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Do children need counting principle knowledge to count on their fingers?

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ABSTRACT

It has been established that young children who use their fingers to solve arithmetic problems outperform those who do not. However, it remains unclear whether finger counting itself enhances arithmetic performance or if children with already advanced numerical abilities are more inclined to use this strategy. In the current study, to shed light on this matter, we observed the behavior of 189 4- and 5-year-old children in an addition task and a task assessing their knowledge of the three "how-to-count" principles (i.e., stable order, one-to-one correspondence, and cardinality principles). Of these children, 169 were reassessed 1 year later (the second testing point). At the first testing point, our results revealed that finger users better know the counting principles than non-finger users. Nevertheless, some children use their fingers without knowing the principles, but in this case they present low performance in the addition task. Moreover, we found that knowing the counting principles does not naturally prompt finger use. Finally, we did not find evidence supporting the idea that finger use has a specific role in the development of counting principles, which questions the idea that finger counting has a functional role in the construction of the number concept. All in all, our results tend to show that children need to know the counting principles to be efficient finger users. Therefore, finger counting seems to be a useful tool when used by children who already possess advanced numerical knowledge.

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Introduction

The relation between fingers and numbers has received considerable attention from researchers in the domains of education, cognitive psychology, and developmental psychology (see Neveu et al., 2023, and Sixtus et al., 2023, for recent reviews). This interest is motivated by the fact that finger counting could play a fundamental role in the development of future numerical abilities (Crollen, Seron, et al., 2011; Crollen & Noël, 2015). Although it has been established that finger counting is not necessary to develop such skills because individuals who do not or cannot use their fingers to count show intact arithmetic abilities (e.g., in blind people: Crollen, Mahe, et al., 2011; in hemiplegic children: Thevenot et al., 2014), the usefulness of finger counting during development has recently received strong support. Indeed, even though many preschool teachers associate finger counting with math difficulties (Poletti et al., 2023), it has been established that young children aged 4 to 6 years who use their fingers to calculate present better arithmetic performance than children who do not (Dupont-Boime & Thevenot, 2018; Jordan et al., 2008; Krenger & Thevenot, 2024; Poletti et al., 2022).

In fact, finger counting not only could be associated with better performance in arithmetic but also could functionally support the acquisition of the number concept (Krajewski & Schneider, 2009; see Barrocas et al., 2020, for a review), which is commonly viewed as reflected by children's understanding of counting principles (Stock et al., 2009). Among these principles, the stable order, one-to-one correspondence, and cardinality principles are of particular importance. Indeed, Gelman and Gallistel (1978) described them as the "how-to-count" principles, closely related to the number concept because they address the fundamental properties of numbers, ensuring that the counting process adheres to a structured, consistent, and meaningful representation of quantities.

Children are considered as understanding the stable order principle in a counting task when they can produce the number sequence to tag the objects of the set in a fixed order across trials. They are considered as mastering the one-to-one correspondence principle when they are able to associate one verbal counting label to one and strictly one object during counting. Finally, in a counting task, they are considered as mastering the cardinality principle when they understand that the last count word uttered after counting corresponds to the total number of objects in the counted set.

The functional hypothesis evoked above therefore is that finger counting could help children in grasping these counting principles (Fayol & Seron, 2005). More precisely, and as explained by Andres et al. (2008), the stable order principle could emerge from the use of consistent finger counting strategies determined by motor constraints and cultural habits (Cipora et al., 2023; Lindemann et al., 2011; Lucidi & Thevenot, 2014). Such cultural habits would confer a symbolic status to finger configurations while keeping one-to-one correspondence between the physical world and numerical symbols and while preserving cardinality. The same idea was taken up more recently by Sixtus et al. (2023), who considered that establishing a relation between one finger and one number (i.e., one-to-one correspondence) enables a direct experience of cardinality and ordinality. In this view, the use of fingers in numerical tasks therefore would support the construction of number.

Nevertheless, and contrary to the hypothesis that finger counting functionally supports the acquisition of the number concept (i.e., the functional hypothesis), it could also be argued that knowledge of the counting principles is necessary before children can implement finger counting strategies. Indeed, associating one finger with one number and enumerating the number sequence in proper order seem to be basic requirements for accurate finger counting. Moreover, because very young children who count on their fingers massively use counting strategies where both operands of the problems are represented (Krenger & Thevenot, 2024; Lê et al., 2024), it is possible that producing the right answer through finger counting requires knowledge of the cardinality principle. Giving proper meaning to finger counting might indeed require the understanding that the entire set of fingers raised corresponds to the problem answer. This hypothesis, suggesting possible emergence of finger counting only after the counting principles are mastered (i.e., the prerequisite hypothesis), could explain why young children who count on their fingers are those with the highest intellectual abilities (Dupont-Boime & Thevenot, 2018; Krenger & Thevenot, 2024; Poletti et al., 2022). Still, it is also possible that children can implement a finger counting strategy as a mechanistic procedure in the specific context of finger counting without understanding abstract principles. In the case that counting principles are a prerequisite for finger counting, the hypothesis could be complemented by assuming that children who master the counting principles will naturally and systematically implement finger counting during an arithmetic task (i.e., prompting hypothesis). Indeed, given that it is established that young finger users perform better in arithmetic than non-finger users (Dupont-Boime & Thevenot, 2018; Jordan et al., 2008; Krenger & Thevenot, 2024; Poletti et al., 2022), it is possible that children who have the required knowledge to implement finger counting naturally do so in order to maximize their performance.

