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The efficacy of manipulatives versus fingers in supporting young children’s addition skills

Mai-Liên Lê [a], Marie-Pascale Noël [b], Catherine Thevenot [c,*]

[a] Faculty of Psychology, University of Social Sciences and Humanities, Vietnam National University, Ho Chi Minh City, Viet Nam
[b] Psychological Institute, University of Louvain, 10 place C. Mercier, 1348 Louvain-la-Neuve., Belgium
[c] Institute of Psychology, University of Lausanne, CH-1015 Lausanne, Switzerland

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ABSTRACT

Recent empirical investigations have revealed that finger counting is a strategy associated with good arithmetic performance in young children. Fingers could have a special status during development because they operate as external support that provide sensory-motor and kinesthetic affordances in addition to visual input. However, it was unknown whether fingers are more helpful than manipulatives such as tokens during arithmetic problem solving. To address this question, we conducted a study with 93 Vietnamese children (48 girls) aged 4 and 5 years (mean = 58 months, range = 47–63) with high arithmetic and counting skills from families with relatively high socioeconomic status. Their behaviors were observed as they solved addition problems with manipulatives at their disposal. We found that children spontaneously used both manipulatives and fingers to solve the problems. Crucially, their performance was not higher when fingers rather than manipulatives were used (i.e., 70% vs. 81% correct answers, respectively). Therefore, at the beginning of learning, it is possible that, at least for children with high numerical skills, fingers are not the only gateway to efficient arithmetic development and manipulatives might also lead to proficient arithmetic.

* Corresponding author.
E-mail address: catherine.thevenot@unil.ch (C. Thevenot).

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Introduction

Over the past years, finger counting has attracted the attention of researchers in the domain of developmental and educational psychology (see Neveu et al., 2023, for a recent review). This renewed interest (see Baroody, 1987b; Sauls & Beeson, 1976, for seminal studies) is mainly explained by the finding that the use of fingers during arithmetic calculations is one of the characteristics of successful solvers, at least for young children up to 8 years of age (Dupont-Boime & Thevenot, 2018; Jordan et al., 2008; Krenger & Thevenot, 2024). This finding challenges the conception that children should be discouraged from using their fingers to solve arithmetic problems and the idea that children who use their fingers are delayed in their numerical development (as reported by Boaler & Chen, 2016; Cowan, 2013; Mutlu et al., 2020; Poletti et al., 2023).

Indeed, Jordan et al. (1992) observed that, in kindergarten, middle-income children used finger-counting strategies more frequently than low-income children and that this was associated with greater accuracy in solving verbal addition and subtraction problems. In first grade, many of these low-income children used their fingers, and this was associated with higher performance on verbal problems (Jordan et al., 1994). Fuson (1982, 1988) and Baroody (1987a) reported a variety of ways in which kindergarteners use their fingers to solve arithmetic problems, but mostly as resources for keeping track of counted units. In agreement with this, Crollen and Noël (2015) showed that preventing finger use in 5-year-old children had a deleterious effect on target counting and, in first graders, had a negative impact on their addition performance.

By crossing the frequency of finger use and the addition proficiency of 5- to 7-year-old children, Reeve and Humberstone (2011) identified four subgroups: (1) those with very low addition accuracy and low finger use, (2) those with high finger use and moderate accuracy, (3) those with moderate finger use and moderate accuracy, and (4) those with rare finger use but high accuracy in addition. Kindergarteners were mainly distributed in Subgroups 1 and 2, indicating that at that age finger use is associated with better accuracy in addition. On the contrary, in Grade 1 addition accuracy seemed quite independent from finger use. These results are in line with those of Dupont-Boime and Thevenot (2018), who showed a strong relation between finger counting and arithmetic accuracy in kindergarteners. Moreover, at that age, children with high working memory capacity are more likely to use their fingers than those with lower capacity. As noted by Baroody (1987b), counting on fingers can be quite a sophisticated invention, and therefore it is understandable that children with limited cognitive resources present delays and difficulties in implementing this strategy. When kindergarteners were followed longitudinally, it was found that those who were the most proficient in calculating on fingers at 5 and 6 years of age were more likely to have abandoned this strategy in Grade 2 (Poletti et al., 2022).

Thus, at the beginning of Grade 2, the positive relation between finger calculation and arithmetic accuracy described in younger children starts to decline. This relation disappears in the middle of Grade 2 and finally reverses at the end of the school year, at a mean age of 8½ years (de Chambrier et al., 2018; Jordan et al., 2008; Poletti et al., 2022). Therefore, whereas calculation on fingers remains a successful strategy until the beginning of Grade 2, it is no longer associated with success by the end of that school year.

However, this is not to say that finger counting no longer plays any role in numerical processing from the age of 8½ years. Indeed, according to the manumerical cognition hypothesis, the use of fingers in numerical tasks forges a strong link between fingers and numbers, which persists lifelong (Fischer, 2018; Sixtus et al., 2023). Fingers could even be recruited unconsciously in expert solvers during numerical activities and especially mental calculations (Fischer et al., 2012; Michaux et al., 2013).

Nevertheless, without denying the specific role that children's use of fingers in arithmetic tasks has during development, the question of whether these benefits are specific to fingers at the very beginning of arithmetical learning or can be generalized to any external aids is still unanswered. This question was at the heart of the current study.

It is conceivable that at the very beginning of their arithmetical development, children need help to keep track of their counting, and any external help (fingers or objects) would do the trick. We might also consider that counting on fingers to solve a problem involving adding apples requires greater abstraction than using plastic apples to solve the problem. Indeed, counting on fingers assumes that fingers can represent any object, which is a step toward abstraction (Sinclair & Pimm, 2015).

