Received: 19 October 2021 | Revised: 13 May 2022 | Accepted: 25 July 2022

DOI: 10.1111/desc.13316

Developmental Science WILEY

SHORT REPORT

Preschool language and visuospatial skills respectively predict multiplication and addition/subtraction skills in middle school children

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Funding information
Agence Nationale de la Recherche, Grant/Award Numbers: ANR-10-IDEX-0001-02 PSL, ANR-12-DSSA-0005-01, ANR-17-EURE-0017

Abstract

A converging body of evidence from neuroimaging, behavioral, and neuropsychology studies suggests that different arithmetic operations rely on distinct neuro-cognitive processes: while addition and subtraction may rely more on visuospatial reasoning, multiplication would depend more on verbal abilities. In this paper, we tested this hypothesis in a longitudinal study measuring language and visuospatial skills in 358 preschoolers, and testing their mental calculation skills at the beginning of middle school. Language skills at 5.5 years significantly predicted multiplication, but not addition nor subtraction scores at 11.5 years. Conversely, early visuospatial skills predicted addition and subtraction, but not multiplication scores. These results provide strong support for the existence of a double dissociation in mental arithmetic operations, and demonstrate the existence of long-lasting links between language/visuospatial skills and specific calculation abilities.

KEYWORDS
addition, arithmetic skills, language, multiplication, visuospatial skills

1 | INTRODUCTION

Behavioral and neuroimaging evidence suggest that different types of arithmetical operations rely on partially different cognitive processes and partially segregated brain circuits (Dehaene et al., 2003). On the one hand, subtraction and addition operations rely more on nonverbal quantitative representation of numbers, underlain by visuospatial abilities. At the neural level, this is associated with an increased activity in mid and posterior parietal activation bilaterally, typically associated with quantity and spatial processing, during subtraction and addition, compared to multiplication (Lee, 2000; Prado et al., 2011; Zhou et al., 2007). On the other hand, multiplication tables are typically rote learnt and stored in verbal memory (Verguts & Fias, 2005). This is reflected by the fact that solving mental multiplication problems (compared to subtractions and additions) results in increased activation in regions involved in verbal processing, such as the left angular gyrus, and the inferior frontal and middle temporal gyri of the left hemisphere (Lee, 2000; Prado et al., 2011; Zhou et al., 2007). Interestingly, such dissociation between operations is so powerful that even the mere view of the arithmetical signs ("+", "-", or "×") triggers different responses: when subjects are presented with addition or subtraction, but not multiplication signs, even in the absence of any arithmetical operation to perform, they engage in involuntary shifts of visuospatial attention along the horizontal plane (Li et al., 2018). Moreover, they activate regions of the posterior parietal cortex linked to spatial attention shifts (Mathieu et al., 2018).

These results are corroborated by behavioral evidence suggesting that addition and subtraction are more closely related to the visuospatial sketchpad, while multiplication is more strongly associated with the phonological loop. For example, Lee and Kang (2002) found that the simultaneous performance of a visuospatial memory task affected subtractions, but not multiplications; while the simultaneous performance of a phonological memory task affected multiplications, but not subtractions. In the same line, visuospatial working memory tasks appear to predict more variance in addition and subtraction compared to multiplication in the early years of primary school children (van der Ven et al., 2013). On the contrary, temporal and frontal cortex activation observed during a phonological processing task have been found to predict progression in multiplication between 10 and 12 years old, but not in subtraction (Suárez-Pellicioni et al., 2019); and phonological awareness seems to correlate with multiplication and retrieval problems, but not with procedural problems involving additions and subtractions (De Smedt et al., 2010).

In neuropsychology, double dissociations have been reported. On one side, patients can be selectively impaired in subtraction and quantity manipulation but completely spared in multiplication fact retrieval (Dehaene & Cohen, 1997; van Harskamp & Cipolotti, 2001). On the other side, some patients present a selective impairment in multiplication fact retrieval, while concurrently remaining able to solve addition and subtraction problems (Cappelletti et al., 2001; Cohen & Dehaene, 2000; Sandrini et al., 2003; van Harskamp & Cipolotti, 2001). Finally, data from individuals with developmental disorders also appears in line with this model: children and adults with impairments in phonological processing (dyslexic individuals) show marked difficulties in multiplication fact retrieval but no impairment in subtractions (Boets & De Smedt, 2010; De Smedt & Boets, 2010; Simmons & Singleton, 2008). Moreover, the number of trials correctly solved by means of a retrieval procedure has been found to be positively correlated with their degree of phonological awareness (De Smedt & Boets, 2010).