According to the prerequisite hypothesis, which posits that counting principles are necessary for accurate finger counting, it is predicted that all finger users should master the counting principles. In addition, according to the prompting hypothesis, all counting principle knowers should use their fingers to calculate. Note that within the prerequisite hypothesis, counting principle knowers could or could not be finger users. Finally, according to the functional hypothesis, which posits that finger counting helps in constructing or reinforcing number comprehension, children who use finger-based strategies are in the acquisition process of the counting principles. Therefore, within the population of finger users, children mastering the counting principles should be more numerous than children not mastering them. Crucially within this last hypothesis, finger users who do not master the counting principles will be more likely to master these principles later during development than non-finger users.

To date, the question of whether counting principles are or are not necessary to implement finger counting has never been addressed, leaving a lack of empirical evidence to support the three hypotheses described above (i.e., prerequisite, prompting, and functional hypotheses) regarding the interplay between finger counting and counting principles. The current study aimed at filling this gap through the observation of a cohort of 189 4-year-old children who were followed over the course of 1 year. They were assessed twice (first testing point: T1; second testing point: T2) on their counting principles, use of fingers, and accuracy in an addition task and were assessed once on their intelligence abilities. Their use of fingers was treated as a dichotomic variable (i.e., yes or no) rather than as a continuous variable representing children's frequency of finger use. Indeed, what we were interested in was whether children have this strategy in their repertoire (Lemaire & Siegler, 1995), not how often they use this strategy when they have it. In fact, the frequency of finger use is a relevant variable only when the type of problems and the adaptability of the strategy are of concern (Shrager & Siegler, 1998), which was not the case here.

Using this design, we first ensured that the classical result of the literature that young finger users are more accurate in an addition task than non-finger users was replicated. To have a more comprehensive view of children's behaviors, this variable (i.e., accuracy in the addition task) was also articulated with children's counting principle knowledge. Then, to more directly test our hypotheses, the numbers of counting principle knowers and non-counting principle knowers in the population of children who calculated with their fingers (i.e., finger users) were compared. Within the prerequisite hypothesis, it was predicted that all finger users would know the counting principles. This was examined for each principle, with particular attention to the cardinality principle, whose requirement for efficient finger counting is more disputable than that of the other principles. Within the prompting hypothesis, all counting principle knowers should be finger users. If not, the idea of a domain-general factor as a determinant of finger use was tested using a regression analysis with counting principle knowledge and intelligence as predictors and finger use as the outcome. This last analysis was conducted at T1, where the intelligence test was administered to children. The prompting hypothesis was also tested using a regression analysis among non-finger users, with the idea that counting principle knowledge at T1 should predict finger use at T2. Finally, within the functional hypothesis, the number of finger users who know the counting principles should be higher than the number of finger users who do not know the principles. Moreover, among non-counting principle knowers at T1, the number of children mastering these principles 1 year later should be higher among finger users than among non-finger users. Note that within the prerequisite hypothesis, the number of children mastering the principle later during development should be independent of the fact that they did or did not use their fingers in the past.

Method

Participants

A total of 212 kindergarteners from various socioeconomic backgrounds were involved in our study. Of this sample, 23 children were excluded either because they did not speak French fluently enough to understand the tasks (n = 19) or because they had been diagnosed with a developmental disorder (autism spectrum disorder or attention-deficit/hyperactivity disorder; n = 4). Therefore, at T1, our sample included 189 children (88 girls). The ages of children ranged from 3 years 10 months to 5 years 2 months (M = 55.7 months, SD = 3.8), with 98.9% of children falling within the range of 50 to 62 months. In fact, only 1 child in the sample was younger than 4 years. At T2 1 year later, the same participants were reassessed. Because 20 children had moved away, our final sample for T2 was reduced to 169 children (87 girls). The ages of children ranged from 4 years 9 months to 6 years 2 months (M = 66.85 months, SD = 3.8).

All children were recruited from three schools in Vaud County, Switzerland. Although children attended different schools, their learning is standardized through the implementation of a common pedagogical framework known as the Plan d'Étude Romand (PER), which sets all the objectives and pedagogical method for each year. This PER mentions that kindergarteners should be presented with additions and subtractions embedded in concrete situations without formalization, either by playing by drawing the situations or by manipulating concrete material. There is no specific instruction concerning finger counting.

The study received the approval from the University of Lausanne's ethics committee, which follows the Code of Ethics of the World Medical Association (Declaration of Helsinki) recommendations. The study also received approval from the Committee for Research in Education of Vaud County. Parental consents were obtained for all children.

Materials and procedure

At each testing point, children were assessed individually for around 20 min in a quiet area of their school. They were assessed using a series of numerical tasks including a numerical sequence recitation task, a counting task, an arithmetic word-problem solving task, and an addition task. They were also assessed on more general cognitive skills, namely a short-term memory task and a general intelligence task. In the current study, the results related to the word-problem solving, numerical sequence, and short-term memory tasks were not considered. All the tasks were administered at T1 and T2 except the intelligence task, which was administered only at T1.

