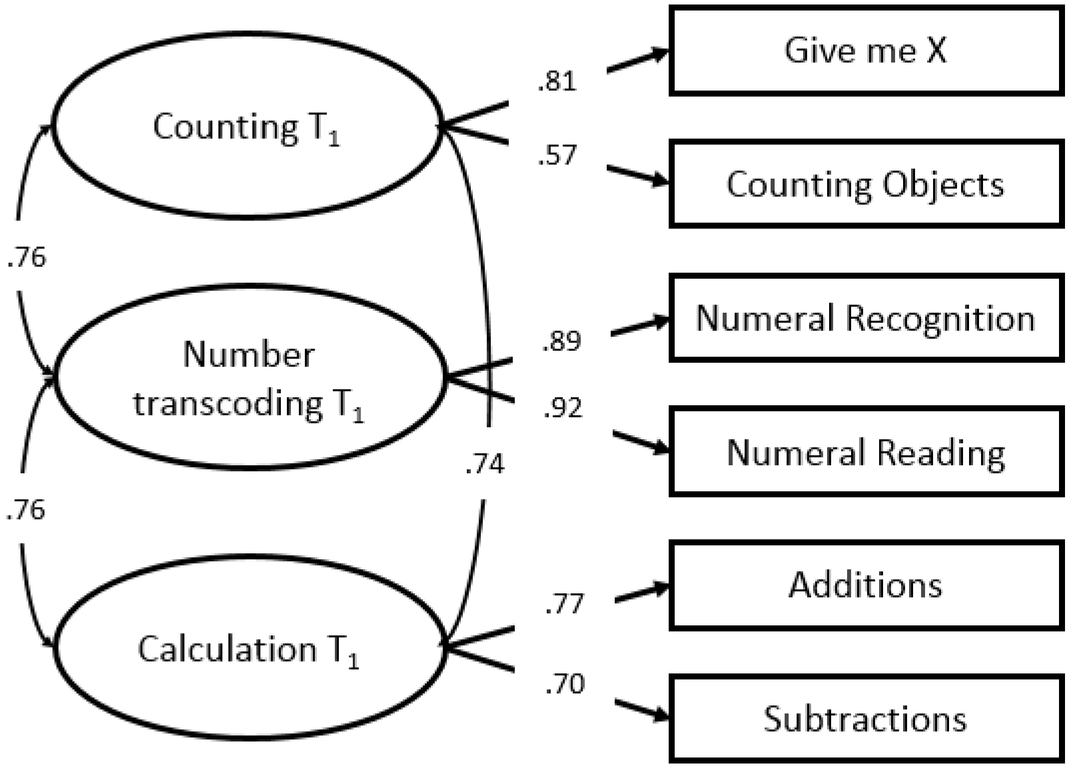
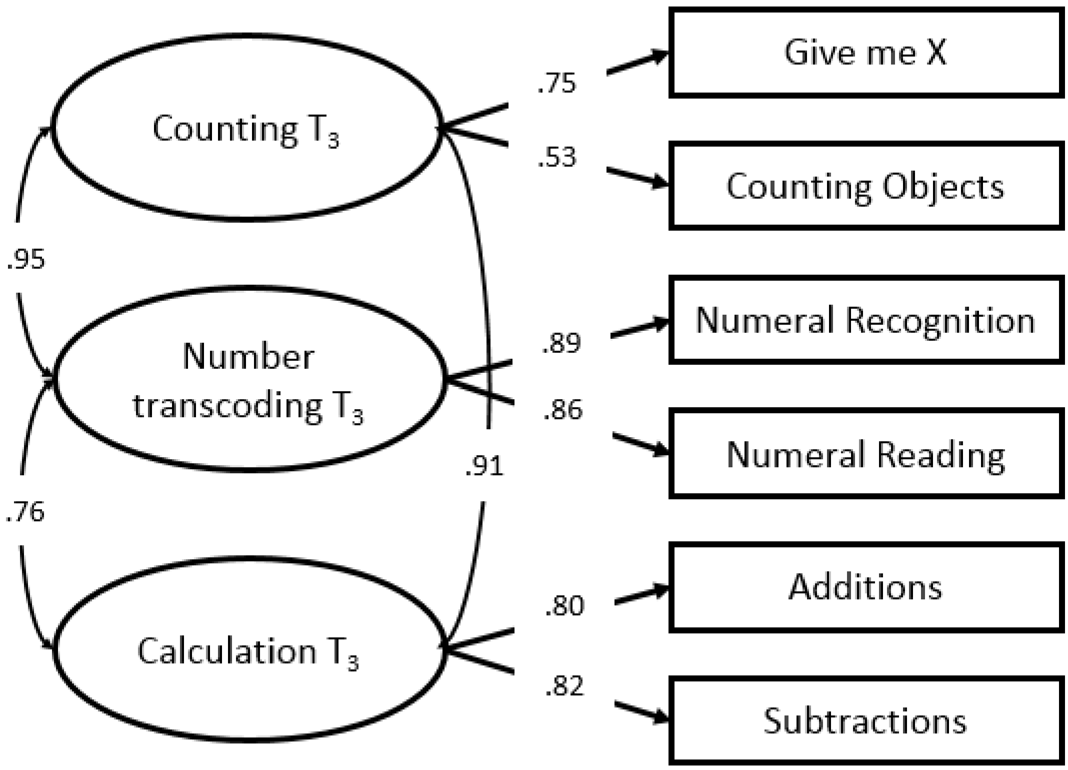