Taken together, these results provide a large body of evidence pointing towards a differentiated effect of visuospatial and language abilities on mental calculation, with visuospatial abilities supporting addition and subtraction, and language supporting multiplication. This dissociation may stem from distinct learning and problem solving strategies: additions and subtractions are usually taught and stored through visuospatial supports, such as counting or number lines (Barrouillet & Thevenot, 2013; Uittenhove et al., 2016), or solved using decomposition strategies (Carr & Alexeev, 2011; Geary, 2011); while multiplication tables are typically learnt by rote in the form of verbal associations. From a developmental standpoint, this suggests that better visuospatial abilities would enhance the acquisition of addition and subtraction, while language abilities would foster the acquisition of multiplication skills. Surprisingly, no study so far has directly tested this hypothesis. Additionally, most of the previous findings are limited by their small sample size ($N \leq 50$; with the notable exception of van der Ven et al., 2013) and cross-sectional design – longitudinal studies examining the association between early visuospatial/language abilities and later calculation skills are scarce (but see Suárez-Pellicioni et al., 2019 for the effect of previous phonological processing abilities on later multiplication and subtraction). Yet, longitudinal evidence is a key step towards establishing causality, by informing and directing future intervention studies. Previous longitudinal studies indicated that both early visuospatial (Yang et al., 2019; Zhang et al., 2014, 2017) and language abilities (Durand et al., 2005; Zhang et al., 2017) play an important role in the acquisition of arithmetic skills, but whether the two sets of abilities have a differentiated influence on the different types of arithmetic operations has not been investigated.

RESEARCH HIGHLIGHTS

- Using structural equation modelling, we analyzed longitudinal data from 358 children.
- Language skills in preschool significantly predicted multiplication, but not addition nor subtraction scores in middle school. The reverse was true for preschool visuospatial skills.
- Importantly, this pattern remained unchanged when we controlled addition and multiplication operations for overall difficulty and for the magnitude of the operands.
- These results provide strong support for the existence of a double dissociation in mental arithmetic operations.

In this paper, we examined whether the association between arithmetical computation and visuospatial skills, and that between multiplication fact retrieval and language, are also reflected in developmental, longitudinal data. Our study relies on large sample size ($N = 358$) and a long-range longitudinal approach, where visuospatial and language skills were measured in preschool (T1), way before kids acquire mental arithmetic (measured at T2, in middle school). In line with previous findings, we hypothesized that there is a specificity in the longitudinal predictors of multiplication versus addition and subtraction, such that: (a) early visuospatial skills predict subtraction and addition scores more than multiplication; and (b) early language skills predict mental multiplication more than addition and subtraction.

2 | METHOD

2.1 | Sample

The data analyzed come from the Eden mother-child cohort (Heude et al., 2016). The initial recruitment sample consisted in 2002 pregnant women seen during a prenatal visit at the departments of Obstetrics and Gynecology of the French University Hospitals of Nancy and Poitiers before their twenty-fourth week of amenorrhea, who agreed to participate and matched the inclusion criteria. Women with a per-

TABLE 1 Child characteristics

Variable	N	Mean	S.D.	Median	Min	Max
Parental education (years)	358	14.23	2.17	14.00	10.00	17.00
Age at last test (years)	347	11.57	0.52	11.52	10.49	13.28
Sex (Male, %)	358	48.32				
Schooled in grade 5 (%)	358	20.39				
Schooled in grade 6 (%)	358	58.94				
Schooled in grade 7 (%)	358	19.83				

sonal history of diabetes, twin pregnancy, intention to deliver outside the university hospital or to move out of the study region within the following 3 years, and who could not speak French, were not eligible for the study. The participation rate among eligible women was 53%. Enrolment started in February 2003 in Poitiers and in September 2003 in Nancy and lasted for 27 months in each center. 1907 women out of 2002 were still in the cohort at delivery. Detailed data on children's environment ant cognitive development were regularly collected from birth to 11.5 years old (age at the last wave: Mean = 11.56, SD = 0.51), with progressive attrition (the numbers of participants at ages 1, 2, 3, 5.5, 8 and 11.5 years of the child were, respectively, 1717, 1611, 1527, 1255, 883, and 538). At the age of 11.5 years old, 358 students completed the mental calculation test and at least half of psychometric tests at 5.5 years old, which were the conditions for inclusion in our study. 51.6% of the participants in this working sample were female. Characteristics of this working sample are reported in Table 1.

