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Age-related changes in how 5- to 8-year-old children use and execute finger-based strategies in arithmetic

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ABSTRACT

To determine how young children use and execute finger-based strategies, 5- to 8-year-olds were asked to solve simple addition problems under a choice condition (i.e., they could choose finger-based or non-finger strategies on each problem) and under two no-choice conditions (one in which they needed to use finger-based strategies on all problems and one in which they could not use finger-based strategies). Results showed that children (a) used both finger-based and non-finger strategies to solve simple addition problems in all age groups, (b) used fingers less and less often as they grew older, especially while solving smaller problems, (c) calibrated their use of finger-based strategies to both problem features and strategy performance, and (d) improved efficiency of both finger-based and non-finger strategy execution. Moreover, (e) strategy performance was the best predictor of strategy selection in all age groups, and (f) when they had the possibility to use fingers, children of all age groups obtained better performance relative to when they could not use fingers, especially on larger problems.

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Introduction

Young children use their fingers to accomplish a variety of math tasks (e.g., counting, enumerating, transcoding, calculating, representing quantities). This use of fingers, which varies with educational and cultural background, has several roles ranging from accompanying verbal resolution and representing the addends to being at the core of an arithmetic strategy (e.g., Bender & Beller, 2012; Carpenter & Moser, 1984; De Corte & Verschaffel, 1987; Fuson, 1992). The current study focused on spontaneous finger use in arithmetic and examined age-related changes in the frequency and efficiency of finger-based strategies. We aimed to further our understanding of whether use of finger-based strategies supports simple, one-digit addition problem solving and whether there are age-related differences in the associations between finger-based strategies and addition problem-solving performance.

Children of all ages use a variety of strategies to solve arithmetic problems (for overviews, see Geary, 1994; Gilmore et al., 2018; Cohen Kadosh & Dowker, 2015; Knops, 2019). For example, to solve simple one-digit addition problems (e.g., 3 + 4), they use (a) counting one by one all the units of the augend and the addend, (b) counting from the augend and adding the addend unit by unit, (c) direct memory retrieval (i.e., retrieving the solution directly from memory), (d) automatized counting (i.e., a "fast, compacted and unconscious procedure" (Thevenot et al., 2016, p. 48), or (e) decomposition strategies (i.e., decomposing one of the operands, e.g., 3 in 8 + 3 being decomposed as 2 + 1 to add first 8 + 2 and then 10 + 1). Children sometimes use their fingers while executing these strategies to solve arithmetic problems and sometimes use no fingers (e.g., Bender & Beller, 2012; Carpenter & Moser, 1984; De Corte & Verschaffel, 1987; Fuson, 1992).

Children's use of finger-based strategies while solving arithmetic problems raises a number of issues. These include what finger strategies children use while solving arithmetic problems, what are the determiners of children's use of finger strategies in arithmetic, and whether using fingers supports computational skills. In addition, it is unknown whether children obtain better arithmetic performance with finger strategies and whether having the possibility to use both finger and no-finger strategies enables children to obtain better arithmetic performance. To shed light on some of these issues, the current study originally used the choice/no-choice method (Siegler & Lemaire, 1997) to compare the frequency and efficiency of finger and no-finger strategies in 5- to 8-year-old children. This age range is characterized by important changes in how often and how efficiently children use finger-based strategies. Before outlining the logic of the current study, we first review previous findings on strategic aspects of age-related changes on children's use and efficiency of finger-based strategies in arithmetic.

Previous studies showed age-related changes in strategic aspects of arithmetic performance such as strategy distribution, execution, and selection (Lemaire & Siegler, 1995). Children use some (more efficient) strategies more often (e.g., direct memory retrieval), and use other strategies (e.g., counting all) less often, as they grow older. They also tend to become more and more efficient (i.e., faster and/or more accurate) while executing strategies, and they select strategies more and more systematically as a function of task, strategy, and problem characteristics such as problem size (e.g., Lemaire & Siegler, 1995; Siegler & Shrager, 1984; Thevenot & Barrouillet, 2020).

Several studies focused on finger strategies that young children use to solve simple arithmetic problems. These studies asked how often and how efficiently children use finger-based strategies, whether finger-based strategies and arithmetic performance correlate, and how these change with children's age (for recent reviews, see Barrocas et al., 2020; Neveu et al., 2023). Regarding finger-based strategy use, previous studies found that younger (pre-elementary school) and older (elementary school) children, as well as adolescents and even adults, use a variety of finger-based strategies (Baroody, 1987; Beller & Bender, 2011; Björklund et al., 2019; Chao et al., 2000; Dupont-Boime & Thevenot, 2018; Fuson & Kwon, 1992; Geary et al., 2004; Kaufmann et al., 2011; Kullberg & Björklund, 2020; LeFevre et al., 1996; Nwabueze, 2001; Siegler & Jenkins, 1989; Wylie et al., 2012).

Previous studies also found important individual differences in finger-based strategy use. Different factors may influence how often different individuals use finger-based strategies. These include participants' characteristics such as their age, gender, socioeconomic status, working memory skills, and arithmetic fluency (e.g., Canobi, 2004; Carr & Davis, 2001; Crollen et al., 2011; de Chambrier et al., 2018; Dupont-Boime & Thevenot, 2018; Geary et al., 1993, 2004; Jordan et al., 2003, 2008; Newman & Soylu, 2014; Poletti et al., 2022; Wylie et al., 2012). For example, Jordan et al. (1992) found that children from low-income families use finger strategies less often than children from middle-income families (7% vs. 24%) and that boys stop using finger-based strategies earlier than girls (see also Jordan et al., 2008). Finally, finger use had been hypothesized to support children with poor working memory capacities (Crollen & Noël, 2015). In addition, 5-year-old children with high working memory capacities have been found to use finger-based strategies more often than 5-year-olds with low working memory (Dupont-Boime & Thevenot, 2018; Poletti et al., 2022; Reeve & Humberstone, 2011).