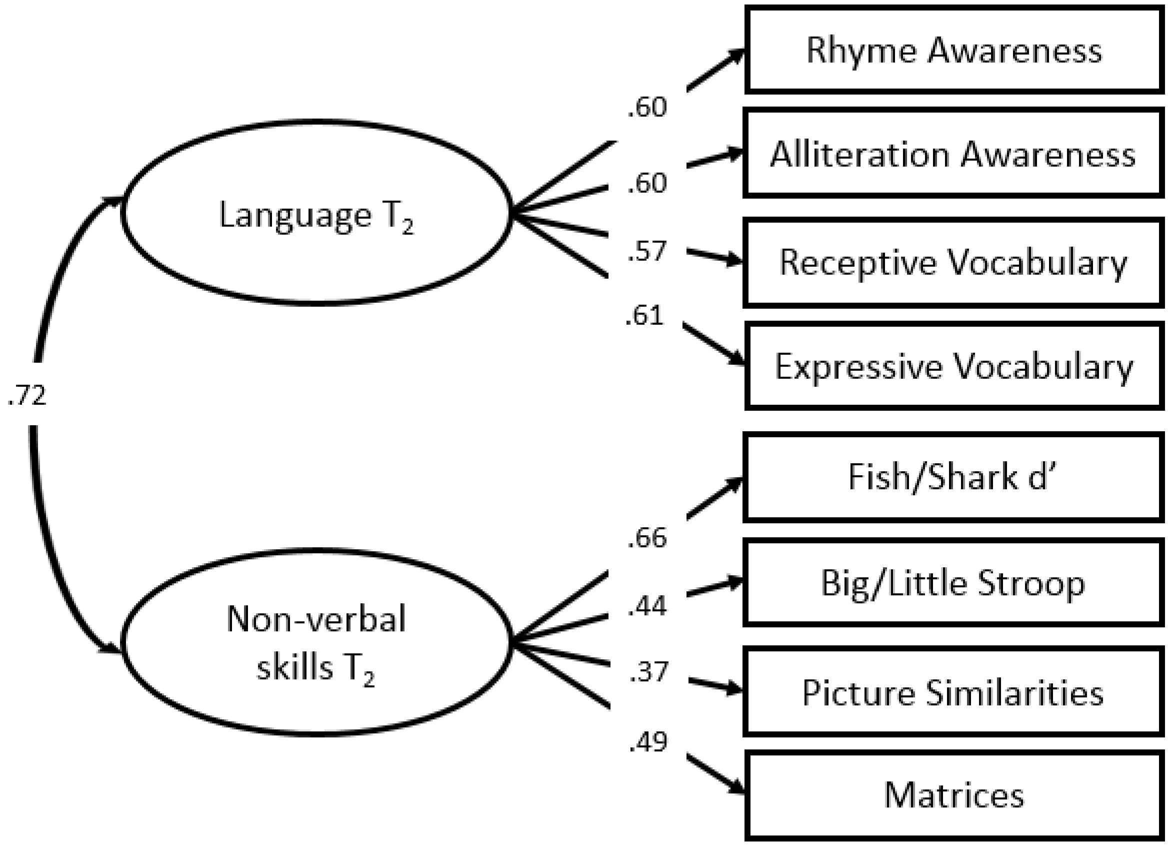