General intelligence task

General intelligence was assessed at T1 using the standardized test of Matrix Reasoning from the Wechsler Intelligence Scale for Children (WISC-V; Wechsler, 2016). In each item of this test, children needed to logically complete a sequentially arranged series of geometrical figures by choosing the right figure among five figures. The first two trials in which children received feedback on their answers were considered as examples and were ignored in the final Matrix Reasoning score. These example trials were followed by 32 items of increasing difficulty, each presented on A4 paper cards (8.27 by 11.7 inches). There was no time limit and no feedback on children's answers for these items. After three consecutive errors, the task was stopped. The Matrix Reasoning score corresponded to the number of items accurately responded.

Addition task

Children were asked to solve a set of 10 addition problems written horizontally with Arabic digits. Each problem was presented individually on paper cards. Given the young age of our participants, to maximize their chance to complete the task, the operands for each addition ranged only from 1 to 5. All 5 tie additions in this range were included (i.e., 1 + 1, 2 + 2, 3 + 3, 4 + 4, and 5 + 5). For the 5 non-tie additions, each digit was presented twice across problems, and the smaller operand was always presented first (i.e., 1 + 2, 2 + 3, 3 + 4, 4 + 5, and 1 + 5).

Again, considering the young age of the children involved in our study and their possible difficulty in reading Arabic digits, the additions were read aloud by the experimenter. Children were asked to find the answers to the problems with no specific instruction on how to solve them. When children said that they did not know the answer, the experimenter encouraged them by saying, "How could you find the answer?" When children gave an incorrect answer but spontaneously corrected themselves, the latest answer was considered. There was no time limit for solving the additions. One point was attributed for each addition solved correctly, resulting in a maximum score of 10 (which is presented in the analyses as percentage of correct answers).

This task was also used to distinguish children who used their fingers to solve the additions from those who did not. To prevent children from masking their hands under the table, both the children and the experimenter were seated on the floor. Children's actions were filmed, and the collected footage was analyzed using BORIS software (Version 7.4.11; Friard & Gamba, 2016). Children were subsequently categorized as "finger users" when they used their fingers at least once during the addition task or as "non-finger users" when they exclusively relied on mental strategies.

Counting principle task

This task was adapted from the TEDI-Math (Van Nieuwenhoven et al., 2001) with the inclusion of additional items. More precisely, children were asked to count seven different sets of animals printed on A4 paper cards, presented one after the other in a fixed order. The sets varied in number, spatial arrangement (linear vs. nonlinear), and homogeneity (homogeneous vs. heterogeneous). The four first sets consisted of 4, 5, 6, and 9 animals of the same kind presented linearly. The two next sets consisted of 5 and 12 animals of the same kind dispatched through the paper card (i.e., homogeneous and nonlinear). The last set consisted of 5 animals of two different kinds (2 lions and 3 tortoises) dispatched through the paper card (i.e., heterogeneous and nonlinear).

In this task, the three how-to-count principles, namely the stable order, one-to-one correspondence, and cardinality principles, were tested on each card as follows. The stable order and one-to-one correspondence principles were assessed as children counted the set. Children were considered as having acquired the stable order principle when they recited the number word sequence in a conventional order. They were considered as having acquired the one-to-one correspondence principle when they established a correspondence between each numeral and one and only one animal in the set. To test the cardinality principle, we assessed whether children could use the last word cardinal answer. To do so, children were asked systematically after their count: "So, how many are there?" Children succeeded in using the last word cardinal answer when they repeated their last count word. Whenever children did not answer this question by repeating their last count word, we concluded that they had not acquired the cardinality principle yet. Children who have not acquired this principle typically recount all the animals or say a numeral other than the last produced.

For each of the 7 items, children could score 1 point for each principle, resulting in a score out of 7 for each of the three principles. Children were considered to have mastered a principle if they succeeded on at least 6 of 7 trials for that principle. A total counting principle score was also calculated by summing the scores obtained across the three principles, resulting in a total score out of 21.

Results

The dataset used for the following analyses is accessible on the Open Science Framework (https://osf.io/f92np/?view_only=bfa1973dae4940959b1ee06cf4159223).

Cross-sectional analysis

An overall description of our results is provided in Table 1, where the addition scores, the counting principle scores at T1 and T2, and the intelligence score at T1 in finger and non-finger users are provided. The result of correlational analyses on the whole sample of children between these variables is also provided in Table 2.

Table 1
Descriptive statistics concerning the variables under study at T1 and T2 for finger users and non-finger users

	F+		F−		
Variable	*n*	*M* (*SD*)	*N*	*M* (*SD*)	*p*
Addition score, T1	33	41.5% (17.9)	156	14.6% (33.7)	<.001
Counting principle score, T1	33	18.0 points (4.6)	156	16.2 points (5.1)	.058
Intelligence score, T1	33	8.1 points (3.4)	156	5.3 points (3.7)	<.001
Addition score, T2	65	78.8% (23.8)	104	33.7% (34.4)	<.001
Counting principle score, T2	65	20.0 points (1.3)	104	19.6 points (2.3)	.191

Note. T1, first testing point; T2, second testing point; F+, finger users; F−, non-finger users. Addition scores correspond to percentages of correct answers out of 10 problems. The maximum counting score is 21 points. The maximum score of intelligence in the Matrix Reasoning task is 32. The *p* values are the outcomes of a series of *t* tests comparing finger users' and non-finger users' performance.