Frequency of finger-based strategies use can also vary for the same individuals as a function of several factors like problem characteristics, including size of the operands, presentation format, and task situations such as when children's hands were free or not (e.g., Chao et al., 2000; Dupont-Boime & Thevenot, 2018; Fuson & Kwon, 1992; Jordan et al., 1992; Nwabueze, 2001; Poletti et al., 2022). Children aged 5 to 8 years used finger strategies to solve addition problems more often after undergoing training in fine motor skills and finger-based strategies (Bonneton-Botté et al., 2022; Fuson & Secada, 1986; Ollivier et al., 2020). Children used finger-based strategies more often to solve larger problems (e.g., sums > 10) than to solve smaller problems (sums < 10) (Dupont-Boime & Thevenot, 2018; Fuson & Kwon, 1992; Nwabueze, 2001; Poletti et al., 2022). Although previous studies have found that finger strategy use varies with problem and task characteristics, much less is known about how effects of these characteristics change with children's age. Moreover, we ignore which factors among strategy characteristics (i.e., speed and accuracy of finger-based vs. no-finger strategies) and problem characteristics (i.e., problem size, position of the larger operand, number of even operands, and presence of 5 as an operand) most strongly predict individuals' strategy use in different age groups.

Interestingly, both cross-sectional and longitudinal studies found that children successfully use finger-based strategies from 4.5 years of age (Krenger & Thevenot, 2024) and less and less often as they grow older (Geary et al., 1991, 2004; Jordan et al., 2008; Poletti et al., 2022; Svenson & Sjöberg, 1983; Wylie et al., 2012). Thus, for example, Wylie et al. (2012) tested the same 5- to 7-year-olds four times, 6 months apart, and found that the percentages of finger use decreased from about 45% to 10% across testing sessions. Such findings were replicated by Poletti et al. (2022; see also Jordan et al., 2008), who found that percentage use of finger-based strategies decreased from 83% to 23% in the same kindergarteners tested again in third grade.

Previous studies also examined relations between finger use and arithmetic performance. Several studies found that young children who use fingers more often obtain higher performance and increase arithmetic proficiency more quickly with age (e.g., Canobi, 2004; Dupont-Boime & Thevenot, 2018; Farrington-Flint et al., 2009; Jordan et al., 1992, 1994, 2008; Lucangeli et al., 2003), whereas other studies found that finger use was associated with lower accuracy (e.g., Jordan et al., 2008; Poletti et al., 2022). For example, Jordan et al. (2008; see also Cho & So, 2018; Dupont-Boime & Thevenot, 2018) found significant correlations ($rs > .57$) between finger use and arithmetic performance in 5- and 6-year-old children but found negative correlations ($r = -.15$) in 8-year-olds. Finally, Poletti et al. (2022) found that kindergarteners who were efficient at executing the finger-based strategies tended to use fingers much less often while solving addition problems in Grade 2.

Studies examining correlations between frequency of use of finger-based strategies and arithmetic performance have yielded mixed results, suggesting that use of finger-based strategies is associated with better arithmetic performance in young children and with lower arithmetic performance at around 8 years of age. However, it is unknown whether individuals benefit from using fingers relative to not using fingers while solving arithmetic problems. To determine this, we need to compare strategy performance (i.e., speed and accuracy of finger-based strategies vs. no-finger strategies) in the same individuals while solving the same problems. Otherwise, finger-based performance benefits (or lack thereof) may be confounded with strategy use (type, distribution, and selection of strategies) and problems' difficulty. For example, if children use finger-based strategies to solve problems for which they are quickly and accurately executed and use no-finger strategies on other problems, finger-based strategies would be more efficient. However, such benefits of finger-based strategies would be confounded with strategy selection across problems.

In sum, previous studies found that (a) 5- to 8-year-old children use finger-based strategies to solve simple arithmetic problems and even more so to solve larger problems, (b) younger (but not older) children who use finger-based strategies more often tend to have better arithmetic performance than those who use them less often, and (c) use of finger-based strategies and relations between finger-based strategy use and arithmetic performance tend to decrease with children's age. However, we ignore how problem characteristics (i.e., problem size, side of the larger operand, parity of the operands, and presence or absence of 5 among the operands) interact with children's age on strategy use and what are the predictors (relative strategy performance in terms of speed and accuracy yielded by the strategies vs. problem size) of individuals' strategy use. We also wondered to what extent finger use supports better arithmetic performance.

Overview of the current study

The current study has several goals. First, we aimed to further our understanding of how often children use finger-based and no-finger strategies and how they execute these strategies. To examine how children execute strategies, we focused on children's speed and accuracy while implementing strategies and did not examine finger processes within finger-based strategies. Second, we studied the benefits of using finger-based strategies on math performance. Third, we examined age-related changes in these for children aged 5 to 8 years while solving addition problems. In the current study, we distinguished between two broad categories of strategies on the basis of whether children used fingers (finger-based strategies) or used no fingers (no-finger strategies). At this stage, we did not make further distinctions about different ways of adding operands (e.g., adding first operand to the second one or the reverse, counting one by one all the units of the augend and the addend, counting from the augend, adding the addend unit by unit) because the goal of this study was not to decipher all different strategies used by children. We examined the frequency of use of finger-based and no-finger strategies when children use them spontaneously (i.e., without being prompted to any strategy) and their association with arithmetic performance. We also sought to determine which of finger-based or no-finger strategies yield faster and more accurate arithmetic performance depending on the problem size and children's age. We also aimed to determine whether being able to choose between finger-based and no-finger strategies on each problem influences performance and how this influence changes with problem size, participants' age, and children's ability to use finger-based and no-finger strategies. Finally, we determined whether having the possibility to choose between finger-based and no-finger strategies on each problem improves children's performance and how this changes with children's age.

We used the choice/no-choice method (Siegler & Lemaire, 1997) to address these issues. Children aged 5 to 8 years were asked to solve simple arithmetic problems under a choice condition (i.e., they could use finger-based and no-finger strategies) and two no-choice conditions (they were required to use their fingers on all problems in one no-choice condition and were forbidden to use any finger-based strategies in another no-choice condition). Because problems varied in size, we could determine whether effects of problem size on finger-based strategy use changed with children's age. We could also determine whether problem size and/or strategy characteristics (accuracy and/or speed) are the best predictors of using finger-based strategies as well as age-related changes in these.

