Preschooler's mastery of advanced counting: the best predictor of arithmetic ability two years later

Introduction

From early numerical skills to arithmetic learning

Arithmetic fluency requires a solid foundation of mathematical knowledge and sophisticated strategies that allow children to reach an answer rapidly and accurately. The most common strategies that first appear in a child's arithmetic development involve verbal counting with or without fingers (Siegler & Shrager, 1984), typically start with counting all (i.e., starting counting from one), then counting on (i.e., starting counting from the smaller addend), and counting min (i.e., starting counting from the larger addend). At one point, more efficient memory-based strategies, such as retrieval or decomposition, appear. The retrieval strategy consists of retrieving the answer from long-term memory. The association in long-term memory between a problem's representation and its answer is called an "*arithmetical fac*t." The decomposition strategy is based on the knowledge of arithmetical facts close to the initial calculation. The decomposition can be based on a ties problem, (e.g., 8 + 9 = (8 + 8) + 1), or on base-10 decomposition (e.g., 8 + 9 = (8 + 2) + 7; Laski, Ermakova, & Vasilyeva, 2014). Counting strategies usually take longer to solve the problem than mental strategies such as decomposition and retrieval (Geary, Hoard, & Bailey, 2012). In the literature (Chu, vanMarle, Rouder, & Geary, 2018), the counting-all strategy is considered the less mature strategy, while retrieval is commonly considered the most mature strategy. However, according to Siegler's (1996) overlapping waves model, most children use various solving strategies at any moment, but more mature strategies tend to be used more frequently as the children progress in the development of their arithmetical abilities.

This paper aims to detect the preschool numerical abilities that best predict later arithmetical ability, which account for all three aspects of children's arithmetic development at the end of first grades, such as performance (accuracy), strategy, and calculation fluency. The present study examines the contribution of several numerical abilities observed before the formal learning of arithmetic in predicting later arithmetic skills.

Before examining the relevant literature, let us briefly report the different numerical abilities children already possess or develop before or in preschool.

First, research with babies has shown that they already have an approximate number system (ANS) that allows them to have an approximate sense of the numerical magnitude of a set of items (Dehaene & Changeux, 1993) and an object tracking system that allows them to discriminate between two small collections of one to three items (Kaufman, Lord, Reese & Volkmann, 1949). These systems then entail approximation and subitizing abilities. For instance, children estimate and discriminate quickly and intuitively in large quantities without counting (Feigenson, Dehaene, & Spelke, 2004).

Around 2 years old, children learn the number words (NWs) sequence (Fuson, Richard, & Briards, 1982). Most 3- to 4-year-olds know the correct sequence of number words from one to ten (Fuson, 1988; Siegler & Robinson, 1982). First, the sequence is made of words that are not different and meaningless. Progressively, by the age of 3, children will differentiate these NWs and use the sequence of NWs to count a set of objects (i.e., procedural knowledge of enumeration") (Fuson, 1988). Then, children (approximately 3.6- to 4-year-olds) understand that the last NW produced refers to the quantity of the set (i.e., the cardinal principle, Gelman & Gallistel, 1978; Wynn, 1990). In parallel, children can perform the "Give-N" objects task, showing that they understand the cardinal meaning of the number "N" (i.e., conceptual knowledge of cardinality) (Wynn, 1992). Children learn the meaning of "one" (one-knower) by age 2.5- to 3 years (Sarnecka & Carey, 2008). Some months later, they become two-knowers, three-knowers, and four-knowers (Le Corre & Carey, 2007). It takes 12 to 18 months from "one-knower" to the time they acquire the meanings of the higher numerals "five," "six" etc and reach what is called the cardinal principle knowledge (CP-knower) (Wynn, 1992).

Understanding the cardinal meaning of an NW serves as the basis for the magnitude comparison of number words (Sella, Lucangeli & Zorzi, 2018) and, later on, of Arabic numbers (Knudsen, Fischerb, Henningc & Aschersleben, 2015) and symbolic number knowledge (Geary & Vanmarle, 2018). In parallel, more advanced counting abilities develop, such as the ability to recite the number sequence starting from a number other than one (or counting on; Fuson et al., 1982; Secada, Fuson & Hall, 1983). Counting-on has been observed in 4-year-olds (Carpenter & Moser, 1984).