Figure 2. Relationships between the number skills measures and number factors at time 3



Language and cognition. Prior to subsequent analyses we used CFA to determine an appropriate factor structure for the language and cognitive factors. Our original intention was to create four factors (vocabulary, phonological awareness, executive functioning and non-verbal reasoning), however this model did not provide an appropriate fit of the data because the executive and non-verbal reasoning measures were too highly related. Consequently, we produced two further models. In the first three-factor model, phonological awareness and vocabulary remained separate factors with a single non-verbal skills factor. In the second we created just two factors, language skills (encompassing both phonological awareness and vocabulary) and non-verbal skills (encompassing both non-verbal reasoning and executive skills). Both these models provided an adequate fit of the data. However, the model comprising two factors, language skills and non-verbal cognition, was taken forward for subsequent analyses (illustrated in Figure 3) because it provided a better fit of the data. Furthermore, within the alternative three-factor model the separate phonological awareness and vocabulary factors were highly correlated which is problematic when entered as simultaneous predictors within longitudinal analyses.

Figure 3. Relationships between the language and cognitive measures and factors at time 2



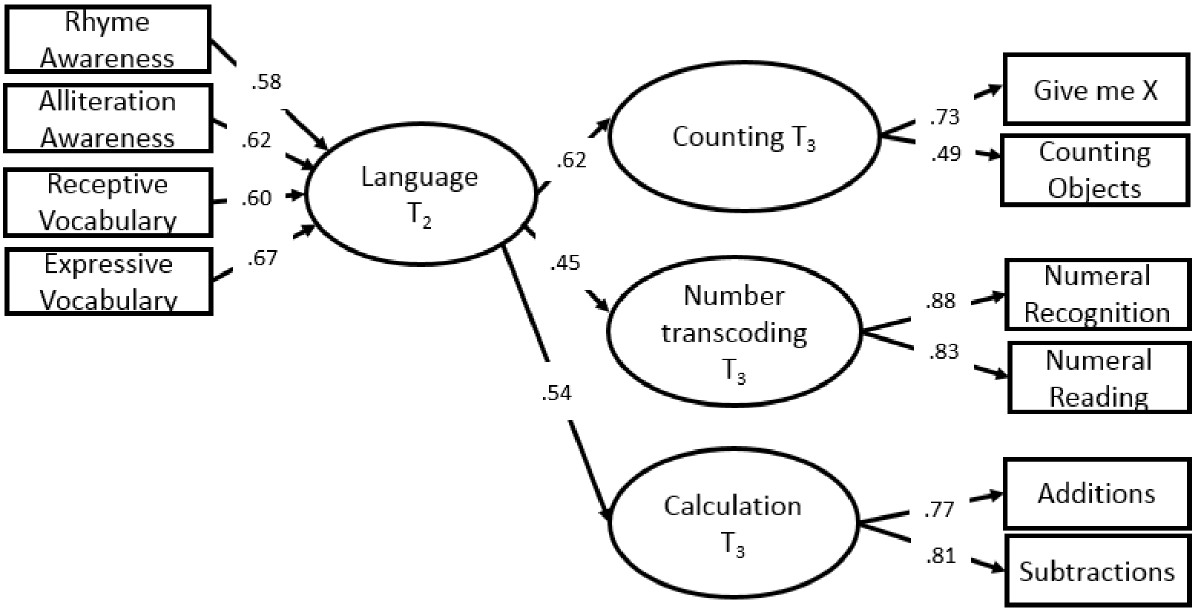
Examining the validity of the early number skills assessments