We tested four hypotheses in the current study. First, we hypothesized that strategy use would be influenced by both children's age and problem size. Mean percentage use of finger-based strategies should decrease with age and should do so more for smaller problems than for larger problems. Second, we hypothesized that children would calibrate their use of finger-based strategies to both problem and strategy characteristics. This hypothesis predicted significant correlations between mean percentage use of finger-based strategies and both problem size and strategy performance (i.e., accuracy and/or response times with finger-based strategies and/or no-finger strategies). The current data also enabled us to further determine, for each age group, which is the best predictor of using finger-based strategies among relative speed and accuracy of finger-based and no-finger strategies and problem size. In addition, we predicted increased arithmetic performance with age while children execute finger-based and no-finger strategies. Our no-choice conditions also enabled us to determine whether age-related improvement in strategy performance differs for finger-based and no-finger strategies while solving smaller and larger problems. Finally, we hypothesized that children would obtain better arithmetic performance (i.e., accuracy and/or latencies) in the choice condition than in the no-choice conditions because the choice condition enabled them to select the better strategy on each item. We also expected that benefits in arithmetic performance from having the choice between finger-based and no-finger strategies would increase with age, following well-established increased adaptivity of strategy use with children's age in different cognitive domains (see Siegler, 1996, for an overview).

Method

Participants

The target sample size was determined using an a priori power analysis program (G*Power; Faul et al., 2007). The required sample size to achieve 80% power for detection of a medium size effect at a significance criterion of α = .05 was N = 90 for a 3 × 3 × 2 mixed-design analysis of variance (ANOVA), with one between-participants factor and two within-participants factors. A total of 93 French children were tested. Data of 3 children needed to be excluded because the children were not able to follow task instructions (i.e., they used their fingers in all the conditions). The final sample (N = 90) was divided into three age groups of 30 each: 5- and 6-year-old kindergarteners (15 boys and 15 girls; M_{age} = 67.7 months, SD = 3.28), 6- and 7-year-old first graders (12 boys and 18 girls; M_{age} = 78. 9 months, SD = 2.95), and 7- and 8-year-old second graders (12 boys and 18 girls; M_{age} = 91.0 months, SD = 4.00). For clarity, the three groups of children are referred to as "5-year-olds," "6-year-olds," and "7-year-olds," respectively. All children had no history of development delay or learning disability. The study was approved by the local ethics committee of the University of Angers. Written informed consent was obtained from children's parents prior to the study, and verbal assent was obtained from individual children.

Stimuli for the addition task

Three matched sets of 20 single-digit addition problems (e.g., 6 + 2, 7 + 9) were selected (see online supplementary material S1 for the list of problems), excluding ties (e.g., 3 + 3). Half the problems were smaller problems, and half were larger problems. Correct sums (e.g., 7 is the correct sum of 4 + 3) were smaller than 10 for smaller problems (e.g., 6 + 2) and larger than 10 for larger problems (e.g., 7 + 8). The three sets of problems were matched on mean correct sums (i.e., mean correct sums were 7.2 and 14 for smaller and larger problems, respectively, in each of the three sets of problems). Finally, none of the problems had a correct sum of 10. Within each set, half the problems had their larger addend in the left position (e.g., 6 + 2) and half in the right position (e.g., 3 + 4).

Procedure

Children were tested in a quiet room at their school. All children were tested in the same period during the academic year. Each session lasted 20 min on average.

We tested children with the choice/no-choice method (Siegler & Lemaire, 1997). Each child was asked to solve three sets of 20 addition problems (see Sets A, B, and C in the supplementary material S1), one each in the three conditions (choice, no-choice/finger, and no-choice/no-finger conditions). For each condition, 20 addition problems were randomly presented to participants on a Dell Latitude 5400 computer screen and were read by the experimenter at display. Children were asked to keep their hands within the experimenter's field of view during the task. Response times were measured from stimulus onset to the beginning of children's oral response.

All children were first tested in a choice condition. In this condition, they were allowed to use whichever strategy they wanted to solve each addition problem of the first set of 20 problems. No manipulatives, pencils, or paper were provided. The experimenters told the children they could use the strategy they wanted (i.e., "You can proceed the way you want") and answered positively to the children who asked whether they could use their fingers. The experimenter noted whether children used fingers or not without taking note of details on how they used fingers (e.g., whether fingers of both hands or of only one hand were used). In the choice and no-choice conditions, occasional encouraging feedback (e.g., "well done," "very good," "super," "bravo") were given to help maintain motivation. However, no feedback on accuracy or strategy was provided.

After a 5-min break following the choice condition, half the children were first tested in a no-choice/no-finger condition followed by a no-choice/finger condition, and the other children saw the reverse order (i.e., no-choice/finger condition followed by no-choice/no-finger condition).

In the no-choice/no-finger condition, children were asked to hold wooden pieces in their hands to prevent finger counting. The position of the pieces of wood was designed to avoid showing the phalanges. Children were explicitly told not to use their fingers. In the no-choice/finger condition, children needed to use their fingers while solving each problem. They were explicitly told they needed to use their fingers and to show their fingers while using them. No instructions were given on which way fingers should be used. Thus, fingers could be used to keep track of an operand or an intermediate result, to count, or both. Finally, children were asked to give their answers orally. The accuracy and response times (duration between problem display to children's answer) were assessed on the basis of the oral responses. If children did not use their fingers, the experimenter gave them the instructions again on the first two trials. No further reminder was needed. All children used their fingers on all trials.

Results

Results are presented in two main parts. We examined age-related differences first in strategy use and second in strategy execution.

Age-related changes in using finger-based strategies

This section analyzes strategy use and strategy variability in the choice condition. We asked whether participants used only one type of strategy (i.e., finger-based or no-finger strategies) or both types of strategies. We also investigated whether both strategies were used equally often and whether strategy use was influenced by participants' age and problem size.

Variability in strategy use

The first question was whether children solved addition problems with only one type of strategy or with both finger-based and no-finger strategies. In other words, was there any within-participants variability in strategy use? One way to answer this question is to tally the number of children using fingers on smaller and larger problems to know how many participants used only one (finger-based or

Table 1
Distributions of use of finger-based strategies across participants and problems in the choice condition.