Finally, some approximate arithmetic abilities are present before formal arithmetic learning. For instance, 5-year-old children can estimate the sum of two Arabic numbers or two sets and compare it to a third number, independent of arithmetic instruction (Barth, La Mont, Lipton, & Spelke, 2005; Gilmore, McCarthy, & Spelke, 2007).

In summary, children are born with an ANS. The question of whether this system codes numerosity, or instead, it codes general magnitude, is still debated (see, for instance, Gebuis, Kadosh, & Gevers, 2016). Children are then introduced to symbolic numbers in the form, first of number words and about three years later, of Arabic digits. The first step in this NW learning is their sequential aspect (i.e., counting). Progressively, the child elaborates an understanding of the cardinal meaning of number words (enumeration and Give-N tasks) and is then able to process the magnitude representation of these symbols (comparison task).

Longitudinal studies' findings of a predictor of first-grade arithmetic outcome

Several studies have sought to determine which of these preschool numerical skills is the best predictor of arithmetic outcome. Among these, we considered those that fulfilled these five criteria: (1) Prospective longitudinal studies that use numerical abilities in preschool or kindergarten as predictors and arithmetic ability in the first grade (G1) or second grade as outcomes. (2) The arithmetic outcome is the child's ability to solve single or double-digit arithmetic problems presented in Arabic written numerals and is measured in terms of accuracy, strategy, or fluency (i.e., the combination of accuracy and speed). (3) The studies investigate typical development in children with control for some cognitive abilities. (4) The variance explained by the prediction model is higher than 20%. Six studies fulfilled all the criteria and are reported in Table 1.

In terms of outcome, most of the studies (4/6 studies) considered fluency; others were interested in reaction time (Major, Paul & Reeve, 2017) or a mix of accuracy and strategy (Chu, vanMarle, Rouder, & Geary, 2018). However, none of them tested both quantitative (accuracy and fluency) and qualitative (strategy) aspects.

Regarding the predictors, a nonsymbolic comparison (measuring the ANS) was tested in 2 out of the six studies. Although studies on young children (3- to 5-year-olds) have shown a correlation with basic arithmetic skills (e.g., single-digit addition; Libertus, Feigenson, & Halberda, 2011, 2013; Mazzocco, Feigenson, & Halberda, 2011), longitudinal studies (Bartelet, Vaessen, Blomert, & Ansari, 2014; Chu et al., 2018; see Table 1) have not demonstrated results supporting that correlation.

Four out of the six studies measured the predictive role of counting skills (measuring the sequential aspects of NW). Three of these studies found that verbal counting (tested on 5-year-old children) is an essential predictor of later arithmetic fluency (Aragón, Navarro & Aguilar, 2016; Locuciak & Jordan, 2008) and sophisticated strategies (Chu et al., 2018), but two studies did not show similar findings when counting was tested in younger (3- to -4.6-year-olds; Chu et al. 2018) or older children (M_{age} = 6.4; Martin, Cirino, Sharp, & Barnes, 2014). However, advanced counting was never tested.

Regarding the child's understanding of cardinality, many of these studies (5/6 studies) assessed the child's object counting skills (i.e., enumeration). Two studies (Table 1) provided evidence that this ability (with a set of collection ≤ 9; Bartelet et al., 2014; Major et al., 2017) is a significant predictor of later arithmetical fluency. However, Martin et al. (2014) used small sets of 4–8 objects, and the other studies (Aragón et al., 2016; Chu et al., 2018) used large sets of 5–20 objects, did not support that result. Moreover, most studies tested the 1:1 correspondence principle, and Martin et al. (2014) was the only study that measured the mastery of the cardinal principle in the task.

Only two studies from the same research group assessed the cardinal knowledge of number words via the Give-N task and showed that it predicts first-graders' sophistication of strategy choice (Chu et al., 2018, Geary et al., 2018). In another study, Locuciak and Jordan (2008) also used this task but mixed it with other abilities in a "*number knowledge*" composite and showed that this composite was a significant predictor of later arithmetic fluency.