Before examining the predictors of early number skills, we examined the validity of the assessments by considering the extent that they explained variance in the standardised test of mathematics. A regression analysis indicated that the three number skills assessed at T_3 could explain 44% of the variance in a standardised measure of early mathematics (*BAS-3 Early number concepts*). Furthermore, counting, number transcoding and calculation all explained unique variance in the mathematics assessment. This suggests that although these three aspects of number are related, they all make unique contributions to children's overall mathematical attainment.

Examining the extent that preschool number, cognitive and language skills predict early number skills

We created a structural equation model (SEM) where the language and cognitive skills at T_2 predicted the early number skills at T_3 (illustrated in figure 4). This model provided an adequate fit of the data with preschool language skills, but not non-verbal skills predicting children's counting, number transcoding and calculation at the end of Reception.

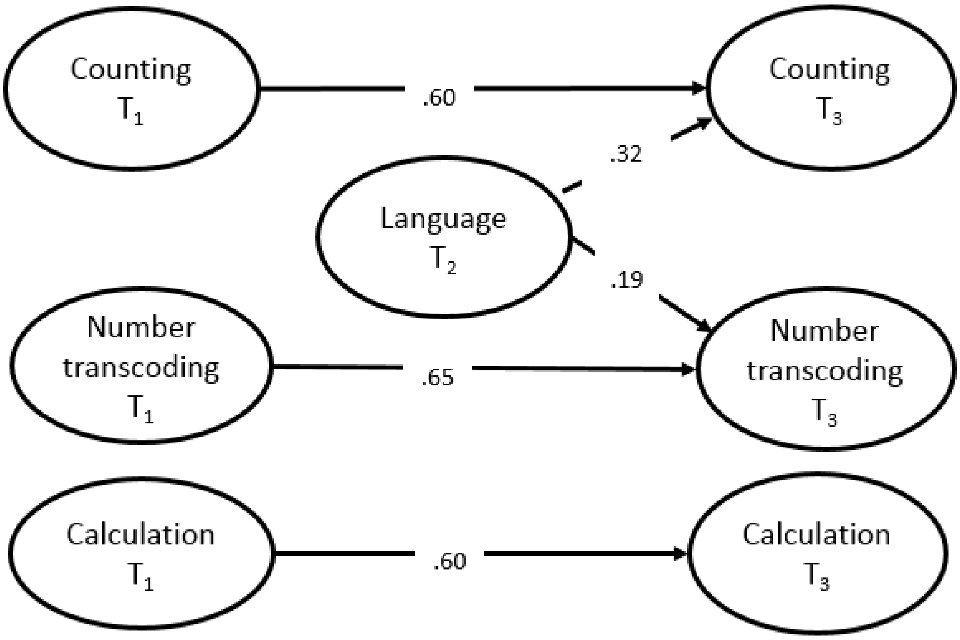
Figure 4. Longitudinal relationships between language (at time 2) and the number factors at time 3



Note. The non-verbal skills factor was entered as a predictor in this model, but is not illustrated as none of the paths from non-verbal skills to the number factors were significant.

A further model of these relationships (illustrated in Figure 5) was then created where children's initial number skills were controlled. Again this model provided an adequate fit of the data. Verbal skills remained a significant predictor of counting and number transcoding indicating that they are predictive of Reception outcomes even when preschool early number skills abilities are controlled. Within this model the relationship between verbal skills and calculation approached conventional levels of significance (p = .07). Furthermore, preschool number skills are also predictors of Reception number skills. We can therefore conclude that language skills predict growth in counting and number transcoding between preschool and the end of Reception.