Age Group	0-33%			34-66%			67-100%		
	Smaller	Larger	*Means*	Smaller	Larger	*Means*	Smaller	Larger	*Means*
Participant-based analyses									
5 y.o.	43.3	53.3	48.3	23.3	6.7	15.0	33.3	40.0	36.7
6 y.o.	80.0	50.0	65.0	6.7	23.3	15.0	13.3	26.7	20.0
7 y.o.	90.0	56.7	73.3	3.3	13.3	8.3	6.7	30.0	18.4
Problem-based analyses									
5 y.o.	10	10	10	90	90	90	0	0	0
6 y.o.	100	30	65	0	70	35	0	0	0
7 y.o.	100	40	70	0	60	30	0	0	0

Note. Each entry in the participant-based analyses represents the percentage of participants using finger strategies on less than 34%, on between 34% or on more than 66% of problems, depending on their size. For example, 23.3% of 5-year-olds used their fingers on between 34 and 66% of smaller problems. Each entry in the problem-based analyses represents the percentage of problems solved with fingers by less than 34%, by between 34 and 66%, or by more than 66% of participants. For example, 90% of smaller problems were solved with fingers by between 34 and 66% of 5-year-olds.

no-finger) strategy and how many used fingers (or no fingers) most often. Strategy variability can be seen in Table 1. Ten 5-year-olds (33.3%), 16 6-year-olds (53.3%), and 23 7-year-olds (76.7%) never used their fingers to solve smaller problems. Four 5-year-olds (13.3%), 2 6-year-olds (6.7%), and 1 7-year-old (3.3%) used their fingers to solve all smaller problems. Eleven 5-year-olds (36.7%), 8 6-year-olds (26.7%), and 10 7-year-olds (33.3%) never used their fingers to solve larger problems. Four 5-year-olds (13.3%), 4 6-year-olds (13.3%), and 2 7-year-olds (6.7%) used their fingers on all larger problems. Ten 5-year-olds (33.3%), 8 6-year-olds (26.7%), and 10 7-year-olds (33.3%) never used their fingers to solve any of the problems. One 6-year-old used their fingers on all problems. None of the problems was solved with fingers by all or any of the participants.

Effects of participants' age and problem size on finger-based strategy use in the choice condition

Mean percentages of use of finger-based strategies in the choice condition were analyzed with a 3 (Age: 5-, 6-, or 7-year-olds) × 2 (Problem Size: smaller or larger) ANOVA, with age as the only between-participants factor.

The main effect of age was marginally significant, $F(2, 87) = 2.96$, $\eta^2 = .05$, $p = .057$, and the main effect of problem size was significant, $F(1, 87) = 21.96$, $\eta^2 = .04$, $p < .001$. The 5-year-olds used finger-based strategies on 42.2% of problems, the 6-year-olds on 28.8% of problems, and the 7-year-olds on 22.7% of problems. Interestingly, the Age × Problem Size interaction was significant, $F(2, 87) = 7.78$, $\eta^2 = .03$, $p < .001$. As can be seen from Fig. 1, children used fingers less and less often on smaller problems as they grew older, $F(2, 87) = 9.13$, $\eta^2 = .17$, $p < .001$, but did not change their frequencies of finger use on larger problems ($F < 1.00$). The 5-year-olds used their fingers equally often on smaller and larger problems (43.3% for smaller problems vs. 41.0% for larger problems; $F < 1.00$). Both the 6- and 7-year-olds used their fingers more often on larger problems than on smaller problems. Thus, 6-year-olds used their fingers on 19.0% of smaller problems and on 38.7% of larger problems, $F(1, 29) = 11.70$, $\eta^2 = .08$, $p = .002$, and 7-year-olds used their fingers on 9.3% of smaller problems and on 36.0% of larger problems, $F(1, 29) = 22.90$, $\eta^2 = .16$, $p < .001$.

Determiners of strategy use

General research in arithmetic found that two types of characteristics predict strategy use on a problem-by-problem basis, namely problem and strategy characteristics (for an overview, see

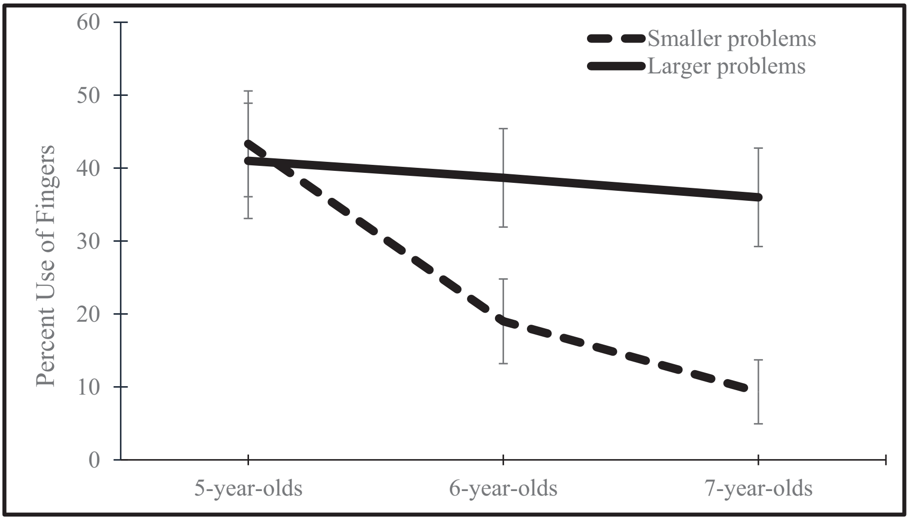

Fig. 1. Mean percentages of finger-based strategy use, with 95% confidence intervals, in each age group for smaller and larger problems in the choice condition.

Gilmore et al., 2018). Problem characteristics refer to a variety of features such as problem size, presence/absence of 5 as an operand, parity of operands, and side of the larger operand. Strategy characteristics refer to response times and percentage errors with a given strategy as well as to relative strategy performance (i.e., differences in latencies and errors between strategies). The goals of these analyses were to determine (a) whether finger strategy use is also influenced by both problem and strategy characteristics, (b) whether these influences change with children's age, (c) which of the problem and strategy characteristics is the best predictor of using fingers, and (d) whether predictors of finger-based strategy use change with children's age.

First, to know whether children calibrated their finger-based strategy use to problem and/or strategy characteristics, we ran a series of problem-based correlation analyses between mean percentage use of fingers in the choice condition and (1) size of the correct sum, (2) position of the larger operand position (left = 0, right = 1), (3) number of even operands (0, 1, or 2), (4) presence (coded 1) versus absence (coded 0) of 5 as an operand in the problem, (5) mean latencies with fingers in the no-choice condition, (6) mean latencies with no fingers in the no-choice condition, (7) mean percentage correct responses with fingers in the no-choice condition, (8) mean percentage correct responses with no fingers in the no-choice condition, (9) relative strategy speed in the no-choice condition (i.e., latencies with fingers/no choice − latencies with no fingers/no choice), and (10) relative strategy accuracy in the no-choice condition (i.e., percentage correct with fingers/no choice − percentage correct with no fingers/no choice). Table 2 presents correlations between finger-based strategy use and problem and strategy characteristics. Holm adjustment was conducted on the p values.