Magnitude comparison of symbolic numbers was tested in 3/6 studies but always using Arabic numbers. Two of these studies (Bartelet et al., 2014; Martin et al., 2014) found that this ability predicted later arithmetic fluency, but one (Major et al., 2017) did not find that. However, all three studies tested older children in the last year of preschool (5- to 6-year-olds) as children are typically introduced with Arabic digits around that age. Examining the predicting role of NW comparison has never been done before but might be very interesting as children are familiar with NW before learning Arabic numbers.

Finally, although early arithmetic ability was sometimes tested, such as nonverbal calculation (2/6 studies) or verbal calculations (1/6 studies), approximate addition was never examined before.

In some cases, these abilities were tested but combined in a global measure (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Jordan, Kaplan, Locuniak, & Ramineni, 2007). This approach hinders identifying which specific numerical process plays a vital prediction role.

Table 1
Review of longitudinal studies of later arithmetic outcomes from preschool predictors.

Study	*N*	Age			% Girls	Outcomes	Predictors			Covariates		Variance
		T1	T2	T3			n	Sig	No Sig	Sig	No sig	
Chu et al. (2018)	134	3.2 − 4.4y 38-54m	T1 + 1y 50-66m	T2 + 2y (G1)	51.49	**Addition strategy: T3** [9 SDA]	10	Give-N [1-6]: T1 VC [1-100]: T2 DQD [5-20]: T2 NL [14, 0-20]: T2	Enum [20]: T1 VC: T1 DQD: T1 OC: T1 NR: T1 NVC: T1 NS [5]: T2 CQD: T1-2	LR	NVIQ EF Par Ed	36-60% probable
Major et al. (2017)	267	72.49 ± 4.5 (5y)	T1 + 1y (G1)	–	41.57	**Addition RT: T2** [16 SDA]	3	Enum [1-8, acc-RT] TEMA-2**	AN-Comp [1-9, RT]		VSWM NVIQ	Path Model
Aragón et al. (2016)	122	69.89 ± 3.44	T1 + 1y (G1)	–	44.26	**Fluency: T2** (64 SDA; 60s)	5	VC (Fwd/Bwd Count[20]) Enum [5, 20], without pointing NL	NR Enum [5, 20], pointing		Logic-C	27.90%
Bartelet et al. (2014)	209	71.8 ± 4.4	(G1)	–	45.93	**Fluency: T2** (50 SDA, DDA; 120s)	4	Enum [1-9, acc-RT] AN-Comp [1-9, acc-RT] Estim [1-16, acc]	Dot comp [1-9, acc]		Speed NVIQ Gender age	22%
Martin et al. (2014)	193	6.16y ± 0.32	7.16 ± 0.32 (G1)	–	40.70	**Fluency: T2** (72 SDA, SDS; 120s)	4	NR [SD,DD,TD, acc] AN-Comp [SD,DD,TD, acc]	Count (VC, acc-RT; Count down from 10,20) Enum [4-8], Cardinal principle	CE	VSWM PA	36.20%
Locuniak & Jordan (2008)	198	66 ± 4m	G2	–	44.00	**Fluency: T2** (50 SDA, SDS, DDA, DDS; 120s)	5	Counting (VC[1-10], count principle [5-9]) NK (NR [SD, DD], Give-N [7], AN-Comp[SD]) NVC [SDA, SDS] Number combinations (NVC, VCs)	VCs [NWA, NWS]	CE	PL NVIQ Age Reading Vocabulary	26-42%

Note. n, number of predictors; m, months; y, year; SD, Single digit; DD, double-digit; TD, triple-digit; SDA, single-digit addition; SDS: single-digit subtraction; DDA, double-digit addition; DDS, double-digit subtraction, acc-RT: accuracy-Reaction time; Par Ed, parental education; EF, executive function; LR, letter recognition; VSWM, visual-spatial working memory; NVIQ, nonverbal intelligence; Logic-C, logical concept; PA, phonological awareness; DS, Digit span; Fwd, forward; Bwd, backward; CE, central executive; PL, phonological loop.
Count, counting; VC, verbal counting; Give-N, give-a-number; DQD, discrete quantity discrimination; Dot comp, dot comparison; OC, ordinal choice; NR, numeral recognition; Enum, enumeration; NVC, nonverbal calculation; VCs, verbal calculations; CQD, continuous quantity discrimination; NL, number lines; NS, number sets; AN, Arabic number; NW, Number words; NWA, number words addition, NWS, number words subtraction; Comp, comparison; SC, structured counting; AN-Comp, Arabic number comparison; Estim, estimation; NK, number knowledge.