The study was approved by the Ethical Research Committee (Comité consultatif de protection des personnes dans la recherche biomédicale) of Bicêtre Hospital and by the Data Protection Authority (Commission Nationale de l'Informatique et des Libertés). Informed written consents were obtained from parents for themselves at the time of enrollment and for the newborn after delivery.

2.2 | Measures

2.2.1 | Mental calculation test at 11.5 years old

At the last data collection session, children were administered an online mental calculation test, taken at home on the family computer, as part of larger test battery. It consisted of 24 mental calculation problems of increasing difficulty, including eight additions, eight subtractions (both with 1- to 3-digit operands), and eight single digit multiplications. Calculations at the left hand side of the equal sign were presented in written form (not spoken), and children had to solve them mentally and then type in their answer on the keyboard (in digits) within 10 s. We computed an Addition score, a Subtraction score, and a Multiplication score as the sum of correct answers for each category. Answers that were not delivered within 10 s were considered wrong. Due to the fact that children were not in the same school grade when tested (ranging from grade 5 to grade 7, see Table 1), which was related to their performance at the test, we adjusted the final score for school grade (taking the residuals from the regression of the raw score on school grade). Example of items:

8 + 5 =	7 + 62 =	245 + 73 =
9 − 4 =	44 − 8 =	157 − 13 =
3 x 6 =	4 x 7 =	9 x 8 =

2.2.2 | Cognitive tests at 5.5 years old

At 5.5 years old, children's cognitive abilities were assessed by a trained psychologist, by means of a range of psychometric tests. All psychometric test scores were adjusted on the child's age.

Subtests from the WISC-III (Wechsler, 1967, 2004) and NEPSY (Kemp et al., 2001; Korkman et al., 2003) batteries were administered, as well as the Peg-moving task (Nunes et al., 2008).

Non-word repetition (NEPSY): This test is scored as the number of syllables repeated correctly (out of 46 syllables in 13 non-words). It taps phonological processing (encoding and decoding) and verbal short-term memory.

Word segment recognition (NEPSY): Children had to identify pictures that represent words (named in the first place by the psychologist) formed from orally presented word segments. This test taps phonological processing (phonemic awareness).

Sentence repetition (NEPSY): This test is scored as the number of sentences (out of 17) repeated correctly. It is designed to measure syntactic skills and verbal short-term memory.

Design-copying task (NEPSY): Children had to copy 18 two-dimensional figures correctly (each item was rated from 0 to 4). This test taps visual perception and organization and visual-motor coordination.

Information (WPPSI-III): Children had to correctly answer (verbally or by pointing) 34 questions that address a broad range of general knowledge topics (34 items). This test measures language comprehension, conceptual knowledge and verbal expressive ability.

Vocabulary (WPPSI-III): Children had to correctly define 25 words. This test is designed to measure receptive vocabulary, conceptual knowledge and verbal expressive ability.

Word reasoning (WPPSI-III): Children had to correctly identify a concept from a series of clues (28 items). This test taps language comprehension, conceptual knowledge and general reasoning ability.

Block design (WPPSI-III): Children had to correctly recreate two-dimensional designs using blocks (20 items). This test is designed to measure nonverbal concept formation, visual perception and organization and visual-motor coordination.

Matrix reasoning (WPPSI-III): Children had to correctly complete 29 matrices correctly completed (29 items). This test taps nonverbal concept formation and visual perception and organization.

Picture concepts (WPPSI-III): Children had to correctly select two or three pictures with common characteristics (28 items). This test is designed to measure abstract categorical reasoning ability.