As can be seen in Table 2, problem size and strategy characteristics were related to children's strategy use. Moreover, correlation patterns varied with children's age.

In 5-year-old children, finger-based strategy use correlated significantly with percentages of correct responses with no-finger strategies under no choice and relative strategy accuracy. The 5-year-olds used finger-based strategies more when it yielded more accurate responses and when it tended to be more accurate than no-finger strategies. In 6-year-old children, finger-based strategy use correlated significantly with size of the correct sum, latency with finger-based strategies under no choice, latency with no-finger strategies under no choice, percentage correct with finger-based strategies under no choice, and percentage correct with no-finger strategies under no choice. Finally, 7-year-olds' finger-based strategy use correlated with the same variables as those of 6-year-olds. In contrast to 5-year-olds, 6- and 7-year-olds increased their use of finger-based strategies with the size of the problem sum. The more often children were able to provide correct answers with no-finger strategies in the no-choice/no-finger condition, the less often they used finger-based strategies in the choice condition. Moreover, the 6- and 7-year-olds who had more accurate or faster addition performance in the no-choice/finger condition used finger-based strategies less often in the choice condition. Taken

Table 2
Correlations between finger-based strategy use in the choice condition and problem and strategy characteristics in the no-choice conditions for each age group.

	Mean percentage use of fingers in the choice condition		
	5-year-olds	6-year-olds	7-year-olds
1. Size of the correct sum	−.06	.65***	.65***
2. Position of the larger operand	.07	.13	.07
3. Number of even operands	.08	.05	−.09
4. Absence/Presence of 5	−.02	.03	.10
5. Latency with fingers under no choice	.05	.48***	.68***
6. Latency with no fingers under no choice	−.04	.54***	.64***
7. Percentages of correct responses with fingers under no choice	.14	−.69***	−.52***
8. Percentages of correct responses with no fingers under no choice	−.46***	−.60***	−.51***
9. Relative strategy speed	.01	.07	−.09
10. Relative strategy accuracy	.46***	.02	.13

Note. The p values have been adjusted with the Holm method.
*** $p < .001$.

together, these results suggest that as they grow older, children were more and more able to calculate the correct sums without using their fingers and, as a consequence, used finger-based strategies less and less often. They continued to use finger-based strategies when they could not calculate the correct sum with no-finger strategies.

Then, stepwise regression analyses were conducted to determine which of problem size or strategy characteristics best predicts mean percentage use of finger-based strategies in the choice condition and whether predictors changed with children's age. Results of these analyses conducted in each age group separately showed that relative strategy accuracy was the best predictor of finger-based strategy use in 5-year-olds (R^2 = .21). The mean percentages of correct responses with no-finger strategy under no choice accounted for 5% additional unique variance in 5-year-olds' finger-based strategy use. In 6-year-olds, the best single predictor of finger-based strategy use was the mean percentage of correct responses with finger-based strategies under no choice (R^2 = .47). Finally, in 7-year-olds, the speed of response with finger-based strategies under no choice best predicted these children's finger-based strategy use (R^2 = .46). In sum, results of these regression analyses showed that the best predictor of finger-based strategy use changed with children's age. The 5-year-olds used finger-based strategies when these strategies were more likely than no-finger strategies to lead them to find the correct answer. The 6-year-olds used finger-based strategies when these strategies enabled them to find the correct answer. Finally, the 7-year-olds' finger-based strategy selection was best predicted by the speed of this strategy.

Age-related differences in executing finger and no-finger strategies

The hypothesis that children will improve at executing strategies with age predicts that performance increases as children grow older. To test this prediction, we first analyzed participants' arithmetic performance (solution latencies and percentage correct responses) under the choice condition and the two no-choice conditions (see means in Table 3) as a function of children's age and problem size in the choice condition. Then, we analyzed effects of children's age and problem size for both finger-based and no-finger strategies in the no-choice conditions. Finally, we compared arithmetic performance when children were free to choose their strategies (under the choice condition) and when they were not (under the no-choice conditions).

Choice condition

Mean percentages of correct responses and response times were analyzed with 3 (Age: 5-, 6-, or 7-year-olds) × 2 (Problem Size: smaller or larger) ANOVAs, with age as the only between-participants factor.

Table 3
Mean percentages of correct responses and response times (in seconds) of addition performance as assessed by children's oral responses in the choice and no-choice conditions as a function of children's age and problem size.

Problem size	5-year-olds			6-year-olds			7-year-olds		
	Choice condition	No-choice conditions		Choice condition	No-choice conditions		Choice condition	No-choice conditions	
		No fingers	Fingers		No fingers	Fingers		No fingers	Fingers
	Mean percentage correct responses								
Smaller	58.3	42.3	54.7	83.3	85.0	92.0	96.7	99.3	98.3
Larger	21.3	14.3	22.0	57.0	48.3	63.0	85.3	75.7	86.3
Mean	39.8	28.3	38.4	71.2	66.7	77.5	91.0	87.5	92.3
	Mean response times (in seconds)								
Smaller	12.0	9.1	12.4	5.4	6.1	8.3	3.3	3.6	5.8
Larger	17.5	12.5	20.0	11.1	11.4	15.9	7.6	9.3	12.2
Mean	14.8	10.8	16.2	8.2	8.8	12.1	5.4	6.4	9.0

The main effect of age on mean percentage correct responses was significant, $F(2, 87) = 39.86$, $\eta^2 = .42$, $p < .001$, as were the main effect of problem size, $F(1, 87) = 105.67$, $\eta^2 = .02$, $p < .001$, and the Age × Problem Size interaction, $F(2, 87) = 9.20$, $\eta^2 = .04$, $p < .001$. Although children solved more and more problems correctly as they grew older, children's performance improved with age more for larger problems, $F(2, 87) = 41.00$, $\eta^2 = .49$, $p < .001$, than for smaller problems, $F(2, 87) = 22.10$, $\eta^2 = .34$, $p < .001$.