Present study

The present study addresses the following question: Among preschoolers' basic numerical abilities, what are the best predictors for later arithmetic outcomes that cover both quantitative (accuracy and fluency) and qualitative aspects (strategy)? To answer this question, preschoolers' performance was assessed in seven numerical tasks covering the ANS (collection magnitude comparison), the sequential aspects of symbolic numbers (counting and advanced counting), the cardinal meaning of NWs (enumeration and Give-N), the magnitude comparison of symbolic numbers (NW comparison), and approximate addition. Some cognitive and contextual factors were also measured (matrix reasoning, digit span, and home numeracy frequency). Two years later, arithmetic outcomes were tested when children were at the end of G1 using single and double-digit addition tasks.

We tested each ability separately to explore the specific numerical mechanisms that best predict arithmetic proficiency two years later. Most previous studies suggest that symbolic abilities (counting, cardinal knowledge, and Arabic comparison) predict later arithmetic achievement (Bartelet et al., 2014; Martin et al., 2014; Chu et al., 2018). However, few studies have examined all of these aspects in the same research (e.g., Chu et al., 2018). In this study, we investigate which aspect is more dominant in predicting later arithmetic skills: the ANS; the sequential, the cardinal, or the magnitude processing of symbolic numbers or the ability to approximate addition?

If the sequential numerical aspect is one consistent predictor, we aim to distinguish whether basic counting (rote counting) or advanced counting (conceptual elaboration of verbal number) is the more important. Advanced counting (i.e., elaboration of NW sequence) is a lengthy process that develops from 4 to 7 or 8 years old, and requires conceptual understanding (one can count at any point in the sequence; Secada et al., 1983) and complex thinking (Nguyen et al., 2016). This ability constitutes the first step toward moving from the counting-all to counting-on addition solving strategy (Secada et al., 1983). However, the role of early advanced counting in predicting later arithmetic achievement and strategy remains unknown because no longitudinal study has examined this ability independently. Aunola, Leskinen, Lerkkanen, and Nurmi (2004) tested advanced counting (i.e., counting from a number task), but this was mixed with basic verbal counting (i.e., count from one and counting as high as possible). Aunola's finding indicated that a preschooler's performance on combined basic and advanced counting predicts later arithmetic fluency. Nguyen et al. (2016) tested advanced counting separately from basic counting in first-grade pupils and showed that advanced counting competence is more of a robust predictor of fifth-grade students' mathematics achievement than basic counting ability. However, in this study, the outcome was a general mathematical achievement.

If cardinal understanding is crucial, we would like to distinguish the contribution of cardinal principle knowledge to enumeration and the cardinal understanding of NWs (via the Give-N task). Wynn (1992) suggested that testing the verbal number's cardinal meaning is more efficient via the Give-N task than via the how many task (which only tests the cardinal principle knowledge). We assumed that to select a sophisticated strategy, children need to understand the meaning of the numbers. Furthermore, this understanding is a prerequisite for number magnitude comparison, which itself is necessary to determine where to start the count in the case of a counting-min strategy to solve addition.

If magnitude understanding is a contributor to later arithmetic learning, we want to examine whether symbolic magnitude (via number word comparison) or nonsymbolic magnitude understanding (via collection comparison) is important. Awareness of numerical magnitude serves as a foundation for higher-level processing competence such as mathematical calculation (Butterworth, 2005). However, few longitudinal studies have investigated the link between symbolic magnitude comparison in early preschool and later arithmetic as most of them used Arabic digits, which are not introduced to children until the age of 5 or 6. Only the study of Doesote et al. (2012) used all three tasks, dots, Arabic, and NW comparison in preschool; and found the inconsistent finding that nonsymbolic magnitude comparison (tested by dot comparison, which did not control for many dimensions of measures) predicted later mathematical achievement in G1.