2.3 | Analyses

Data processing and descriptive statistics were performed with the software SAS 9.4, and factor analyses and structural equation modeling were performed with the software Mplus 8.[1] Two latent factors for early language and visuospatial skills, respectively, were constructed from the 10 psychometric tests with confirmatory factor analysis, with the language latent factor loading on non-word repetition, word-segment recognition, sentence repetition, information, vocabulary, word reasoning and picture concepts, and the visuospatial latent factor loading on matrices, block design, design copying, the peg-moving task, coding, and picture concepts. We ran structural equation models (SEM) with these two latent factors as concurrent predictors and the three mental calculation scores as outcomes. Language and visuospatial skills at 5.5 years were allowed to covary, as well as the addition, subtraction and multiplication scores at 11.5 years. The MLR estimator was used to handle the non-normality of the multiplication score. In the first baseline model (Model a), we only controlled for the recruitment center, by regressing latent cognitive abilities and mental calculation scores on the recruitment center within the model. In a second model (Model b), we controlled in addition for parental education and sex in the same way.

The models' goodness of fit was examined using the comparative fit index (CFI), the Tucker–Lewis index (TLI), and the root mean squared error of approximation (RMSEA). CFI and TLI values greater than 0.95 and values of RMSEA less than 0.06 were used as cut-offs. We only interpreted standardized coefficients in order to compare the effect sizes of the different predictors. The significance of coefficients was assessed with two-sided t-tests. We accounted for multiple comparison with the Benjamini-Hochberg False Discovery Rate (FDR), setting the total number of tests equal to the number of regression coefficients of interest estimated (9) and the false discovery threshold q to 0.05. We excluded from the analysis children who had missing data on at least one of the mental calculation score, and on more than six psychometric tests (remaining $N = 358$). The remaining missing data was treated using full information maximum likelihood (FIML) estimation.

3 | RESULTS

3.1 | Descriptive statistics

Table S1 (Supplementary files) presents the distribution of socio-demographic characteristics and cognitive abilities in included and excluded participants. Included children had significantly more highly educated parents and higher cognitive abilities than excluded ones (except for the word segment recognition task). The proportion of female and male children was not significantly different in included and excluded participants. Table 2 presents the characteristics of the

TABLE 2 Descriptive statistics of tests at 11.5 and 5.5 years

Variable	N	Mean	S.D.	Median	Min	Max
Tests at 11.5 years						
Additions (out of 8)	358	5.02	1.53	5.00	1.00	8.00
Subtraction (out of 8)	358	4.68	1.43	5.00	1.00	8.00
Multiplication (out of 8)	358	6.63	1.45	7.00	1.00	8.00
Tests at 5.5 years						
Nonword repetition (NEPSY)	356	29.31	7.72	30.00	5.00	45.00
Word-segment recognition (NEPSY)	352	10.99	1.78	11.00	4.20	14.00
Sentence repetition (NEPSY)	341	16.43	3.96	16.00	7.00	28.00
Design copying (NEPSY)	351	52.85	7.19	52.80	36.00	69.60
Information (WPPSI-III)	358	25.66	2.70	26.00	17.00	31.00
Vocabulary (WPPSI-III)	357	24.42	5.55	24.00	8.00	40.00
Word reasoning (WPPSI-III)	357	17.01	4.29	18.00	0.00	27.00
Block design (WPPSI-III)	356	29.08	3.65	30.00	20.00	40.00
Matrix reasoning (WPPSI-III)	358	16.21	3.96	16.00	6.00	28.00
Picture concepts (WPPSI-III)	357	14.91	3.79	15.00	5.00	24.00

TABLE 3 Correlations between the three mental calculation scores at 11.5 years

	Addition	Subtraction	Multiplication
Addition	1.00	0.52	0.38
Subtraction		1.00	0.39
Multiplication			1.00

Note: Adjusted scores (on the child's school grade).

distribution of the three mental calculation raw scores at 11.5 years as well as the twelve psychometric tests at 5.5 years. Table 3 presents the correlations between the three mental calculations scores.