The ANOVA on mean response times showed significant main effects of age, $F(2, 87) = 29.54$, $\eta^2 = .34$, $p < .001$, problem size, $F(1, 87) = 87.50$, $\eta^2 = .21$, $p < .001$, and the Age × Problem Size interaction, $F(2, 87) = 4.05$, $\eta^2 = .02$, $p = .02$. Children were faster and faster as they grew older and solved smaller problems more quickly than larger problems. On average, 7-year-olds solved smaller problems 2.4 times faster than larger problems, whereas 5-year-olds solved smaller problems 1.2 times faster than larger problems.

No-choice conditions

Mean percentages of correct responses and mean response times were analyzed with 3 (Age: 5-, 6-, or 7-year-olds) × 2 (Strategy: finger-based or no-finger) × 2 (Problem Size: smaller or larger) ANOVAs, with age as the only between-participants factor.

The following effects were significant on mean percentage correct responses: age, $F(2, 87) = 55.14$, $\eta^2 = .46$, $p < .001$, strategy, $F(1, 87) = 26.08$, $\eta^2 = .03$, $p < .001$, problem size, $F(1, 87) = 147.44$, $\eta^2 = .22$, $p < .001$, and Age × Problem Size, $F(2, 87) = 4.35$, $\eta^2 = .02$, $p = .016$. Children were more accurate with smaller problems while using finger-based strategies and became more and more accurate as they grew older.

Analyses of mean response times showed significant main effects of age, $F(2, 87) = 7.77$, $\eta^2 = .08$, $p < .001$, strategy, $F(1, 87) = 42.22$, $\eta^2 = .10$, $p < .001$, and problem size, $F(1, 87) = 117.64$, $\eta^2 = .20$, $p < .001$. The Age × Problem Size interaction, $F(2, 87) = 3.77$, $\eta^2 = .02$, $p = .03$, and the Strategy × Problem Size interaction, $F(1, 87) = 4.19$, $\eta^2 = .01$, $p = .04$, came out significant. The effect of problem size increased with age, $F(1, 29) = 10.18$, $\eta^2 = .07$, $p = .001$ for 5-year-olds, $F(1, 29) = 61.24$, $\eta^2 = .27$, $p < .001$ for 6-year-olds, and $F(1, 29) = 105.38$, $\eta^2 = =.34$, $p < .001$ for 7-year-olds, whereas the effect of strategy decreased with age, $F(1. 29) = 20.06$, $\eta^2 = .15$, $p < .001$ for 5-year-olds, $F(1, 29) = 16.19$, $\eta^2 = .07$, $p < .001$ for 6-year-olds, and $F(1. 29) = 7.96$, $\eta^2 = .07$, $p < .009$ for 7-year-olds. Children were faster and faster as they grew older. On average, 5-year-olds took 11.6 s, 6-year-olds took 10.9 s, and 7-year-olds took 7.9 s. They were slower when using finger-based strategies than when using no-finger strategies (12.0 vs. 8.3 s) and on larger problems than on smaller problems (12.9 vs. 7.4 s).

Comparison of participants' performance under the choice and no-choice conditions

We hypothesized that children could adaptively use finger-based and no-finger strategies for arithmetic performance in the choice condition, in contrast to being required to use both strategies on all problems (including those on which each strategy was not the more efficient one) in the no-choice condition. This predicts better performance in the choice condition than in the no-choice condition. The next analyses tested this prediction. Mean percentages of correct responses and response times (see Fig. 2) were analyzed with 3 (Age: 5-, 6-, or 7-year-olds) × 2 (Problem Size: smaller or larger) × 2 (Condition: choice or no-choice) ANOVAs, with age as the only between-participants factor. Addition performance was pooled across both no-choice conditions.

Above and beyond effects on mean percentage correct responses of age, $F(2, 87) = 50.33$, $\eta^2 = .46$, $p < .001$, problem size, $F(1, 87) = 157.49$, $\eta^2 = .23$, $p < .001$, and Age × Problem Size, $F(2, 87) = 7.98$, $\eta^2 = .03$, $p < .001$, it is interesting that the following two interactions came out significant: Age × Condition, $F(2, 87) = 3.94$, $\eta^2 = .004$, $p = .04$, and Age × Problem Size × Condition, $F(2, 87) = 3.56$, $\eta^2 = .004$, $p = .03$. The Age × Condition interaction showed that 5-year-old children were more accurate in the choice condition than in the no-choice condition, $F(1, 29) = 7.53$, $\eta^2 = .01$, $p = .01$, and that the other two age groups were equally accurate in these two conditions. The Age × Problem Size × Condition interaction came out significant because the choice-related advantage on accuracy in 5-year-olds was significant on smaller problems, $F(1, 29) = 6.13$, $\eta^2 = .02$, $p = .02$, but not on larger problems, $F(1, 29) = 2.07$, $p = .16$), and the same levels of accuracy in the choice and no-choice conditions were found while both 6- and 7-year-olds solved smaller problems [6-year-olds:

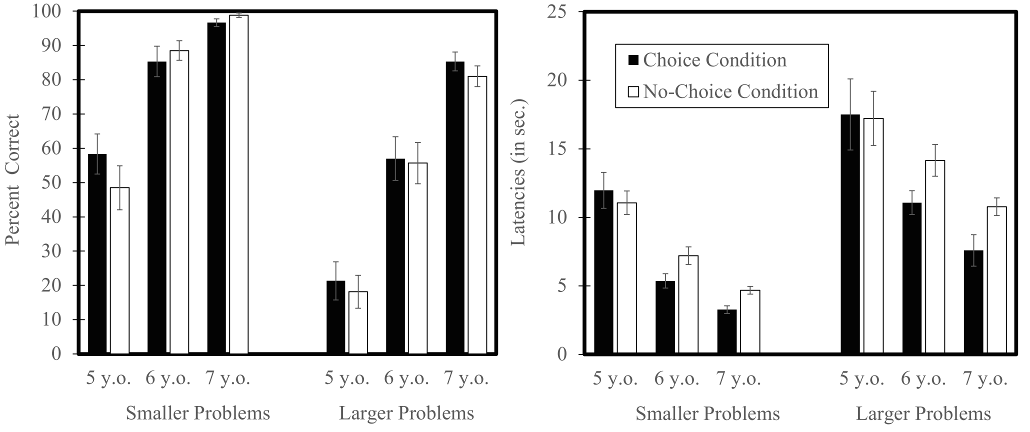

Fig. 2. Mean percentage correct responses and latencies, with 95% confidence intervals, in each age group for smaller and larger problems in the choice and no-choice conditions. y.o., years old.