A specific role of fingers in arithmetic can also be envisioned because their sensory-motor and kinesthetic affordances could make them a particularly powerful tool for the development of numerical abilities (Barrocas et al., 2019; Soylu et al., 2018; Thevenot et al., 2014). Children can indeed not only see the quantities represented on fingers but also feel them. These sensorimotor experiences could play a specific role in number encoding and processing (Sixtus et al., 2023). It has actually been shown that children with higher cognitive skills have fewer looks at their hands when they use their fingers to count than children with lower skills (de Chambrier et al., 2018). Therefore, this would be the embodiment of numbers through finger representations that could grant them a special status for the development of numerical abilities (e.g., Fischer, 2018; Fischer & Shaki, 2018). Moreover, reduced reliance of visual monitoring for fingers than for manipulatives could allow children to allocate more attentional resources to the task at hand, hence an additional advantage of using fingers over manipulatives in numerical tasks. At the same time, the creation of an embodied link between fingers and numbers might require a certain amount of practice, and therefore it is possible that in the early stages of arithmetic development fingers are no more valuable than any external aid.

These hypotheses were tested in the current study by observing the behavior of children who are at the very beginning of their arithmetical development. Previous research focused on children aged 5 or 6 years and showed that finger counting is a sign of cognitive strength and enhanced ease with numbers (Dupont-Boime & Thevenot, 2018; Jordan et al., 2008; Krenger & Thevenot, 2024). Yet, none of this research provided children with the possibility of using manipulatives. Here, we tested younger 4- and 5-year-old children at the very beginning of their arithmetical development and offered them different types of manipulatives at their disposal. We then observed whether children use fingers or manipulatives more frequently to support their calculations. Therefore, the question was to determine whether, at this very early stage of development fingers already have a special status during arithmetic tasks compared with other manipulatives or, alternatively, whether fingers could be used as any other manipulatives without conferring a specific performance advantage during the arithmetic task. More specifically, we observed the behavior of 242 children aged 4 and 5 years while they solved simple addition problems, and we focused our attention on the 93 children from this sample who were able to complete the task. We recorded whether children solved the problems mentally, used their fingers, or used manipulatives at their disposal. We then established the relation between children's choice of strategy and performance in the addition task. We also considered problem characteristics, namely whether the problem to be solved was a tie or non-tie problem and whether it involved 1. Indeed, it is known that children and adults do not represent and solve tie and non-tie problems similarly (e.g., Bagnoud, Dewi, Castel, et al., 2021; Campbell & Gunter, 2002; LeFevre et al., 1996). Therefore, determining how children process these problems early in development could shed light on the origins of these differences. Likewise, $n + 1$ problems are supposed to be processed differently than non-$n + 1$ problems by expert children and adults. More precisely, a number after rule consisting of retrieving the number word after n could be used to solve the problem instead of specifically adding 1 to n (e.g., Bagnoud, Dewi, & Thevenot, 2021; Baroody, 2006; Baroody et al., 2009). In this case, the reliance on external aids, either fingers or manipulatives, to solve $n + 1$ problems at the beginning of learning could be more seldom than for non-$n + 1$ problems. Finally, children's behaviors were examined in light of their general cognitive abilities.

To promote inclusivity and diversity and to extend the generalizability of our observations beyond Western industrialized nations, Asian children were involved in our study. We specifically chose Vietnamese children because, contrary to other Asian countries such as China (e.g., Geary et al., 1996), there is no overemphasis on arithmetic rote learning in Vietnam at the beginning of schooling (Vietnam Ministry of Education and Training [MOET], 2021).

Method

Participants

Children were recruited from six nursery kindergartens (four private and two public schools) in Ho Chi Minh City, Binh Duong, and Nghe An, Vietnam. Consent forms were sent to all parents of the preschoolers, and the sample comprised the children whose parents voluntarily consented to their participation. All children were monolingual Vietnamese speakers from families with relatively high socioeconomic status. More precisely, of seven levels—primary school, secondary school, high school, college, university, master, and PhD (Levels 1–7, respectively, following the educational system of Vietnam)—the mean socioeconomic status was of 3.27 for the mother and 3.37 for the father.

A total of 265 children were tested during the second semester of Year 1 in preschool; among them, 23 were excluded because of low IQ scores (e.g., IQ score below 2 standard deviations from the mean; $n = 6$), failure to complete the preschool tasks (e.g., because of poor attention; $n = 4$), presence of a neurodevelopment disorder (e.g., autism spectrum or language delay; $n = 5$), or participation in early math education programs outside the school (e.g., Kumon programs or other; $n = 8$). (These data were collected in the context of a longitudinal study in which the data of 149 children followed during 2 years were analyzed.). Among the remaining 242 children, 149 could not solve any addition problems they were presented with and therefore were not considered in the analyses aimed at answering our research questions. Nonetheless, their characteristics (i.e., age, counting ability, advanced counting ability, nonverbal intelligence, and working memory) were compared with those of the 93 children (48 girls) with high numerical skills retained in all our analyses (see Results). The 93 children in the retained group were aged 4 years and 8 months on average (mean = 57.82 months, range = 43–63).

Material and procedure

Preschoolers were tested on three numerical tasks and two general cognitive tasks.

Numerical tasks

Counting. Children were asked to count out loud as far as possible and were stopped if they reached 50. The score was the highest number word counted.

Counting on from a number (Advan-Count). Children were asked to "count from *n*" ($n = 3, 5, 7, 13, 11, 12$). If for a trial (e.g., count from 2), a child did not start, the experimenter gave an example: "I count from two; that is two, three, four, five, six." The trial was correct if the child counted from *n* as required (and did not start from "one") and produced the next four numbers in the correct order. The task was stopped if children were unsuccessful in 3 successive trials. The score was the total number of correct responses (CRs).

Addition. This task was similar to the one used by Noël (2009). A series of 14 additions that summed to 10 or less was given to each child, namely 4 ties (2 + 2, 3 + 3, 4 + 4, and 5 + 5) and 10 additions presented with the smaller addend first (1 + 3, 3 + 4, 2 + 3, 3 + 5, 1 + 4, 2 + 5, 2 + 4, 1 + 5, 4 + 5, and 1 + 6) to allow a distinction to be made between the COUNT-ON (FIRST STRATEGY) and COUNT-MIN strategies. For each item, the child had a drawing of a collection of items (apples) representing the first operand, and tokens (10) and plastic apples (10) were at the child's disposal (see Fig. 1). The problem was presented orally (e.g., "Look, here Snow White has three apples; if the dwarfs give her four more, how many apples will she have?"). If the child failed 5 successive trials, the task was stopped; otherwise, the task was continued up to the last item. The total number of CRs was used as the dependent variable.