3.2 | Early cognitive predictors of mental calculation skills at 11.5 years

Table 4 presents the factor structure of the 10 psychometric tasks at 5.5 years. Results from the ensuing structural equation models predicting the three mental calculation tasks at 11.5 years with latent cognitive skills at 5.5 years are presented in Table 5 and illustrated in Figure 1. Latent visuospatial skills were a significant predictor of addition and subtraction skills, but not of multiplication skills (Model a). Thus, an increase in visuospatial skills at 5.5 years by 1 SD predicted an increase of 0.3 SD in addition and subtraction scores at 11.5 years, but not in multiplication scores. On the contrary, latent language skills at 5.5 was a significant predictor of multiplication skills at 11.5, but not of addition nor subtraction skills. The same trends were observed when controlling for parental education and sex, with slightly smaller coefficients (Model b). In order to ensure that our results did not merely reflect differences in difficulty between the multiplication (which were single digits only) and addition/subtraction tasks (which combined one, two and three digits operations), we ran two additional analyses. In the first one, we compared multiplications to easy (including at least one digit operand) and difficult (including only two and three digit operands) additions/subtractions (Supplementary files, Table S2). In the second one, we compared multiplications to single-digits-only (which might also be rote-learnt) and multidigits additions/subtractions (Supplementary files, Table S3). Results from these two analyses indicate that whatever the difficulty level, additions and subtractions are supported by early visuospatial abilities, but not by early language, and vice versa.

4 | DISCUSSION

A substantial and converging body of evidence from neuroimaging, behavioral and neuropsychology studies suggest that all mental calculation tasks are not supported by the same neuro-cognitive processes. While addition and subtraction seem to rely more on visuospatial functions, multiplication depends more on verbal abilities. It is thought that this double dissociation, mainly observed through correlational approaches, is caused by the fact that the two types of arithmetical operations are formally taught, at least in Western school, in very different ways: while additions and subtractions are taught and stored through visuospatial supports, such as counting or number lines, multiplication tables are typically learnt by rote in the form of verbal associations. This predicts that the early inter-individual variations across children in visuospatial and language skills before they enter formal schooling should be predictive of later proficiency in solving arithmetical operations, as learnt at school.

TABLE 4 Confirmatory factor analysis of the 10 psychometric test scores at 5.5 years

	Latent factors			
	Language skills		Visuospatial skills	
Measured variables	Estimate	S.E.	Estimate	S.E.
Non-word repetition	0.55	0.02		
Sentence repetition	0.71	0.02		
Word-segment recognition	0.33	0.03		
Information	0.82	0.01		
Vocabulary	0.72	0.02		
Word Reasoning	0.86	0.01		
Picture concepts	0.20	0.04	0.34	0.05
Design copying			0.55	0.03
Block design			0.73	0.03
Matrix reasoning			0.59	0.03
Correlations between latent factors				
Language skills	1.00		0.60	
Visuospatial skills			1.00	

Note: CFI = 0.988; TLI = 0.983; RMSEA = 0.034 [0.024;0.045]. Nonword repetition and sentence repetition were allowed to covary (r = 0.38).

TABLE 5 Results from the structural equation model with the three mental calculation tasks at 11.5 years predicted by latent cognitive skills at 5.5 years

	Addition		Subtraction		Multiplication	
Latent predictors at 5.5 years	β (S.E.)	p-value	β (S.E.)	p-value	β (S.E.)	p-value
Model a						
Language skills	−0.06 (0.07)	0.386	0.01 (0.07)	0.861	0.21* (0.07)	0.002
visuospatial skills	0.32* (0.08)	<0.0001	0.27* (0.08)	0.001	0.10 (0.08)	0.204
Model b						
Language skills	−0.06 (0.07)	0.338	0.00 (0.07)	0.999	0.19* (0.07)	0.005
Visuospatial skills	0.28* (0.07)	<0.0001	0.23* (0.07)	0.002	0.06 (0.08)	0.392

Note: Mental calculation scores and cognitive predictors are solely adjusted on recruitment center in Model a; and on recruitment center, parental education and sex in Model b. * denotes significance after FDR correction with q = 0.05 and the number of tests equal to 9. Standardized coefficients are reported (with standard errors in parenthesis). The addition, subtraction and multiplication scores were simultaneously entered as dependent variables in the model and were allowed to covary; and the latent cognitive predictors were allowed to covary. Model a: CFI = 0.986; TLI = 0.978; RMSEA = 0.029 [0.000;0.047]. Model b: CFI = 0.981; TLI = 0.961; RMSEA = 0.036 [0.017;0.052]. The MLR estimator was used to handle the non-normality of the multiplication score.