Table 2
Correlations between the variables under study at T1 and T2

Variable	1	2	3	4
1. Addition score, T1	–			
2. Counting principle score, T1	.307***	–		
3. Intelligence score, T1	.428***	.371***	–	
4. Addition score, T2	.366***	.385***	.331***	–
5. Counting principle score, T2	.183*	.423***	.167*	0.231**

Note. T1, first testing point; T2, second testing point.
* p < .05.
** p < .01.
*** *p* < .001.

The distribution of children in the different categories (finger users who know the principles: F+C+; finger users who do not know the principle, F+C−; non-finger users who know the principle: F−C+; and non-finger users who do not know the principles: F−C−) for T1 and T2 can be found in Table 3.

At T1, among 33 finger users (17.5% of the whole sample), 21 were counting principle knowers (63.6%) and 12 were not (36.4%). A one-sample *z* test for proportions showed that the number of finger users who were not counting principle knowers differed from 0 ($z = 5.048$, $p < .001$). As a matter of fact, a binomial test revealed that the percentages of finger users knowing and not knowing the counting principles did not differ significantly ($p = .163$). A *t* test conducted on children's performance in the addition task revealed that among finger users, counting principle knowers outperformed (81.7% of correct answers) non-counting principle knowers (64.5%), $t(63) = 2.24$, $p = .029$, $d = 0.741$ (Table 3).

At T2, among 65 finger users (38.5% of the whole sample), 54 were counting principle knowers (83.1%) and 11 were not (16.9%). A one-sample *z* test for proportions showed that the number of finger users who were not counting principle knowers differed from 0 ($z = 1.861$, $p = .031$). As attested by a binomial test, the percentages of finger users knowing and not knowing the counting principles differed significantly ($p < .001$). A *t* test conducted on children's performance in the addition task revealed that among finger users, counting principle knowers outperformed (52.4 % of correct answers) non-counting principle knowers (22.5%), $t(31) = 2.67$, $p = .012$, $d = 0.967$ (Table 3).

At a more fine-grained level depending on each principle, when children did not know the three counting principles at T1, they failed in one, two, or all three. The percentage of children who mastered the three principles was higher in finger users (63.6%) than in non-finger users (42.9%), $\chi^2(1, N = 189) = 4.69$, $p = .030$. However, the percentages of children who failed the three principles were similar in both groups (9.1% vs. 13.5% for finger users and non-finger users, respectively), $\chi^2(1, N = 189) = 0.47$, $p = .493$. At T2, the percentage of children who mastered the three principles was not significantly higher in finger users (83.1%) than in non-finger users (78.8%), $\chi^2(1, N = 169) = 0.46$, $p = .500$. Moreover, the percentages of children who failed the three principles were similar in both groups (0% vs. 3.1% for finger users and non-finger users, respectively), $\chi^2(1, N = 169) = 1.26$, $p = .261$.

Table 3
Number of children in each category (finger users and non-finger users) depending on their counting principle knowledge, mean percentages of finger use in the addition task (and standard deviations), and mean percentages of additions solved correctly (and standard deviations) at T1 and T2

		Number of children	% of finger use	% of correct answers
T1	F+C+	21	47.6% (26.8)	52.4% (33.5)
	F−C+	67	–	17.8% (20.4)
	F+C−	12	37.5% (27.3)	22.5% (25.6)
	F−C−	89	–	12.1% (15.3)
T2	F+C+	54	42.2% (26.8)	81.7% (20.4)
	F−C+	82	–	35.5% (35.1)
	F+C−	11	57.3% (25.3)	64.5% (33.9)
	F−C−	22	–	26.8% (31.7)

Note. F+, finger users; F−, non-finger users; C+, counting principle knowers; C−, non-counting principle knowers; T1, first testing point; T2, second testing point.

A 3 (Type of Principle: stable order vs. cardinality vs. one-to-one correspondence) × 2 (Finger Use: finger users vs. non-finger users) analysis of variance (ANOVA) was conducted on the counting principle scores with the first factor as a within measure and the second one as a between measure (Fig. 1 for T1 and Fig. 2 for T2). At T1, the results showed a significant main effect of finger use, $F(1, 187) = 3.63$, $p = .058$, $\eta_p^2 = .019$, with finger users scoring more than non-finger users (6.00 vs. 5.39 points, respectively). The main effect of type of principle was also significant, $F(2, 374) = 6.48$, $p = .002$, $\eta_p^2 = .033$. Post hoc analysis showed that the stable order principle was more successful ($M = 6.11$ points) than the cardinality principle ($M = 5.56$ points), $t(187) = 2.58$, $p < .029$, and the one-to-one correspondence principle ($M = 5.41$ points), $t(187) = 4.12$, $p < .001$. There was no difference between the cardinality and one-to-one correspondence principles, $t(187) = 0.68$, $p = .773$. The interaction between finger use and type of principle was not significant, $F(2, 374) = 0.243$, $p = .785$, $\eta_p^2 = .001$.