$F(1, 29) = 1.69$, $p = .20$; 7-year-olds: $F(1, 29) = 3.31$, $\eta^2 = .05$, $p = .08$] and larger problems [6-year-olds: $F(1, 29) = 0.18$, $p = .67$; 7-year-olds: $F(1, 29) = 1.98$, $p = .17$].

Analyses of mean response times showed significant main effects of age, $F(1, 87) = 20.94$, $\eta^2 = .13$, $p < .001$, and problem size, $F(1, 87) = 134.47$, $\eta^2 = .22$, $p < .001$, but showed nonsignificant effects of condition, $F(1, 87) = 0.23$. The following two-way interactions came out significant: Age × Condition, $F(2, 87) = 26.86$, $\eta^2 = .18$, $p < .001$, Age × Problem Size, $F(2, 87) = 4.21$, $\eta^2 = .02$, $p = .02$, and Problem Size × Condition, $F(1, 87) = 4.75$, $\eta^2 = .01$, $p = .03$. The Age × Problem Size × Condition interaction did not come out significant, $F(2, 87) = 1.11$, $\eta^2 = .00$, $p = .33$. Further testing of the Age × Problem Size interaction showed significant problem size effects in all age groups (*ps* < .001), with faster responses while solving smaller problems. The Age × Condition interaction showed significant condition effects in 5- and 7-year-olds (*ps* < .001) but not in 6-year-olds ($p = .29$). The 5-year-olds were faster in the no-choice condition, and the 7-year-olds were faster in the choice condition.

In sum, choice benefits were observed only in the 7-year-olds' latencies. The 5-year-olds were more accurate but slower in the choice condition than in the no-choice condition (most likely as a result of the speed–accuracy trade-off), and the 6-year-olds showed no differences between the choice and no-choice conditions on either latency or accuracy.

Discussion

Previous research established that 5- to 8-year-old children use a variety of strategies to solve simple arithmetic problems, including finger-based strategies (for overviews, see Cohen Kadosh & Dowker, 2015; Geary, 1994; Gilmore et al., 2018; Knops, 2019). Finger-based strategies decrease with children's age, and young children who use their fingers to solve arithmetic problems tend to obtain better arithmetic performance and/or to switch more quickly to internalized strategies as they grow older. In this context, we investigated how 5- to 8-year-olds use finger-based and no-finger strategies as well as the relation between using finger-based or no-finger strategies and arithmetic performance. More specifically, we examined how often children used finger- and no-finger strategies while solving single-digit addition in choice and no-choice conditions, how this strategy use varied with participants' age and problem size, and how children executed these two types of strategies. Our data also document benefits of being able to choose between finger-based and non-finger strategies relative to being unable to make strategy choices on a problem-by-problem basis. Results showed that children (a) used both finger-based and no-finger strategies to solve simple addition problems in all age groups, (b) used fingers less and less often as they grew older, especially while solving smaller problems, (c) calibrated their use of finger-based strategies to both problem size and strategy performance, and (d) improved efficiency of both finger and no-finger strategies with age. Moreover, (e) strategy performance in terms of speed or accuracy was the best predictor of strategy selection in all age groups, and (f) having the choice led 7-year-olds to be faster than having no choice between strategies but did not benefit younger children's performance.

First, our results show that all children use finger-based strategies to solve simple addition problems. Moreover, the use of finger-based strategies was influenced by problem size in 6- and 7-year-olds. This suggests that finger-based strategies are not chosen at random but rather are systematically selected on a problem-by-problem basis from 6 years of age. Kindergarteners used finger-based strategies equally often on smaller and larger problems. As they grew older, children used these strategies less and less often on smaller problems but did not decrease their use of finger-based strategies on larger problems. This does not mean that children will continue to use these strategies on larger problems as they age. Most likely, with higher levels of arithmetic proficiency, they will solve larger problems less and less often with finger-based strategies and more and more often with no-finger strategies. In addition, it is possible that children used finger representations covertly (e.g., without raising their fingers) to solve some of the addition problems in the no-choice/no-finger condition (Berteletti & Booth, 2015), a possibility that we could not test here and that could be tested in future studies by collecting verbal protocols (i.e., asking children to indicate after each problem how they solved the problem).

The Age × Problem Size interaction on mean percentage use of finger-based strategy found here (i.e., age-related decrease in using finger-based strategy for smaller problems but not for larger problems) differs from Poletti et al.'s (2022) findings. These authors observed that children used finger-based strategies less and less often as they grew older, and this decrease was of equal magnitude for smaller and larger problems. The two studies differ in several methodological details (e.g., Poletti et al.'s study tested fewer participants and problems in a choice condition, whereas the current study used choice and no-choice conditions; Poletti et al.'s study was longitudinal, whereas the current study was cross-sectional). Several of these methodological differences may explain different outcomes here and in Poletti et al.'s (2022) study. For example, although the cross-sectional design used here may have been less powerful to reveal age-related changes in finger-based strategy use on larger problems, it may be possible that testing the same individuals longitudinally led older children in Poletti et al.'s study to decrease their use of finger-based strategies on larger problems more often as a result of greater task and/or problem familiarity from being tested twice on the same problems. Replicating the Age × Problem Size found here in future studies would be interesting given the expected greater decrease in finger-based strategies on smaller problems than on larger problems. Indeed, increased working memory capacity with age is likely to enable more memory-based strategies for smaller problems first, leading to less use of finger-based strategies for smaller problems before larger problems.