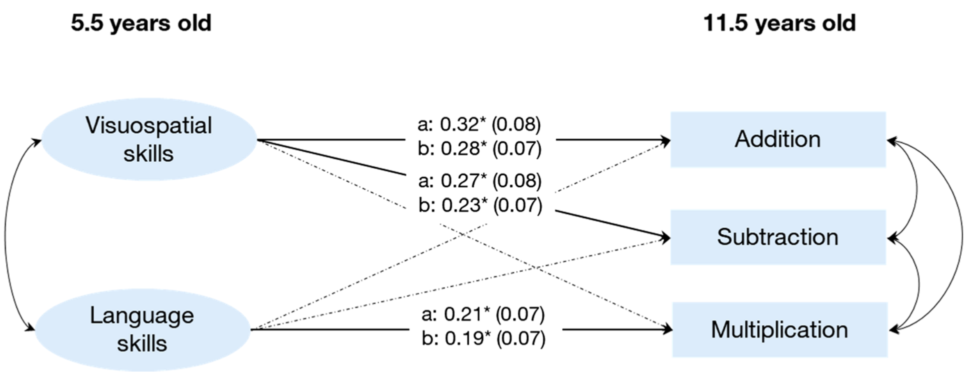

FIGURE 1 Results from structural equation models with mental calculation tasks as outcomes and latent cognitive skills as predictors. In Model a, mental calculation scores and cognitive predictors are adjusted on recruitment center; in Model b they are adjusted on recruitment center, parental education and sex in Model b. * denotes significance after FDR correction with q = 0.05 and the number of tests equal to 9. Standardized coefficients are reported (with standard errors in parenthesis)

In order to test this prediction, we implemented a longitudinal paradigm where we measured language and visuospatial skills in 358 young preschoolers before they were trained in mental arithmetic, and then tested them at the beginning of middle school to measure their calculation skills. We found that visuospatial skills at 5.5 years old significantly predicted later addition and subtraction scores, but not multiplication scores at 11.5 years old. Conversely, early language skills predicted later multiplication scores, but not addition nor subtraction. Thus, these results provide a strong support for the existence of a double dissociation in mental arithmetic operations (Dehaene et al., 2003). Furthermore, we show that this dissociation not only exists concurrently, but also longitudinally: children with better early visuospatial abilities are more likely to compute additions and subtractions correctly 6 years later, while those with better early language abilities are more likely to retrieve multiplication facts correctly 6 years later. Importantly, this double dissociation existed also when we controlled addition and multiplication operations for overall difficulty and for the magnitude of the operands. These findings thus considerably refine the current knowledge and implications from longitudinal data that early language and visuospatial skills are important building blocks for the acquisition of arithmetic abilities (Durand et al., 2005; Yang et al., 2019; Zhang et al., 2017). They demonstrate the existence of long-lasting and differentiated links, with a specific directionality, between these functions.

Research in the last decades has casted light on the mechanisms that may be underlying this dissociation. While multiplication facts are typically rote-learnt and solved through the use of a retrieval strategy, the processes lying beneath even elementary additions and subtractions appear to be more complex. Contrary to the previously established belief that simple arithmetic calculations are also solved primarily by direct fact retrieval (Ashcraft, 1992; LeFevre et al., 1996; Siegler & Shrager, 1984), more recent research has provided evidence that basic additions and subtractions are performed by fast automated procedures relying on a spatially organized mental representation of numbers (Barrouillet & Thevenot, 2013; Uittenhove et al., 2016). In this framework, symbolic and non-symbolic additions and subtractions would thus be solved, respectively, through rightward and leftward shifts along a mental number line (Knops et al., 2009; McCrink et al., 2007; Pinhas & Fischer, 2008; Pinheiro-Chagas et al, 2017; Pinheiro-Chagas et al., 2018). Other problem-solving strategies typically used in addition and subtraction may also explain the association with visuospatial skills. In particular, decomposition (decomposing a problem into simple math facts) has been shown to be associated with better arithmetic performance (Carr & Alexeev, 2011; Geary, 2011). Furthermore, previous studies suggest that decomposition may be mediating the association between visuospatial skills and addition/subtraction skills (Casey et al., 2017; Foley et al., 2016).