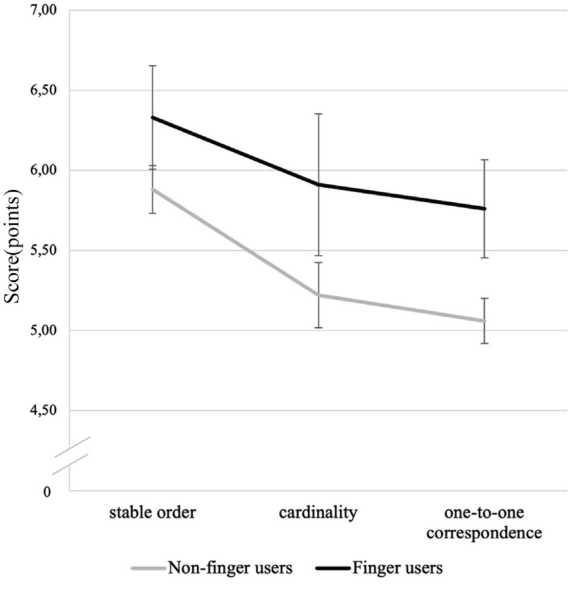

Fig. 1. Scores (out of 7) in the stable order, cardinality, and one-to-one correspondence principles in finger and non-finger users at the first testing point.

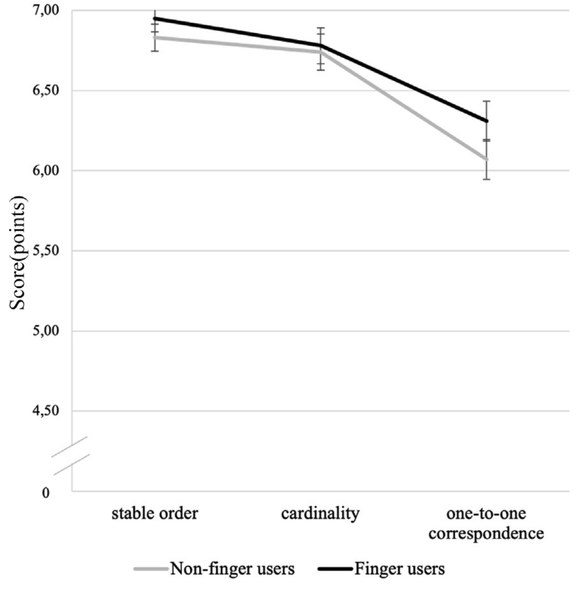

Fig. 2. Scores (out of 7) in the stable order, cardinality, and one-to-one correspondence principles in finger and non-finger users at the second testing point.

At T2, there was no main effect of finger use, $F(1, 167) = 1.72$, $p = .191$, $\eta_p^2 = .010$, showing no difference between finger users and non-finger users on counting principle scores (6.68 vs. 6.54 points, respectively). However, the main effect of type of principle was significant, $F(2, 334) = 46.79$, $p < .001$, $\eta_p^2 = .219$. Post hoc analysis showed that the stable order was more successful ($M = 6.89$ points) than the cardinality principle ($M = 6.76$ points), $t(167) = 2.32$, $p = .056$, and the one-to-one correspondence principle ($M = 6.19$ points), $t(167) = 9.03$, $p < .001$. The cardinality principle was also more successful than the one-to-one correspondence principle, $t(167) = 6.10$, $p < .001$. The interaction between finger use and type of principle was not significant, $F(2, 334) = 0.809$, $p = .446$, $\eta_p^2 = .005$.

As shown in Table 3, among the 88 counting principle knowers from our sample (46.6% of the whole sample) at T1, 21 were finger users (23.9%), whereas 67 were non-finger users (76.1%). A one-sample *z* test for proportions showed that the number of non-finger users who were counting principle knowers differed from 0 ($z = 20.680$, $p < .001$). A *t* test conducted on children's performance in the addition task revealed that among counting principle knowers, finger users outperformed (52.4% of correct answers) non-finger users (17.8%), $t(86) = 5.74$, $p < .001$, $d = 1.44$ (Table 3). At T2, among the 136 counting principle knowers from our sample (80.5% of the whole sample), 54 were finger users (39.7%), whereas 82 were non-finger users (60.3%) (see Table 3). A one-sample *z* test for proportions showed that the number of non-finger users who were counting principle knowers differed from 0 ($z = 19.551$, $p < .001$). A *t* test conducted on children's performance in the addition task revealed that among counting principle knowers, finger users outperformed (81.7% of correct answers) non-finger users (35.5%), $t(134) = 8.74$, $p < .001$, $d = 1.53$ (Table 3).

Then, a binomial regression analysis with a stepwise variable entry method was conducted on the whole sample of children at T1 by considering children's intelligence scores as an additional predictor of finger use. The first model, considering only the counting principle score, was significant, $\chi^2(df = 1) = 4.16$, $p = .041$, correctly classifying 57.6% of finger users and 63.5% of non-finger users (cutoff sensitivity specificity set at 0.20), with a very small explanation of variance [McFadden's R^2 (R^2McF) = .024, Akaike information criterion (AIC) = 175]. The predictor itself was marginally significant [$z = 1.85$, odds ratio (*OR*) = 1.10, $p = .065$]. In the second model, the intelligence score was added. The overall model was found to be significant $\chi^2(df = 2) = 16.09$, $p < .001$, with a modest explanation of variance (R^2McF = .092, AIC = 165). This model correctly classified 63.6% of finger users and 70.5% of non-finger users. Notably, only the intelligence score emerged as a significant predictor of finger use (z = 3.33, OR = 1.21, p < .001), whereas the counting principle score lost significance (z = 0.68, OR = 1.04, p = .499). The comparison of the first and second models was significant, $\chi^2(df = 1) = 11.90$, p < .001, indicating that the second model was more predictive than the first.