The experimenter used the paper answer protocol to write the child's answer and strategy. Three counting-based strategies (COUNT STRATEGY) were distinguished: COUNT-ALL (i.e., representing the two quantities (on the picture, with tokens, with objects, or by raising fingers) and counting all of them, starting from one), COUNT-ON (i.e., keeping one number in mind [either the first or the

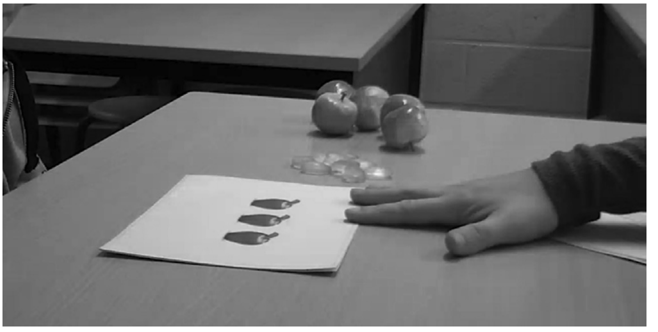

Fig. 1. Material at the child's disposal for the addition problems.

smallest] and counting from this number a number corresponding to the value of the other number), and COUNT-MIN (i.e., counting from the larger addend and not more basically from the first one). MENTAL STRATEGIES was encoded if children did not count, reached the answer in less than 3 s, and explained that they knew the answers or had this answer in their head. The last category named NOTHING referred to four situations, namely (1) the item was not presented because the child failed three previous consecutive items; (2) there was no answer from the child or the child said "I don't know"; (3) the child guessed; and (4) the child took more than 3 s to give the answer and we could not identify any other strategy. Use of external support such as using the drawing presented, tokens, objects, or fingers was recorded as well.

General cognitive tasks

Matrix reasoning task (IQ). Matrix reasoning is a nonverbal intelligence subtest from the Wechsler Preschool and Primary Scale of Intelligence (WPPSI; Wechsler, 2012). Children were invited to select the one from the visually presented response options that best completed a matrix.

Digit span. This task (from the Kaufman Assessment Battery for Children—Second Edition [KABC-II]; Kaufman & Kaufman, 2004) measured the phonological loop (PL) capacity in short-term memory. The experimenter read a string of numbers at the rate of one per second, and the child repeated the string in the same order. The 22 trials ranged from two to nine one-digit numbers. Each length contained three series of numbers. After three failures of the 3 trials, the task was stopped. The score corresponded to the longest length for which at least 3 trials were correctly repeated plus 0.5 if 1 trial of the next series length was successful.

Results

The set of data that we used to conduct the analyses can be found online (https://drive.google.com/drive/folders/1JJA1FqaXrYiVdXhFmZA8Dwl6mzxZ84rs?usp=drive_link).

A total of 149 children were not presented with the last 9 items because they did not produce any correct responses for the first 5 items. Thus, they did not produce any correct answers for the whole addition task. These children's data were not included in our further analysis.

When comparing the retained group and the dropped-out group, they differ in age, with the remaining group being 1 month older than the dropped-out group. These 93 children also outperformed the 149 excluded children in counting ability, advanced counting ability, nonverbal intelligence, and digit span (see Table 1). Even controlling for age differences between the two groups, these 93 children still outperformed the other 149 children in counting ability, $F(1, 239) = 17.35$, $p < .001$, $\eta_p^2 = .068$, advanced counting ability, $F(1, 239) = 28.42$, $p < .001$, $\eta_p^2 = .106$, nonverbal intelligence, $F(1, 239) = 21.72$, $p < .001$, $\eta_p^2 = .083$, and digit span, $F(1, 239) = 22.94$, $p < .001$, $\eta_p^2 = .088$. Therefore, it is important to note that the analyses carried out in this study relate to a population of children

Table 1
Task analysis and group results

			Reliability		Range		Remained group			Dropped-out group			Independent *t* test	
	N	α	Min	Max	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*df*	*p*	*d*
Age			47	68	93	57.82	4.16	149	56.56	3.98	2.35	240	.019	.309
Preschool numerical skills														
Counting			5	50	93	30.30	12.90	149	23.22	11.97	4.34	240	<.001	.568
Advan-Count	242	.95	0	6	93	3.98	2.50	149	2.26	2.39	5.33	240	<.001	.703
General cognitive abilities														
Matrix	242	.84	2	16	93	10.49	2.90	149	8.89	2.77	4.29	240	<.001	.564
Digit span	242	.89	3	9	93	6.15	0.95	149	5.52	0.96	4.98	240	<.001	.659
Parental educational level														
Mother			1	7	88	3.27	.85	140	3.26	0.87	0.07	226	.943	.011
Father			1	7	88	3.43	.71	141	3.31	0.93	1.04	227	.301	.145

who showed overall good numerical development. However, the two groups did not differ in terms of parents' level of education.

The reliability of the addition scale was good (Cronbach $\alpha = .91$). Accuracy ranged from 2 to 14 CRs, with an average of 9.24 ± 4.47 and with 864 CRs of 1302 answers (66.36% of CRs) (see Table 2). There was no difference between girls (8.71) and boys (9.87) concerning the mean CRs, $t(91) = 1.26$, $p = .210$.

Solving strategies were recorded. However, in the counting strategies, counting ON and counting MIN were very rarely used (32 times in 1342 responses; 0.02%). Therefore, we grouped all the counting strategies together (see Table 6 in discussion of Question 3 below).

Generalized linear mixed models predicting arithmetic accuracy and strategies

Further analyses used the generalized linear mixed-effect model (GLMM) and aimed to determine which problem types and strategies predict better performance. Five questions were addressed in these analyses:

1. What types of items result in more CRs?
2. What types of items result in more counting strategies?
3. Do counting strategies result in more CRs?
4. What problems cause more finger counting?
5. Does using fingers give better performance?