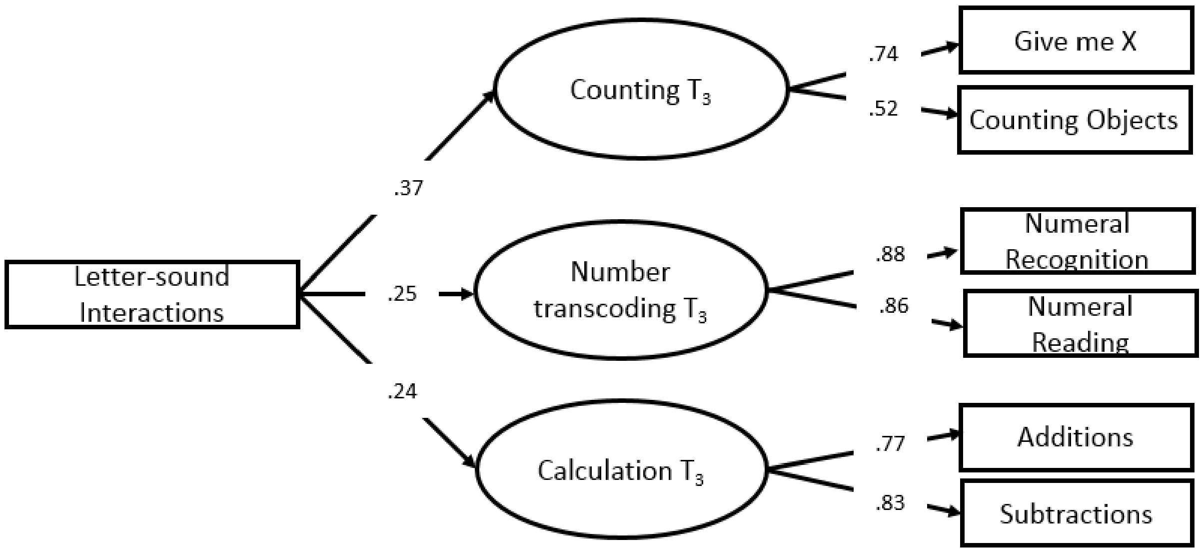
Figure 5. Longitudinal relationships between language (at time 2) and the number factors (at time 3) with initial skill levels controlled



Examining the aspects of the home learning environment that predict early number skills

Before creating a longitudinal SEM to predict number skills in Reception we considered which aspects of the home learning environment were correlates of the early number skills at T_3. Whilst number-focused home experiences and letter-sound interactions were consistent significant correlates of the children's early number skills, the correlations between meaning-focused home literacy experiences, book exposure and the mathematical attitudes were broadly nonsignificant. We therefore concluded that for our sample, meaning-focused home literacy experiences, shared reading and mathematical attitudes were not important determinants of early number skills. As both were indices of code-focused literacy, letter activities and letter-sound interactions were related. To avoid issues arising from of multicolinarity disrupting the models, we chose to take forward letter-sound interactions as our code-focused literacy index in our longitudinal analyses. Letter-sound interactions was chosen as the index of code-focused literacy because it had stronger and more consistent relationships with the early number skills. Consequently, we created SEMs to examine whether preschool number skills were independently predicted by letter-sound experiences and number experiences. Alongside these aspects of the home learning environment, we entered two indices of socio-economic status (home postcode deprivation decile and parental qualification level) and the number of preschool hours attended as controls. This model (illustrated in Figure 6) had a good fit of the data. Home letter-sound interactions was a significant predictor, whereas the other predictor variables were not. We can therefore conclude that letter-sound interactions are the key aspect of the preschool home learning environment that best predicts number skills at the end of Reception.