Longitudinal analysis

Only the 89 children who took both testing points and who did not know the counting principles at T1 were considered here (Fig. 3, which describes all the trajectories adopted by children). Among them, 7 of the 11 finger users at T1 became counting principle knowers at T2 (63.7%) and 57 of the 78 non-finger users at T1 became finger users at T2 (73.1%). As attested by a chi-square, these proportions did not differ significantly, $\chi^2(1, N = 86) = 0.425$, p = .514.

A longitudinal binomial regression analysis considering the knowledge of counting principles among the 138 non-finger users at T1 as a predictor of finger use at T2 was conducted (Fig. 4). The analysis showed no significant effect, $\chi^2(df = 1) = 0.687$, p = .407.

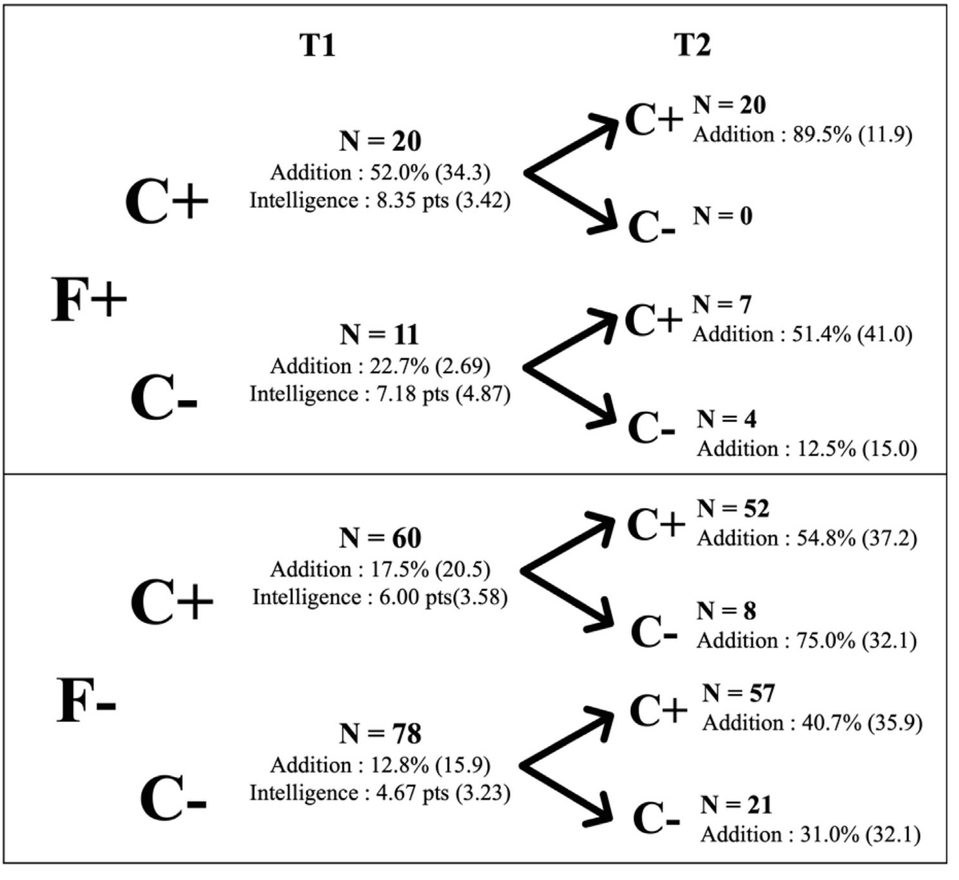

Fig. 3. Developmental trajectories of finger users (F+) and non-finger users (F−) over the first testing point (T1) and second testing point (T2) on their knowledge of the counting principles (C+ or C−) as well as their addition performance (% of additions solved correctly) and intelligence scores.