Preliminary data restructuration

Fourteen arithmetic trials were administered. The arithmetic accuracy (CR) was considered binary (i.e., 1 for a correct response and 0 for an incorrect response). Trials were characterized along with three criteria: the sum, the tie, and the adding 1 problem. Sum corresponds to the correct answer of the addition problem (e.g., 8 for the trial 2 + 6) and ranges from 4 to 10. Tie refers to whether the two operands are equal or not. Tie trials (four items: 2 + 2, 3 + 3, 4 + 4, and 5 + 5) were coded 1, and non-tie trials (e.g., 1 + 3, 3 + 4, 2 + 3, 3 + 5) were coded 0. For some subanalyses, we also distinguished between problems with 1 as an addend (3 trials: 1 + 4, 1 + 5, and 1 + 6) and comparable problems in terms of sum without 1 (2 + 3, 2 + 4, and 3 + 4). Add1 problems were coded 1, and non-Add1 problems were coded 0.

Strategies were coded for each trial: counting strategy (1 = yes, 0 = no); mental strategy (1 = yes, 0 = no); nothing (1 = yes, 0 = no); and types of support used: finger counting (1 = yes, 0 = no), object counting (1 = yes, 0 = no), both finger and object counting (1 = yes, 0 = no).

Data were restructured from a wide format into a long format (see Field, 2018, p. 216) to organize the two-level hierarchical data. Level 1 data included arithmetic accuracy of each trial, trial natures/characteristics including Tie and Add1 strategies. Level 2 data comprised the individual participants

Table 2
Descriptive results of strategies and percentages of correct responses

	Counting			Mental			Nothing					Total answers	Total CRs	Total % CRs
	n	*n* CRs	% CRs	*n*	*n* CRs	% CRs	*n*	Not identified	No answer	*n* CRs	% CRs			
1 + 3	68	57	83.82	21	19	90.48	4	3	1	3	75	93	79	84.95
3 + 4	70	37	52.86	8	5	62.50	14	3	11	0	0	93	42	45.16
2 + 3	63	51	80.95	19	16	84.21	11	2	9	2	18.18	93	69	74.19
3 + 3	41	34	82.93	42	31	73.81	10	5	5	2	20	93	67	72.04
3 + 5	68	50	73.53	8	6	75	19	5	14	3	15.79	93	59	63.44
1 + 4	63	52	82.54	17	14	82.35	11	3	8	0	0	93	66	70.97
2 + 5	72	53	73.61	9	6	66.67	13	4	9	0	0	93	59	63.44
4 + 4	46	42	91.30	32	20	62.50	15	4	11	3	20	93	65	69.89
2 + 4	68	48	70.59	10	6	60	15	4	11	0	0	93	54	58.06
1 + 5	66	54	81.82	11	8	72.73	16	3	13	3	18.75	93	65	69.89
2 + 2	33	29	87.88	53	45	84.91	7	3	4	1	14.29	93	75	80.65
4 + 5	65	40	61.54	8	5	62.50	20	5	15	2	10	93	47	50.54
1 + 6	64	45	70.31	8	7	87.50	21	3	18	3	14.29	93	55	59.14
5 + 5	50	39	78	23	20	86.96	20	3	17	3	15	93	62	66.67
All	837	631	75.39	269	208	77.32	196	50	146	25	12.76	1302	864	66.36

Note. CRs, correct responses.

Table 3
Generalized linear mixed model on arithmetic accuracy (CRs)

	F	*df1*	*df2*	*p*
Corrected model	10.454	8	1293	<.001**
Tie	6.429	1	1293	.011*
Add1	6.717	1	1293	.01**
Sum	7.852	6	1293	<.001**

Note. CRs, correct responses.
* $p < .05$.
** $p < .01$.

(ID). Level 1 data were nested in participant Level 2 data. Accordingly, data from a single participant appeared over multiple rows in the long format data, resulting in 1302 data points for 93 participants (93 × 14 trials; there were no missing values).

Generalized linear mixed-effect models

We ran GLMMs with a binary logistic regression to predict arithmetic accuracy and strategies. Predictors in Level 1 data were considered as fixed main effects; Level 2 (child or ID) data were considered a random effect. The fixed effects show the predictors for the interindividual difference on the arithmetic accuracy and strategies.

Question 1: What types of items result in more CRs?

A binary logistic regression mixed model was run on 1302 lines (93 participants × 14 trials) with ID as a random effect, Sum, Tie, and Add1 as fixed effects, and CRs as the dependent measure. A first model with the interactions (Add1*Sum and Tie*Sum) showed that none of them was significant, $F(1, 1289) = 1.70$, $p = .182$ and $F(1, 1289) < 1$, respectively. The new model with only the main effects indicated significant main effects of Sum, Tie, and Add1, with the random effect of participants also being significant ($z = 5.24$, $p < .001$) (see Table 3). CRs decreased as the sum of the problem increased (82.80%, 73.66%, 66.31%, 55.56%, 65.59%, 50.54%, and 66.67% for sums from 4 to 10, respectively). Tie problems led to higher CRs (72.31%) than non-Tie problems (63.55%), and Add1 problems also led to higher accuracy than non-Add1 problems (72.04% and 63.87%, respectively).

Question 2: What types of items led to more counting strategies?

A binary logistic regression mixed model was run on 1302 lines (93 participants × 14 trials) with ID as a random effect, Sum, Tie, and Add1 as fixed effects, and Counting strategy as the dependent measure (837 cases were coded 1 because they were solved using a counting strategy, and 465 were coded 0). Because the two interactions were not significant, $F(1, 1289) = 1.18$, $p = .278$ for Tie*Sum and $F(2, 1289) = 1.57$, $p = .209$ for Add1*Sum, a new model was run with only the main effects. Tie significantly predicted the interindividual difference in counting strategies (Table 4). Indeed, counting strategies were used much more often in response to non-tie problems (71.72% of the non-tie trials) than to

Table 4
Generalized linear mixed model on counting strategies

	F	*df1*	*df2*	*p*
Corrected model	17.24	8	1293	.000**
Tie	82.91	1	1293	.000**
Add1	0.13	1	1293	.72
Sum	2.15	6	1293	.046*

* $p < .05$.
** $p < .01$.

tie problems (45.70% of the tie trials). The effect of sum was also slightly significant but in a nonlinear way (with 54.30%, 68.82%, 62.72%, 73.84%, 60.22%, 69.89%, and 53.76% frequency of counting for sums of 4 to 10, respectively) and with fewer percentage of trials solved by counting when the sum was 4 (i.e., for additions 1 + 3 and 2 + 2) or 10 (5 + 5). Add1 was not significant. The random effect was significant ($z = 5.23$, $p < .001$).