Figure 6. Longitudinal relationships between letter-sound interactions (at time 1) and the number factors at time 3



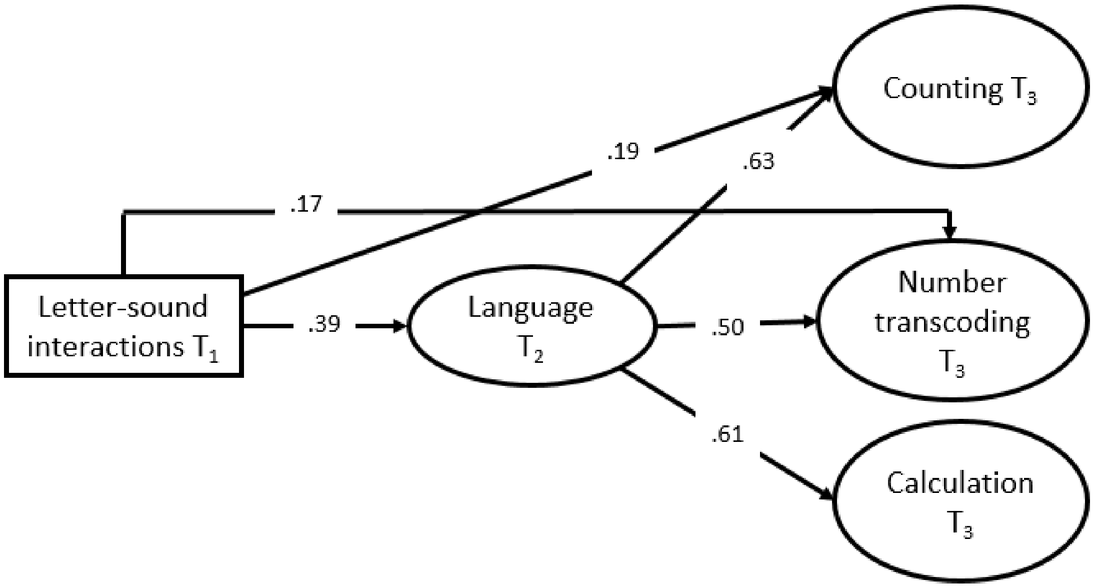
Note. Home number experiences, book exposure, preschool hours, postcode deprivation and parental qualifications were all entered as predictors in this model, but are not illustrated as none of their paths to the number factors were significant

Alongside our SEM we conducted hierarchical linear regressions to determine whether letter-sound interactions could predict significant variance in the early number skills in Reception *over and above* the variance explained by children's preschool number skills. These regressions explained 45% of children's number transcoding skills, 26% of children's counting skills and 30% of children's calculation skills. Significant variation in children's counting and number transcoding could be explained in both children's counting and number transcoding once children's initial abilities in these skills levels were controlled. However, this was not the case for calculation; once children's initial skill levels were controlled, letter-sound interactions no longer explained significant variance in Reception calculation skills.

Determining whether language skills mediate the relationship between letter-sound interactions and early number skills.

Given that both letter-sound interactions at home and language skills predicted number skills at the end of Reception it is important to determine the nature of the interrelationships. One possibility is that letter-sound interactions support early number skills via their support for language skills. Alternatively (or additionally) they may have a direct relationship with children's early number skills potentially because these experiences provide direct support for the development of the number skills. For example, such experiences may develop children's broader understanding that symbols have meaning. We therefore created a SEM (illustrated in Figure 7) to test both the direct and indirect paths between letter-sound interactions in preschool and the early number skills in Reception. This model provided a good fit of the data. Letter-sound interaction was significantly related to children's language skills and their language skills were related to counting, number transcoding and calculation. Furthermore, direct paths from letter-sound interactions to counting and number transcoding were also significant. The direct path from letter-sound interactions to calculation was not significant. Consequently, we can conclude that there is a direct path between the frequency of preschoolers' letter-sound interactions at home and their counting and number transcoding abilities in Reception, even when variation in language skills has been accounted for. The relationship between letter-sound interactions and counting and between letter-sound interactions and number transcoding is only partially mediated by children's language skills. In contrast, the relationship between children's letter-sound interactions and calculation is fully mediated by their language skills.