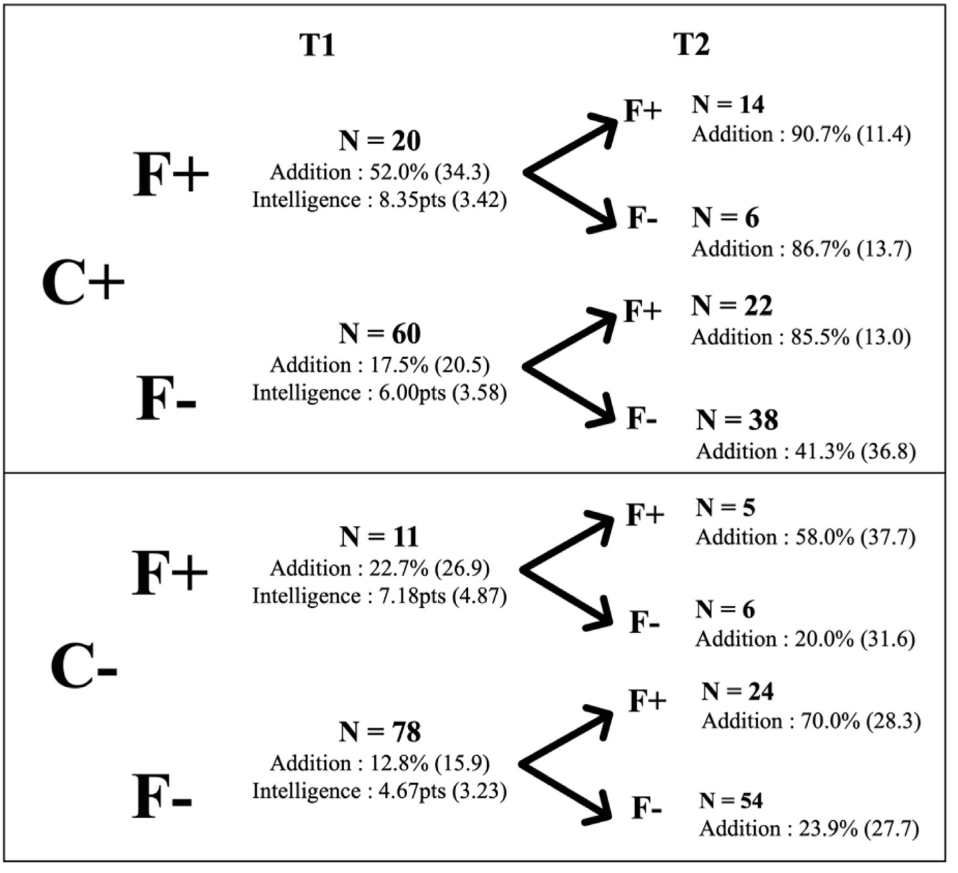

Fig. 4. Developmental trajectories of counting principle knowers (C+) and non-counting principle knowers (C−) over the first testing point (T1) and second testing point (T2) on their use of fingers in the addition task (F+ or F−) as well as their addition performance (% of additions solved correctly) and intelligence scores.

Discussion

In this research, our main question was to determine whether children need to know the fundamental counting principles to implement finger counting. We also asked whether knowing the counting principles naturally prompts finger counting. Finally, we asked whether finger counting helps in the construction of counting principles. The empirical evidence gathered within the current study concerning these questions is summarized and discussed below in three different sections.

Is counting principle knowledge a prerequisite for finger counting?

Our results revealed that at 4 or 5 years of age (T1) and 5 or 6 years of age (T2), a minority but non-negligible number of children used their fingers without knowing the counting principle (i.e., 12 of 33 at T1 and 11 of 65 at T2), which shows that this knowledge is not a prerequisite for finger counting. Nevertheless, at both T1 and T2, children who did not know the counting principle and calculated on their fingers were less efficient in the addition task (22.5% and 64.5% of correct responses at T1 and T2, respectively) than finger users who knew the principles (52.4% and 81.7% of correct responses at T1 and T2, respectively). In fact, at both testing points, only a very few children managed to solve more than 3 of 10 additions when they did not know the counting principles (2 of 189 at T1 and 8 of 169 at T2). Therefore, although knowing the principles is not a prerequisite for finger counting, it is a prerequisite for accurate finger counting. This means that children who count on their fingers without knowing the principles cannot solve the problems correctly through the application of mechanistic procedures in the specific context of finger counting. This conclusion alleviates the concern often formulated by educators and mainly advocated by Brissiaud (2013) that finger counting could trap children in a meaningless method that allows problem solving without understanding the underlying numerical concepts.

Does counting principle knowledge naturally prompt finger counting?

Our results revealed that at 4 or 5 years of age (T1), 67 of 88 children were counting principle knowers but not finger users. One year later (T2), 82 of 136 children belonged to this category. Therefore, knowing the counting principles does not naturally prompt finger counting. A regression analysis conducted in a longitudinal approach allowed us to reach the same conclusion, with no predictor role of counting principle knowledge at T1 on finger use at T2.

These results could have been explained by the fact that counting principle knowers who do not count on their fingers were already at a stage where fingers were no longer useful. However, this explanation does not hold because counting principle knowers who did not use their fingers in the addition task were outperformed by children who used their fingers in the addition task. Therefore, implementing efficient finger-based counting strategies requires more than a good concept of number.

In fact, a regression analysis informed us that although knowing the counting principles increases the probability of being a finger user, it is no longer the case when children's intelligence scores are entered into the model. This reveals that, as explained before, counting principle knowledge is a necessary but not sufficient ability for the development of accurate finger counting strategies. This knowledge must be accompanied by good cognitive abilities to give rise to efficient finger counting strategies. Therefore, it is possible that the emergence of finger counting during development needs sufficient mental resources to translate and articulate the prerequired numerical concepts into an efficient strategy (Halford, 1993). The role of cognitive abilities in the implementation of finger-based strategies could also be explained by higher abstract abilities in more intelligent children (Brooks, 1991; Cattell, 1943). These abilities could be needed for the implementation of finger counting because children must have understood that a quantity can be represented by different means (Sinclair & Pimm, 2015). Nevertheless, it is also possible that cognitive efficiency boosts the emergence of finger-based strategies because intelligent children are more responsive to explicit teaching than less intelligent children. Indeed, we do not know in our study whether children from our sample discovered their finger-based strategies by themselves or whether they were taught to use these strategies. The possibility that children were somehow taught the finger strategy during their life is open because, as mentioned earlier, there is no explicit reference to finger counting in the school curriculum in Switzerland, leaving teachers free to select their pedagogical approach. In our study, what is going on at home and in schools was also unknown, and it is possible that some parents demonstrated or taught explicitly how to calculate with fingers to their children.