Question 3: Do counting strategies result in more CRs?

Three main strategies were observed in this study: counting, mental, and nothing strategies. Because this last strategy was obviously inefficient (leading to only 12.76% of CRs), the trials solved using this strategy were disregarded for this analysis. Accordingly, the question is whether counting strategy, in comparison with mental strategy, leads to more CRs.

A binary logistic regression mixed model was run on 1106 lines (1302 − 196 lines) with ID as a random effect, Sum, Tie, Add1, and Count (in this case, 1 = counting and 0 = mental) as fixed effects and CRs as the dependent measure. First, a model including the interactions between each of the fixed effects and Count was run. Because none of these interactions was significant, $F(6, 1088) = 1.68$, $p = .122$, $F(1, 1088) < 1$, and $F(1, 1088) = 2.10$, $p = .147$ for Count*Sum, Count*Add1, and Count*Tie, respectively, a new model with only the main effects was run. Results are reported in Table 5. As in

Table 5
Generalized linear mixed model on arithmetic accuracy

	F	*df1*	*df2*	*p*
Corrected model	6.26	9	1096	<.001**
Sum	3.87	6	1096	<.001**
Tie	3.14	1	1096	.076
Add1	6.56	1	1096	.011*
Strategy (count or mental)	0.91	1	1096	.342

* $p < .05$.
** $p < .01$.

Table 6
Descriptive results (frequencies and percentages of correct responses) of counting supports: with fingers, objects, both fingers and objects, or verbal only

	CF Count on fingers			CO Count objects			CB Counting both fingers and objects			CV Count verbal only			Total CF + CO + CB + CV	Total CRs
	n	*n* CRs	% CRs	*n*	*n* CRs	% CRs	*n*	*n* CRs	% CRs	*n*	*n* CRs	% CRs		
1 + 3	32	27	84.38	27	24	88.89	8	5	62.50	1	1	100	68	57
3 + 4	33	15	45.45	26	14	53.85	7	4	57.14	4	4	100	70	37
2 + 3	33	26	78.79	22	19	86.36	7	5	71.43	1	1	100	63	51
3 + 3	19	15	78.95	18	15	83.33	4	4	100	0	0	–	41	34
3 + 5	31	21	67.74	25	18	72	5	4	80	7	7	100	68	50
1 + 4	32	25	78.13	23	21	91.30	6	4	66.67	2	2	100	63	52
2 + 5	24	16	66.67	38	29	76.32	6	4	66.67	4	4	100	72	53
4 + 4	32	28	87.50	10	10	100	4	4	100	0	0	–	46	42
2 + 4	37	22	59.46	20	16	80	6	5	83.33	5	5	100	68	48
1 + 5	27	23	85.19	32	24	75	4	4	100	3	3	100	66	54
2 + 2	14	13	92.86	16	13	81.25	3	3	100	0	0	–	33	29
4 + 5	35	18	51.43	22	16	72.73	5	3	60	3	3	100	65	40
1 + 6	30	18	60	29	23	79.31	3	2	66.67	2	2	100	64	45
5 + 5	22	16	72.73	23	19	82.61	5	4	80	0	0	–	50	39
Total	401	283	70.57	331	266	80.36	73	55	75.34	32	32	100	837	631

Note. CRs, correct responses.

the analysis for Question 1, Add1 and Sum were significant predictors of the accuracy, but more important the strategy effect was not significant. Indeed, whether trials were solved using the counting or mental strategy led to the same CR percentage (74.91% and 77.32%, respectively). The random effect was significant ($z = 4.86$, $p < .001$), meaning that there was a significant difference in arithmetic accuracy between participants.

The next analysis regarded the supports that the child used when counting for solving the problems. Table 6 reports the frequency of counting on fingers, objects, both fingers and objects, or only verbal counting. As can be seen, children mostly counted on their fingers (47.9% of the cases) or on objects (39.54% of the cases), and more rarely they counted on both fingers and objects (8.72% of the cases) or counted verbally without any external support (3.82% of the cases).

Question 4: What problems lead to more finger counting?

On the 837 trials solved by counting, we ran a binary logistic regression mixed model with ID as a random effect, Sum, Tie, and Add1 as fixed effects, and finger counting as the dependent measure. The two interactions were not significant, $F(1, 824) < 1$ in both cases. The model was then run with the main effects only. The effect of Sum was the only significant one (see Table 7) The random effect of ID was also significant ($z = 4.87$, $p < .001$).

We then wanted to look more carefully at the Add1 problems by comparing 3 Add1 problems with 3 comparable non-Add1 problems equated in terms of their sum (i.e., 1 + 4, 1 + 5, 1 + 6 and 2 + 3, 2 + 4, 3 + 4). On these 6 problems (397 lines), we ran a mixed model using ID as a random factor, Add1 as a fixed factor, and finger use as the dependent measure. The main effect of Add1 was not significant, $F(1, 395) < 1$, with only the random effect of participants being significant ($z = 4.53$, $p < .001$).

Question 5: Does using fingers give better performance?

On the 837 trials solved by counting, we ran a binary logistic regression mixed model with ID as a random effect, Sum, Tie, Add1, and Finger as fixed effects, and CRs as the dependent measure. The three interactions with Finger were added to the first model, but none of them was significant, Finger*Add1, $F(1, 819) < 1$, Finger*Tie, $F(1, 819) < 1$, and Finger*Sum, $F(6, 819) < 1$. A restricted model with only the main effects showed significant effects of Sum and Tie (see Table 8) but not of Add1 and use of

Table 7
Generalized linear mixed model on finger counting strategy

	F	*df1*	*df2*	*p*
Corrected model	2.43	8	828	.013
Tie	1.33	1	828	.249
Add1	3.03	1	828	.082
Sum	2.68	6	828	.014

Table 8
Generalized linear mixed model on addition accuracy (CRs)

	F	*df1*	*df2*	*p*
Corrected model	4.42	9	827	<.001**
Tie	6.89	6	827	.009*
Add1	2.22	1	827	.137
Sum	3.29	1	827	.003*
Finger	0.79	1	827	.374

Note. CRs, correct responses.
* $p < .05$.
** $p < .01$.