Based on previous findings in the literature (Aunola et al., 2004; Bartelet et al., 2014; Chu et al., 2018; Locuciak & Jordan, 2008), we expect to find that mostly sequential and cardinal symbolic number abilities, such as counting, advanced counting, Give-N, and NW comparison, will predict later arithmetic outcomes. We expect that the contributing role of conceptual cardinal principle knowledge (enumeration) and nonsymbolic magnitude understanding (via collection comparison) might be less important. Furthermore, among the symbolic skills and according to the importance of the elaboration of the NW sequence (Fuson et al., 1982; Nguyen et al., 2016; Secada et al., 1983), we assume early mastering of advanced counting is the best candidate for the prediction of later arithmetic achievement, strategy choice and calculation fluency. As it was never examined in a longitudinal study, the predictive role of approximate addition (Gilmore et al., 2007) for later mathematical achievement remains an open question.

The present study also examines the generalizability of previous findings by examining a sample of Vietnamese 4- to 6-year-olds. Indeed, most previous studies exploring relations between early numerical abilities and later arithmetic achievement have been performed for Western, industrialized, developed nations (as seen in Table 1). For instance, there is a lack of longitudinal studies conducted with young Asian children. We choose Vietnamese children because, similar to children in many Western countries, they officially learn formal symbolic addition in G1. In contrast, Chinese children, for instance, learn different calculations in kindergarten (at the age of 3) and have already mastered simple calculations when they reach elementary school (Wei, Guo, Georgiou, Tavouktsoglou & Deng, 2018). When asked to perform simple calculations, they rely more on fact retrieval than procedural strategies (e.g., Geary, Bow-Thomas, Liu & Siegler, 1996). In our study, all children who participated in early math education programs outside school were excluded.

Thus, the current study's contribution is a two-year longitudinal study testing seven different numerical predictors of arithmetic skills. Among the predictors considered, several have not or have rarely been tested before (e.g., advanced counting, Give-N, NW comparison, and approximate addition). Furthermore, arithmetical skills are measured in both quantitative and qualitative aspects (accuracy, fluency and strategy choice). Finally, the sample used (i.e., Vietnamese children) will allow the generalization of previous results beyond Western culture.

Methods

Participants

Children were recruited from six preschools (four private and two public schools) in Ho Chi Minh City, Binh Duong, and Nghe An, Vietnam. Consent forms were sent to all preschoolers, and the sample comprised the children whose parents consented to their participation. Children were drawn from middle socioeconomic backgrounds and were all monolingual Vietnamese speakers.

Two hundred sixty-five children were tested during the second semester of year 1 in preschool; among them, 23 were excluded because of low nonverbal intelligence subtest scores (e.g., score below two SD from the mean; $n = 6$), failure to complete the preschool tasks (e.g., because of poor attention, $n = 4$), presence of a neurodevelopment disorder (e.g., Autism spectrum or language delay, $n = 5$), or participation in early math education programs outside the school ($n = 8$).

Two hundred and forty-two Vietnamese preschoolers ($M_{age} = 4.8$, 126 boys) were tested for their cognitive and numerical abilities in preschool (T1). Two years later (i.e., at the end of G1, T2), the arithmetic ability of 157 of these children ($M_{age} = 6.7$) was tested. The final sample comprised 157 children (82 boys) who participated in these two testing times.

Eighty-five children dropped out of the study at T2 because of relocating to another country or province ($n = 26$), failure to contact the parents ($n = 10$), or the difficulty of accessing their new school due to complicated administrative requirements ($n = 49$). Ten primary schools (nine public schools and one private school) participated in the T2 testing and allowed us to assess the calculation abilities of 157 children. Notably, the educational program in Vietnam is identical for all private and public schools because they follow the same school books and a precise agenda.