Figure 7. Direct and indirect longitudinal relationships between letter-sound interactions (at time 1) and the number factors (at time 3)



The role of preschool quality

For the subsample of children for whom we had a preschool quality measure we examined the extent that preschool quality could predict children's preschool counting and number transcoding skills independently of socio-economic status and our core home learning environment predictor (letter-sound interactions). We created three linear regressions predicting counting, number transcoding and calculation, respectively. Each regression had the same four predictors (preschool quality, letter-sound interactions, postcode deprivation decile and parental qualification level) entered simultaneously. Each regression predicted a modest but statistically significant proportion of the variance in the number skills (counting 15%, transcoding 17% and calculation 8%). Letter-sound interactions was a significant, independent predictor of all the number skills with preschool quality also being a significant predictor of counting and number transcoding. These findings highlight a relationship between the quality of preschool provision and children's counting and number transcoding attainments.

Examining the relationships between letter-sound interactions, language skills and early reading

The central focus of our study was examining the development of early number skills, however, we also included a reading measure. We conducted a regression to examine whether preschool letter-sound interactions and book exposure predicted reading alongside established language predictors. The regression had eight predictors (alliteration awareness, rhyme awareness, expressive vocabulary, receptive vocabulary, book exposure, letter-sound interactions, postcode deprivation decile and parental qualification level) entered simultaneously, with children's scores on the early word decoding test (Hulme et al., 2009) taken in the final term of Reception as the outcome. A significant proportion (28%) of the variance in children's reading scores was explained. In common with previous findings, measures of phonological awareness (alliteration awareness) and vocabulary (expressive vocabulary) were significant predictors. Letter-sound interactions, but not book exposure, was also a significant predictor. These findings suggest that home letter-sound interactions have a role in reading development alongside children's language skills.

Key conclusions

- Preschool children's language skills predict children's counting and number transcoding at the end of Reception (even when preschool number skill level is controlled). This suggests that language skills support growth in these number skills between preschool and the end of Reception.
- Children's preschool non-verbal skills (executive functioning and non-verbal reasoning) were related to number skills at the end of Reception. However, these relationships were not independent of preschool language skills.
- Preschool number skills are predictive of children's number skills at the end of Reception (even when general language abilities are controlled). This suggests that the number skills acquired during the preschool period provide a foundation for children's mathematical development when they move into Reception.

- Letter-sound interactions at home during the preschool period are related to both preschool children's language skills and to their number skills at the end of Reception. These experiences also predict a significant proportion of variance in children's word reading at the end of Reception even when children's language skills are controlled.
- Preschool home number experiences were related to children's number skills both in preschool and Reception. However, these relationships were not independent of letter-sound interactions.
- The relationship between letter-sound interactions and both counting and number transcoding is particularly robust. Letter-sound interactions in preschool can predict significant variance in both counting and number transcoding over and above the variance that can be explained by children's preschool initial skill level. Furthermore, there is a significant direct pathway between letter-sound interactions and counting and between letter-sound interactions and number transcoding even when language skills are accounted for. This suggests that letter-sound interactions at home are supportive of the development of counting and number transcoding between preschool and the end of Reception.
- Preschool quality is associated with preschool counting and number transcoding skills.

Implications for policy and practice

The influence of preschool number skills

Our findings highlight that the number skills with which children start Reception support their numerical development over the first year of primary school. Children acquire counting, number transcoding and early calculation skills during the preschool period although there are large individual differences in their level of attainment. Both parents and early years practitioners have a role in supporting the development of these skills. Our findings indicate that overall preschool quality is linked to preschool counting and number transcoding abilities, suggesting that high-quality settings can play an important role in the development of these skills. Our quality measure was a very broad index of overall setting quality therefore a priority for future research will be analysing which aspects of quality preschool practice best support children's developing number skills.

The influence of preschool language skills

Our findings further reinforce the message that developing preschoolers' language skills lays a foundation for their future academic development. Much previous research has identified the role early language plays in supporting early reading (e. g. Bradley & Bryant, 1983; Maclean, Bryant, & Bradley, 1987; Senechal & LeFevre, 2002), which is reinforced by our own findings relating both measures of preschool phonological awareness and vocabulary to children's reading attainment at the end of Reception. Furthermore, we add to this literature by showing that even after accounting for initial skill levels in preschool, preschool language abilities predict significant variance in number skills assessed at the end of Reception. This suggests that developing children's vocabulary abilities and phonological awareness in preschool would be supportive not only of later reading, but also of later counting and number transcoding.