Table 9
Generalized linear mixed model on finger counting strategy

	F	*df1*	*df2*	*p*
Corrected model	6.09	2	394	.002**
Add1	8.82	1	394	.003**
Finger	3.12	1	394	.078

** $p < .01$.

fingers. Using fingers to count did not lead to better accuracy than using other support (e.g., using fingers only was related to 70.57% of CRs, whereas using objects only was related to 80.36% of CRs).

Finally, the same question was addressed on 6 specific items (3 Add1 and 3 no-Add1). A binary logistic regression mixed model with ID as a random effect and Add1, Finger, and Add1*Finger as fixed effects was run with CRs as the dependent measure. Because the interaction between Finger and Add1 was not significant, $F(1, 393) = 1.64$, $p = .201$, a model was run with the main effects of Add1 and Finger only (see Table 9). This model showed a significant effect of Add1 only, indicating that when Add1 problems are solved by counting, they lead to higher accuracy (154 of 195 CRs; 78.97%) than non-Add1 problems (134 of 202 CRs; 66.34%), but this is independent of whether the counting was on fingers or not.

Regressions

> *Question 6:* Is the profile of children in the addition task influenced by cognitive characteristics of the child?

This question involves several subquestions that were addressed using regression analyses. First, we may wonder what characteristics of the children predict good performance in the addition task. To address this question, we ran a linear regression model with CRs as the dependent variable and age (in months), matrix, counting, advanced counting, and digit span as predictors on the 93 children

Table 10
Regression on child's cognitive characteristics that influenced CRs

	B	*SE*	*β*	*t*	Significance (*p*)
Constant	−9.886	6.151		−1.60	.113
Age	.196	.099	.183	1.99	.050
Counting	.006	.036	.017	0.16	.871
Advanced counting	.760	.187	.426	4.07	<.001[2]
Matrix	.492	.141	.320	3.48	.001
Digit span	−.099	.461	−.021	−0.21	.831

Note. CRs, correct responses. $R^2 = .550$; $\Delta R^2 = .262$.
[2] $p < .001$.

Table 11
Regression on child's cognitive characteristics that influenced finger support

	B	*SE*	*β*	*t*	Significance (*p*)
Constant	6.006	7.084		0.848	.399
Age	−.149	.114	−.135	−1.308	.194
Counting	.011	.042	.030	0.252	.801
Advanced counting	.096	.215	.052	0.448	.655
Matrix	−.274	.163	−.173	−1.686	.095
Digit span	−1.475	.531	.304	−2.780	.007

Note. $R^2 = .127$; $\Delta R^2 = .077$.

Table 12
Regression on child's using of finger or object that influenced CRs

	B	*SE*	*β*	*t*	Significance (*p*)
Constant	6.99	.77		9.08	<.001
Counting with finger	.228	.098	.235	2.32	.023
Counting with object	.364	.107	.347	3.41	.001

Note. R^2 = .550; ΔR^2 = .262.

who completed the addition task; the model was significant, $F(5, 92) = 7.59$, $p < .001$, $R^2 = .304$, and indicated that both advanced counting and matrix were significant predictors. Higher scores in advanced counting and in the matrix subtest were indeed associated with higher CRs in the addition task (see Table 10).

Second, are there any characteristics of the children that would predict the number of trials solved using fingers? The same regression model was run, but this time with the number of trials solved using fingers as the dependent measure. The model was significant, $F(4, 88) = 2.71$, $p = .035$, $R^2 = .127$, and indicated that digit span was the only significant predictor. The lower digit span was indeed associated with a higher number of trials solved using finger support (see Table 11).

When the dependent measure was the number of trials solved by the child counting objects, the model was not significant, $F(5, 87) < 1$. Finally, if both types of support were added and used as a new dependent measure, the model was not significant either, $F(5, 87) = 1.60$, $p = .169$.

Finally, we looked at whether the type of support used by the child could predict the child's accuracy in the addition task. A regression analysis was run comparing the child's frequency of solving addition using (a) fingers or (b) objects to predict the child's accuracy in the addition task. Both counting with fingers and counting with objects significantly predicted the total CRs of addition. External supports, such as fingers and manipulatives, both were both associated with higher accuracy in addition (see Table 12).

Discussion

Although it was an old idea, especially in the educational field, that counting on fingers is a sign of immature numerical development and should be discouraged in children (Boaler & Chen, 2016; Cowan, 2013; Mutlu et al., 2020; Poletti et al., 2023), more recent research shows that it is not always true. In particular, when examining children's development, it appears that this idea is true in older children, but in young children using fingers to solve calculation is actually a characteristic of successful solvers (Dupont-Boime & Thevenot, 2018; Jordan et al., 2008; Krenger & Thevenot, 2024; Poletti et al., 2022). For instance, at the beginning of kindergarten (mean age = 5.7 years), Jordan et al. (2008) measured a correlation of .58 between frequency of finger use and accuracy in solving additions. This correlation decreased with children's development and ceased to be significant by Grade 2.

In the current study, we tested whether we could replicate previous observed associations between finger use and proficiency in arithmetic in younger children when they are at the very beginning of their arithmetic development and in a non-Western population. At this very young age, addition is still a very abstract concept and problems need to be presented in a concrete way. Therefore, calculations were contextualized within a story using a picture to represent the first operand. Children were also given some manipulatives at their disposal (tokens, plastic apples, etc.). This allowed us to address a second question: whether fingers would be preferentially used over manipulatives by these children and whether the benefits reported in the literature of young children using their fingers are specific to fingers or rather can be generalized to any external aids. Indeed, both manipulatives and fingers can alleviate the working memory demands while using counting to solve an arithmetic problem (Crollen & Noël, 2015; Ross et al., 2020) and thus could equally lead to better accuracy.