The next important findings here concern finger-based strategy selection. Our correlation and regression analyses revealed that children were very adaptive in their strategy selection. Indeed, they calibrated their use of finger-based strategies on both problem features and strategy characteristics. More specifically, mean percentage use of finger-based strategies correlated with both accuracy of no-finger strategies and relative strategy accuracy in 5-year-old children. These findings are consistent with longitudinal data reported by Krenger and Thevenot (2024). The authors found that children aged 4.5 to 5.5 years who had previously used their fingers performed better in arithmetic than children who had not, and that consistent use of finger-based strategies was associated with greater improvement than never using fingers or discontinuing finger use. Percentage use of finger-based strategies correlated with size of correct sums and with latencies and accuracy of each finger-based and no-finger strategy in both 6- and 7-year-olds. That younger children's strategy selection did not correlate with problem features, in contrast to older children, can be easily understood as the result of these younger children using finger-based strategies when they could not solve the problem otherwise (with internalized counting or retrieval strategies). In older children, because problem size and strategy performance are highly but not totally correlated (e.g., latency with fingers under no choice and size of the correct sums were highly correlated in both 6-year-olds, $r = .73$, and 7-year-olds, $r = .91$), these older children based their strategy choices on both problem and strategy characteristics. Most interestingly, strategy performance was the best predictor of finger-based strategy selection in all age groups. Indeed, as early as 5 years of age, children were able to select finger-based strategies when these strategies yielded either better accuracy or latency. Increased predictive power of strategy performance on finger-based strategy use (R^2 values increased from.26 in 5-year-olds to.47 and.46 in 6- and 7-year-olds, respectively) suggests that children were more and more systematic and relied on strategy performance to select strategies on each problem. Note that this remarkable early strategy adaptivity in finger-based strategy selection and age-related improvement in it are not specific to early arithmetic. In fact, it is a hallmark of strategic behaviors in all cognitive domains, including arithmetic, and at all ages during cognitive development (for an overview, see Siegler, 1996). Theoretically, these findings suggest that similar strategy selection mechanisms are used by young children while choosing between finger-based and no-finger strategies to solve simple addition problems. Early on, the cognitive system is calculating relative costs/benefits of available strategies, selects the best strategies (i.e., with lowest costs and/or largest benefits), and is more and more finely tuned to strategy efficiency while selecting strategies on each problem, again like it has been found in numerous cognitive domains.

The next set of interesting findings concerns strategy execution. Above and beyond general improvement with age in both finger-based and no-finger strategy performance, children of all age groups performed better when asked to execute finger-based strategies relative to no-finger strategies. In addition, 7-year-old children were more accurate with finger-based strategies than with no-finger strategies on larger problems but not on smaller problems, whereas younger children were more accurate with finger-based strategies on both smaller and larger problems. Most likely, older children were able to execute no-finger strategies sufficiently accurately on smaller problems but less so on larger problems. Children of all age groups tended to be faster with no-finger strategies, which makes sense given that executing finger-based strategies requires a set of both motor processes (e.g., raising fingers) and cognitive processes (e.g., counting and adding raised fingers).

Interestingly, the improved strategy execution with age in no-choice conditions was not contaminated by strategy use (frequency of strategy use and selection of strategies across problems and participants) in the current study, in contrast to previous studies. This finding was possible because no-choice conditions required each participant of each age group to execute both strategies on all problems, enabling investigating strategy-related differences in arithmetic performance across development. Such findings on strategy execution and age-related changes in finger-based and no-finger strategies, unconfounded with other strategy dimensions, are important in order to understand how efficient children are at solving simple addition problems and the sources of age-related changes in their performance.

Finally, unique features of our study yielded important novel findings concerning participants' performance benefits associated with the possibility to use finger-based strategies. We found that having the choice between finger-based and no-finger strategies helped 7-year-old children to be faster (but equally accurate). This result has been found in numerous previous arithmetic studies in children of different age groups, with different sets of available strategies for different arithmetic operations and tasks (e.g., Lemaire & Brun, 2016; Lemaire & Callies, 2009; Lemaire et al., 2017; Luwel et al., 2005). Like in previous studies, the choice benefits found here in older children are the result of children's being able to select each strategy when it works best (i.e., when it yields more accurate or faster performance or both) on each problem. This is consistent with previous correlational studies showing that finger-based strategies might support children's computational skills (e.g., Dupont-Boime & Thevenot, 2018; Farrington-Flint et al., 2009; Jordan et al., 1992; Lucangeli et al., 2003; Newman & Soylu, 2014). Such findings are important to think about educational implications regarding finger use during arithmetic learning. Indeed, given that using fingers sometimes increases children's arithmetic performance and promotes mathematical growth, our findings together with previous findings suggest that it may be important to not discourage children from using fingers as is often suggested (e.g., Albayrak, 2010; Koenker, 1958; Sauls & Beeson, 1976) while they are learning arithmetic.

It is important to note that no choice benefits on addition performance were found in younger children. It may be too premature to conclude that strategy choices do not help younger children's addition performance. The lack of choice benefits in our younger groups of children may stem from several sources, including (a) benefits of choices being absorbed by costs of choices given that choosing strategy may be resource-consuming and (b) benefits of strategy choices being more obvious in situations where different finger-based and no-finger strategies are distinguished, a possibility that future research may test.

At a general level, the current findings are consistent with previous findings in other age groups and other arithmetic and cognitive tasks. They show that sources of age-related improvement in children's arithmetic performance involves strategic changes or age-related changes in how often children use available strategies as well as how they select and execute strategies on each problem. This proves to be important to understand how using fingers helps children's arithmetic and arithmetic development. Future studies may investigate in more detail specific finger strategies given that one limitation of the current study is that finger-based strategies were not distinguished. Given that previous research found that there are a variety of finger-based strategies (e.g., Baroody, 1987; Björklund et al., 2019; Canobi, 2004; Carpenter & Moser, 1984; De Corte & Verschaffel, 1987; Dupont-Boime & Thevenot, 2018; Farrington-Flint et al., 2009; Fuson, 1992; Jordan et al., 1992, 1994, 2008; Kullberg & Björklund, 2020; Lucangeli et al., 2003; Nwabueze, 2001; Poletti et al., 2022), it would be important to determine how age-related changes in strategy use and execution might differ for each finger-based strategy. In addition, our approach did not enable us to determine the component processes within finger-based strategies (e.g., deciding fingers of which hands to use first) or how different finger-based strategies are executed (e.g., using fingers of both hands vs. one hand, raising fingers while raising or not raising hands). Combined with longitudinal study of these strategic changes, such an investigation would contribute to our deeper understanding of how children use their fingers in arithmetic and, more generally, age-related changes in arithmetic processing during early childhood before children start formal schooling and during the first years of elementary school.

CRediT authorship contribution statement

Fanny Ollivier: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Patrick Lemaire:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Data availability

The data of this study can be found on a public repository (https://osf.io/5swvg).

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2024.106031.

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