Does finger use functionally help in discovering counting principles?

Our results revealed that at 4 or 5 years of age (T1), the numbers of children who counted on their fingers in an addition task was not significantly higher in the group of children who knew the counting principle ($n = 21$) than in the group who did not know the principle ($n = 12$). However, at this age finger users know the counting principles better than non-finger users, whatever the principle including the cardinality principle. At T2, the difference in the number of finger users who knew ($n = 54$) and did not know ($n = 11$) the principle became significant. This could suggest that finger users are more engaged in the process of counting principle acquisition than non-finger users. Nonetheless, a longitudinal analysis of our data showed that non-counting principle knowers who were finger users were not more likely to master the counting principles 1 year later than non-finger users. This result does not support the hypothesis that finger counting serves as a facilitator for the development of the number concept (e.g., Andres et al., 2008). Nevertheless, this conclusion must be considered cautiously because, as developed in the previous paragraph and in accordance with the prerequisite hypothesis, the number of finger users who did not know the counting principle was very low (i.e., $n = 12$ at T1; see Fig. 3), which limits the reliability of statistical analyses.

Conclusions and future directions

These conclusions and interpretations open some discussions concerning the help that could be provided to children through educational programs. Our results, and especially the fact that finger users who mastered the counting principles outperformed those who did not, suggest that the first step for the development of efficient finger-based strategies is the understanding of the principles underlying the concept of number (e.g., Bideaud et al., 1992; Vergnaud, 1992). Several intervention studies have already been developed with this aim (e.g., Björklund et al., 2021; Paliwal & Baroody, 2018, 2020; Tirosh et al., 2020). Nevertheless, and because the current research revealed that knowing these principles is not sufficient to systematically observe the emergence of finger counting, explicitly teaching finger counting strategies might constitute a golden way to improve children's performance in arithmetic. To date, even though several intervention studies have highlighted the specific role that fingers could play in the development of arithmetical abilities (e.g., Bonneton-Botté et al., 2022; Gracia-Bafalluy & Noël, 2008; Ollivier et al., 2020; Schild et al., 2020), only one such study has proven the efficacy of finger counting training (Poletti et al., 2024). However, in this study and within a sample of 88 children aged 5 and 6 years, 25% of them were not sensitive to the training program and therefore did not adopt the finger counting strategy taught. These children remained at a poor level of performance in an addition task before and after the intervention. The current research could suggest that these children may lack the required counting principles to understand the finger counting strategy and adopt it. This hypothesis should be explored further in future research.

Before concluding, several potential limitations of our study must be noted. First, we inferred advanced numerical skills in young children from their success in understanding the counting principles in a counting task. However, it is possible that other dimensions of the number concept play a central role in the discovery and implementation of the finger counting strategy. Children's number sense is, for example, often assessed using number comparison tasks or representation of numbers on a number line (e.g., Booth & Siegler, 2006). In future studies embracing the same path as the current one, therefore, it might be interesting to assess children's numerical abilities on a broader range of numerical skills. Moreover, testing the cardinality principle with the "how many" task might not have been the optimal way. Indeed, this task is suspected to overestimate children's mastery of the cardinality principle (e.g., Frye et al., 1989; Fuson et al., 1985; Sarnecka & Carey, 2008), and this is a bias that we cannot ignore in our assessment of children's numerical understanding. On the contrary, it has been suggested that without interviews and discussions with children, their counting skill abilities might be underestimated (Johnson et al., 2019). In the future, assessing the counting principles with several tasks and deeper interactions with children therefore might be required.

In summary, our new findings indicate that children who efficiently use their fingers in an arithmetic task to solve the problems know the fundamental counting principles, including the cardinality principle. Moreover, within the current study, we did not find evidence that finger use functionally supports the construction of the counting principles. We also found that knowing the counting principles does not naturally prompt finger counting. It seems that this knowledge needs to be coupled with high intellectual abilities to give rise to a successful finger counting strategy.

Finally, it is important to clarify that concluding here that finger use does not support the construction of the principles underlying the comprehension of the number concept does not imply that finger counting is unconstructive for the development of arithmetic skills. Indeed, through the use of increasingly abstract finger strategies, from strict modeling of the problems to count-on strategies where one operand is kept in mind, finger users could sooner and better rely on fully internalized strategies (i.e., keeping the two operands in mind) than children who had never used their fingers to calculate during development or who had not used them efficiently (Baroody, 1987). However, empirical evidence supporting this claim has yet to be provided.

Author contributions

Both authors designed the study and wrote the manuscript. M.K. collected the data and analyzed the results of the study. C.T. supervised the work.

CRediT authorship contribution statement

Marie Krenger: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Catherine Thevenot:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Data availability

We have shared the link to our data in the manuscript

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