Our results first showed that at this age such a task was too difficult for many of the children. Indeed, 61% of the children were not able to answer any of the first 5 addition problems presented, and thus the task was stopped there. These children were only 1 month younger than children who succeeded at the task but had slower numerical development (as observed in the two counting tasks), lower memory capacities (measured in the digit span), and lower nonverbal intelligence (measured by the matrix subtest). These differences were not explained by the slight difference in age. Therefore, our conclusions are restricted to children with already quite advanced numerical abilities (i.e., arithmetical and counting skills) for their age. For this one third of the sample group, the global accuracy rate was quite good (66% of CRs). Regression analyses showed that in this subsample children with higher accuracy were those who had higher scores in advanced counting and in the matrix subtest, that is, more advanced numerical development and reasoning skills (see also Lê & Noël, 2021).

Several questions were addressed in this study. First, we wanted to discover what types of items resulted in better accuracy. In this very young sample of children, we replicated the typical size effect because CRs decreased with the increase of the sum of the problem (going from 83% of CRs for a sum of 4 down to 51% of CRs for a sum of 9). Tie problems led to higher CRs (72%) than non-Tie problems (64%), and Add1 problems also led to higher accuracy than non-Add1 problems (72% and 64%, respectively). In summary, the typical effects reported in the literature for addition tasks—the size (Ashcraft & Guillaume, 2009; Barrouillet & Thevenot, 2013; LeFevre et al., 1996; Thevenot et al., 2016; Uittenhove et al., 2016), the tie (e.g., Bagnoud, Dewi, Castel, et al., 2021; Campbell & Gunter, 2002; LeFevre et al., 1996), and the n + 1 effects (Bagnoud, Dewi, & Thevenot, 2021; Baroody, 1985)—were already present and observable in this very young population.

Second, we were interested in determining the associations between children's strategies and the types of items presented. The "nothing strategy" (i.e., the child guesses, does not know, gives no answer, etc.) was quite infrequent in this subsample (15% of the cases) and unsurprisingly led to a low accuracy rate (13%). The two other strategies observed were the mental and external counting strategies. The mental strategy was used in one fifth of the problems and led to very good accuracy (77% of CRs). External counting was the most used strategy, being used in 64% of the trials. It also led to very good accuracy (75% of CRs). Thus, the mental and counting strategies were equally efficient for solving addition problems at that age, which answered our third question. However, these strategies were not distributed equally on the different items. Specifically, counting strategies were used more often in response to non-tie problems (72% of the non-tie trials) than to tie problems (46% of the tie trials). The sum of the problem also affected the use of counting but in a nonlinear way. Noticeably, the very small sum of 4 and the very large sum of 10 were less often solved using counting strategies. Therefore, it seems that children selected the items where they could give a solution through the mental strategy and those where a counting strategy was more appropriate. Nevertheless, mental strategies were not used more often for add1 problems (12.9%) than for non-add1 problems of a comparable sum (13.3%).

Among external counting strategies, children mostly counted on their fingers (48% of the cases) or on objects (39% of the cases) and more rarely counted on both fingers and objects (9% of the cases) or verbally without any external support (4% of the cases). Thus, counting strategies were supported by fingers or manipulatives 96% of the time. On these trials solved by counting using an external support, fingers were used more often used for non-tie problems (51% of the cases) than for tie problems (43% of the cases). However, the size of the problem and the presence of 1 as an addend in the problem did not affect the frequency of using fingers to count. Importantly, we found that using fingers to count did not lead to better accuracy than using other support. More precisely, using fingers only was related to 70% of CRs, whereas using objects only was related to 81% of CRs.

Although it was not directly the subject of our article, the link between digit span and arithmetic skills deserves some discussion. Indeed, our results on this matter can appear somewhat contradictory. On the one hand, we observed that children from the dropped-out group had a lower digit span than children in the retained group. On the other hand, in this last group the correlation between the digit span and addition accuracy was not significant. This apparent contradiction is linked to the fact that the analysis was restricted to a group of children at a good mathematical level. When the same analysis was carried out on the whole sample, a significant correlation between working memory and addition accuracy was obtained (n = 242; r = .31, p < .001). This result aligns with those of Noël (2009), who showed better addition skills in 4- and 5-year-old children among those with higher working memory capacities. Now, regarding the type of support used in the retained group, the only significant relation observed indicates that children with a lower digit span use their fingers more than other children. These results are in line with those of two studies on 6-year-old children: Noël et al. (2004), who found more finger counting in children who had the lower digit span, and Crollen and Noël (2015), who found that, when prevented from using their fingers to solve additions, children with low working memory capacity was associated with lower accuracy in the addition task. However, they contradict the results of Dupont-Boime and Thevenot (2018), who showed also in 6-year-old children a positive relation between digit span and finger use in an addition task. Yet again, it must be borne in mind that our analyses were conducted only on efficient children with high memory span and that if children with lower memory span had been considered in our sample, the positive relation between working memory and finger use in the addition task could have been observed. This question might merit further research to more definitely determine whether poor memory skills are associated with greater use of fingers (and other external supports) to keep track of counting or whether the use of finger-counting strategies is a sign of maturity in young children and that only children with better cognitive skills (including memory) can implement them at the start of learning.

The crucial result of the current study is that, as stated above, children using mostly their fingers to solve addition problems were not more accurate in the addition task than those using mostly manipulatives. Our results indeed showed that both the frequency of using manipulatives and the frequency of using fingers were significant predictors of accuracy in the addition task. Recent literature has put a lot of emphasis on the role of fingers in numerical development and has shown that using fingers to solve addition problems is a sign of numerical maturity in young children. Finger use is an external support that is always available, which provides sensory-motor and kinesthetic affordances in addition to visual input (Soylu et al., 2018). For all these reasons, an advantage of fingers over manipulatives in numerical tasks could have been predicted. However, at the age of the children in this study and for children with especially high numerical abilities, our results do not speak in favor of this hypothesis. The fact that both manipulatives and fingers are effective support for arithmetic indicates that offloading or externalizing cognitive load, whatever the means, seems to be the principle for efficient cognition (Crollen & Noël, 2015). Of course, this does not mean that fingers do not have a special status over the course of children's development. Indeed, whereas this study establishes that the use of fingers at the very beginning of learning does not benefit children more than the use of manipulatives, it does not provide information on children's future performance. Within the embodied cognition framework (Bender & Beller, 2012; Fischer et al., 2012; Soylu et al., 2018; Tschentscher et al., 2012), the hypothesis that children who use their fingers rather than manipulatives will develop a better number sense and will better understand and internalize the meaning and outcomes of arithmetical operations, at least for addition problems, is still plausible. Nevertheless, this hypothesis will remain open until longitudinal studies where the behavior and performance of children are observed over the course of several years are conducted.