The influence of the preschool home learning environment

Our index of the code-focused aspects of the preschool home literacy environment, letter-sound interactions, was the strongest environmental predictor we identified. It was the only aspect of the home learning environment that predicted language skills and the only aspect of the home learning environment that could predict *unique* variance in the children's number skills at the end of Reception. The relationships between letter-sound interactions and both counting and number transcoding are particularly robust with significant variance being explained even if initial number skill levels or language skills are controlled. In contrast, the meaning-focused indices of the home learning environment were largely unrelated to children's early number skills. Together these findings indicate that it is code-, not meaning-focused home literacy experiences, that are supportive of early number skills development. The role of the home number experiences is more equivocal. Whilst these experiences were significantly correlated with the early number skills, they could not explain significant unique variance when analysed alongside letter-sound interactions.

The findings suggest that the experiences encompassed in the letter-sound interactions scale are likely to support preschoolers' academic and language development. These activities emphasise the sounds within words and the sounds that letters make. The experiences do not need to be 'formal' and can involve discussing letter-sounds and letters as part of preschoolers' everyday activities. We would suggest that early years practitioners and parents should be encouraged to talk about the sounds within words and their relationships with letters as part of their everyday interactions with preschoolers. In the same way that adults commonly identify colours and numbers to young children, our findings suggest that it is also important to highlight letter-sounds. This could involve talking about sounds at the start of words in rhymes or songs, discussing whose name starts with a particular sound, identifying letters and the sounds they make in environmental print or talking about letter sounds when sharing books or toys. Such experiences are likely to be beneficial to children's language and academic development and if integrated into daily activities in supportive, sensitive and age-appropriate manners have few, if any, negatives. Consequently, we would view the key policy implication of our findings as raising awareness both with the public and with early years professionals of the value of such interactions for academic development.

An important further step is investigating how best to support parents and early years practitioners in integrating such letter-sound interactions into their activities with preschoolers. Awareness of the value of such activities alone may not be enough. Parents and early years practitioners may lack the confidence to discuss the phonological or orthographic aspects of language and links between them with very young children or lack confidence in their ideas as to how they can be easily integrated into children's daily experiences. The benefits of small group interventions that develop phonological skills in the preschoolers have been intensively studied (see Ehri et al., 2001). However, a priority for future research would be to assess the value of low-intensity interventions that aim to support parents in including more code-focused literacy interactions into their everyday activities.

The inability of home number interactions to predict early number skills once variance explained by letter-sound interactions was accounted for was somewhat unexpected. Although a relationship was identified between home number experiences and early number skills it was not as robust as the relationship with letter-sound interactions. We believe there are at least two possible explanations for this. The first may relate to the frequency of the different types of experiences. Number experiences were reported less frequently than either meaning-focused literacy experiences or letter-sound interactions. It may be that with home number experiences being relatively infrequent that they do not impact on individual differences in early number skills. The second relates to the 'challenge' provided by the activities in the questionnaire. Recent research (Elliot & Bachman, 2017; Skwarchuk et al., 2014; Thompson, Napoli, & Purpura, 2017) has suggested that more challenging home number activities have a closer relationship with children's mathematical attainment than less challenging ones. We chose the activities in the questionnaire to be broadly appropriate for the age of the children in the sample, however, large individual differences in the development of these skills was expected and observed. Future research would need to investigate whether more challenging home number activities are stronger predictors of children's developing mathematical skills.

The present study has been able to identify home experiences that are beneficial to the development of early number skills. In addition, the extent to which specific early number skills may be associated with these experiences has also been clarified. We have succeeded in quantifying the relative associations between both external and within-child factors and the attainment of early number skills, which are critical to later mathematical development in school.

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