These results need to be interpreted with the classical limitations associated with the use of cohort studies. First, this study remains correlational, due to the observational nature of our data. While it is assumed that language and visuospatial abilities play a causal role in determining later proficiency in mental arithmetic abilities at school, it is also possible that, in turn, the cultural acquisition of mental arithmetic contributes to improving language and visuospatial abilities, in a form of circular causality that also occurs in other domains (e.g., Hulme et al., 2012; Piazza et al., 2010). Our finding that preschool language and visuospatial abilities are differentially associated with middle-school calculation skills is remarkable in itself and due to its longitudinal nature does suggest the existence of a causal link. This result thus calls for a further investigation of the purported causal links between language/visuospatial skills and different calculation skills through intervention studies. There is meta-analytical evidence which suggests that spatial training does significantly increases mathematics performance (Hawes et al., 2021), but whether it differentially impacts addition, subtraction and multiplication skills has not been investigated yet. A second limitation concerns the representativeness of our sample. Indeed, while our sample size is large compared to most studies in the domain, it is worth considering that its external validity may not be complete given the selective attrition between inclusion in the Eden cohort and the 11.5 years old wave. Indeed, children present at 11.5 years old have more highly educated parents and higher cognitive abilities than those present at the 5.5 years wave who could not be followed-up and included in our sample. However, this limitation applies to the vast majority of studies in the domain, where representativeness of the tested sample relative to the whole population is often very hard to achieve. As a consequence of this selective attrition, there is probably a lower variability in the cognitive and arithmetic skills measured than what would be observed in the general population. It is thus likely that we would observe even stronger associations in a representative sample including more children with lower cognitive and arithmetic abilities.

In spite of these limitations, our study provides strong evidence, from a large longitudinal sample, that visuospatial and language abilities measured before formal mathematics instruction differentially predict addition, subtraction, and multiplication. These results suggest that training early visuospatial skills may enhance later addition and subtraction abilities but have no influence on multiplication abilities; and conversely, training early language skills may benefit the later acquisition of multiplication skills, but not addition nor subtraction.

ACKNOWLEDGMENTS

We thank Céline Sardano and Anne Forhan, as well as the EDEN mother-child cohort study group, whose members are I. Annesi-Maesano, J.Y. Bernard, J. Botton, M.A. Charles, P. Dargent-Molina, B. de Lauzon-Guillain, P. Ducimetière, M. de Agostini, B. Foliguet, A. Forhan, X. Fritel, A. Germa, V. Goua, R. Hankard, B. Heude, M. Kaminski, B. Larroquey, N. Lelong, J. Lepeule, G. Magnin, L. Marchand, C. Nabet, F Pierre, R. Slama, M.J. Saurel-Cubizolles, M. Schweitzer, and O. Thiebaugeorges. The EDEN study was supported by Foundation for medical research (FRM), National Agency for Research (ANR), National Institute for Research in Public health (IRESP: TGIR cohorte santé 2008 program), French Ministry of Health (DGS), French Ministry of Research, INSERM Bone and Joint Diseases National Research (PRO-A), and Human Nutrition National Research Programs, Paris-Sud University, Nestlé, French National Institute for Population Health Surveillance (InVS), French National Institute for Health Education (INPES), the European Union FP7 programmes (FP7/2007—2013, HELIX, ESCAPE, ENRIECO, Medall projects), Diabetes National Research Program (through a collaboration with the French Association of Diabetic Patients (AFD)), French Agency for Environmental Health Safety (now ANSES), Mutuelle Générale de l'Education Nationale a complementary health insurance (MGEN), French national agency for food security, French-speaking association for the study of diabetes and metabolism (ALFEDIAM). We acknowledge additional funding from Agence Nationale de la Recherche (ANR-17-EURE-0017, ANR-10-IDEX-0001-02 PSL, and ANR-12-DSSA-0005-01).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

We analyzed cohort data that are not under our direct control; requests to access the data should be directed to the Eden cohort steering committee (http://eden.vjf.inserm.fr/index.php/fr/contact). Our complete analysis scripts have been posted on OSF at https://osf.io/fq2vx/.

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ENDNOTE

[1] Our scripts are available on OSF (https://osf.io/fq2vx/?view_only = eb50809f26f849e79b0e61489efb0c1e).

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How to cite this article: Guez, A., Piazza, M., Pinheiro-Chagas, P., Peyre, H., Heude, B., & Ramus, F. (2022). Preschool language and visuospatial skills respectively predict multiplication and addition/subtraction skills in middle school children. *Developmental Science*, e13316. https://doi.org/10.1111/desc.13316