We also need to consider that our results might apply only to children with advanced numerical development such as those included in the current analyses. Future studies will need to examine whether our results are generalizable to a larger sample of children with more heterogeneous numerical abilities. This can be done in two ways. First, the addition task that we used might have been too difficult for the young children involved in our study. This task could be simplified by limiting the number of problems presented (e.g., 8 or 10 instead of 14) and by including problems with smaller sums than in the current version of the task (e.g., 1 + 1, 1 + 2). This simplification could eliminate the need for a stop criterion, potentially allowing for analysis of data from more children. Alternatively, children could be tested at a higher developmental stage when more of them are able to complete the task.

The use of manipulatives in children's mathematic education has been at the center of several studies. In their meta-analysis, Carbonneau et al. (2013) found that instruction that used manipulatives produced greater effects in young children assumed to be at the concrete operational stage than in older children assumed to be in formal operations. Because the children tested here were very young, it is not surprising to find that using manipulatives is really helpful for them.

One could possibly argue that manipulatives are to be used only at a very young stage and that, contrarily to fingers, they will never be internally integrated in such a way that, even in adulthood, they would be unconsciously recruited during mental calculations (for fingers, see Fischer et al., 2012, Michaux et al., 2013). However, in some Asian countries (but not in the sample we tested here), very structured manipulatives are used to help children learn arithmetical skills. This is the case of the mental abacus (MA), a technique in which users first move the beads of wood structure to add and subtract but then progressively visualize the beads on the abacus and produce movements in gestures that accompany the calculations. These learning tools have proven to be more efficient at supporting children's arithmetic skill development than more standard mathematics techniques (see Barner et al., 2016). After a few years of practice, users do not need the physical abacus to calculate, but evidence indicates that an MA is activated when they solve arithmetical problems. More specifically, this MA is represented in visual working memory by splitting the abacus into a series of columns, each of which is independently stored as a unit with its own detailed substructure. Users of an MA are relatively insensitive to verbal interference during an arithmetic task, whereas such an interference significantly deteriorates the performance of control participants. These results are consistent with the hypothesis that an MA is represented in a nonlinguistic format. Also consistent with this view, Brooks et al. (2018) found that the size and number of MA gestures reflect the length and difficulty of math problems but also that participants perform significantly worse on an MA under motor interference, suggesting that premotor processes involved in the planning of gestures are critical to mental representation in an MA.

Because the sample of this study was an Asian population, we could raise the question of the generalization of these results to other cultures. Indeed, previous work showed that Asian people usually outperform Western people in different numerical tasks (see Miller et al., 2005, and Okamoto, 2015, for reviews). For instance, Geary et al. (1993) found that Chinese kindergarteners (5–6 years old) solved more addition problems correctly and used more advanced solving strategies than U.S. kindergarteners. Many factors could account for these differences, including social or parents' emphasis on education or on math learning in particular, differences in the structure of the number naming system (Miller et al., 1995; Miura et al., 1993), and the fact that in China it is quite common for children to follow extra-school numerical development programs using abacuses, for example.

In this study, we tested Vietnamese children who indeed have a very transparent number naming system that has been shown to facilitate their development of the counting string (Lê & Noël, 2020) and of number transcoding (Lê & Noël, 2022). Yet, at this very young age, the advantages have been shown to be quite limited given that there were no differences between Vietnamese and Belgian preschoolers in numerical tasks such as advanced counting, enumeration, Give-N, number-word comparison, collection comparison, addition, and approximate addition (Lê & Noël, 2020). Similarly, regarding parents' home numerical stimulation, there was only a moderate difference between Vietnamese and Belgian parents, with the former stimulating their children a little more frequently. Finally, to reduce the impact of external factors, in this research we specifically discarded the few children who participated in early math education programs outside the school such as the Kumon programs. Nevertheless, it might be interesting to replicate this research with a sample of Western children and determine whether similar results would be found.

To conclude, based on the current research, it seems that, for children with high arithmetical and counting abilities, fingers might not be the only gateway to efficient arithmetic development and using manipulatives might also lead to proficient arithmetic. However, fingers are a simple and structured tool that is always available, which is not always the case for manipulatives, and therefore it is possible that fingers play a more specific role in numerical abilities at a later stage of development than the one reached by children in the current study. As mentioned previously, future studies will need to address this question by applying the same research protocol to older children. As also stated earlier, generalizing our results to a non-Asian population and to children with more various levels of arithmetic proficiency are other avenues for research that will need to be explored in the future. A last point deserving discussion here is related to the relatively high socioeconomic background of the children involved in our study. It is known that, probably through home numeracy (Girard et al., 2021), children's socioeconomic status affects the development of numerical skills. Even more related to the current study, and as revealed by Jordan et al. (2008), middle-income children present a decrease of finger use from Grade 2, whereas low-income children show a linear growth in finger use from the beginning of kindergarten until Grade 2. Therefore, it is possible that the results we obtained in the current study are specific to children with relatively high socioeconomic status, and future studies will need to explore the generalizability of our conclusions to children from lower backgrounds.

Author contributions

All authors conceived the rationale of the study; M-L.L. and M-P.N. designed the study; M-L.L. collected the data; M-L.L. and M-P.N. analyzed the data; C.T. wrote the Introduction part of the manuscript, M-L.L. and M-P.N. wrote the Method and Results, and M-P.N. wrote the Discussion.

CRediT authorship contribution statement

Mai-Liên Lê: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marie-Pascale Noël:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Catherine Thevenot:** Writing – review & editing, Writing – original draft, Supervision.

Data availability

We have shared the link to our data in the paper

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