In the final sample, 149 parents of children reported their highest educational level. Mothers' and fathers' educational levels were highly correlated, $r(149) = .52$, $p < .001$. Nearly half of them (77 mothers and 81 fathers) had a university-level degree; 8 mothers and 13 fathers had a Master or a Ph.D.; 64 mothers and 63 fathers had an educational level below university (i.e., the primary [1 mother and 1 father], secondary [7 mothers and 31 fathers], high school [30 mothers and 31 fathers], college [32 mothers and 24 fathers]).

Tasks

Preschoolers were tested on seven numerical tasks and three general cognitive tasks. Computerized tasks (collection comparison, NW Comparison, and approximate addition) were developed by using E-prime (Version 2.0, Psychology Software Tools, Inc., Pittsburgh) and used a PC with a response box (left and right touch).

Preschool numerical tasks

Counting: Children were asked to count out loud as far as possible and were stopped when they reached 50. The score was the highest NW counted.

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

Enumeration (Enum): Children were invited to enumerate each set of aligned figures of animals (N = 4, 6, 9, 10, 12, 15, 16, 17) and then answer the question: "*How many animals are there?*" If they enumerated correctly and responded to the "*how many*" question with the last NW, the trial was considered successful, and the response was coded 1. If they recounted or responded to the question by an NW different than the last one, the trial was considered incorrect, and these answers were coded 0. The score was the total of CRs.

Give-me a number (Give-N): Children were asked to give the rabbit precisely 1, 2, 3, 4, 5, or 6 carrots from the bowl. If a child did not react, the experimenter provided a demonstration.

Children began at set size one: They advanced to the next set size after a correct response and went down one set size after an incorrect response. The task stopped when a child made two mistakes on the same item arrived at the last item (as in Sarnecka & Carey, 2008). The score was the highest number of objects the child reached correctly twice.

Number-word comparison (NW-Comp): Children were presented with two number words, given orally and asked to select the largest (task from Honoré & Noël, 2016). Stimuli were of two distances (close: distance of 1 and far: distance of 3) and two sizes (small: 1 – 9 and large: 11 – 19). There were 24 trials in total: 6 trials in each of the conditions (close distance - small size: 2–3, 5–6, 8–9, 8–7, 5–4, 5–3; far distance - small size: 2–5, 4–7, 6–9, 9–6, 8–5, 7–4; close distance - large size: 10–11, 13–14, 16–17, 18–17, 16–15, 19–18; and far distance - large size: 11–14, 15–18, 16–19, 19–16, 17–14, 18–15). Their score was the total of CRs.

Collection comparison (Collection-Comp): Children were shown two collections of puzzle pieces and asked to select the larger one (task from Rousselle, Dembour & Noël, 2013 adapted by Honoré & Noël, 2016). The number of puzzle pieces varied from 5 to 18. Six practice pairs of sets differing by a ratio of 1:3 familiarized the children with the task. The test trials were pairs of sets differing by ratios of 1:2, 2:3, 3:4, 4:5, 5:6, 6:7, and 7:8. Each ratio comprised two pairs (7−14 and 8−16; 6−9 and 10−15; 6−8 and 12−16; 8−10 and 12−15; 5−6 and 10−12; 6−7 and 12−14; 7−8 and 14−16). Each pair was presented four times, varying according to the presentation order (smaller set on the left or the right side) and the condition (congruent or incongruent), resulting in 56 items. In the congruent trials, the larger collection in number also had the larger density and the larger cumulative area of the puzzle pieces, whereas, in the incongruent trials, the larger collection in number had the smaller density and the smaller cumulative area of the puzzle pieces. Their score was the total of CRs.

Approximate addition task (Appro-Add): This task was adapted from Gilmore et al., (2007). Children were invited to estimate the result of the addition of two Arabic numbers and compare it with a third Arabic number (e.g., 5 + 4 and 7). A verbal guidance was given in each trial (*"Babar has five candies. He gets four more. Celeste has seven candies. Who has more?"*). This task entailed two practice and 16 test trials corresponding to four additions (5+4, 7+5, 4+6, 6+5), associated with two smaller and two larger numbers (5+4 and 6, 7, 11, 13; 7+5 and 8, 10, 15, 18; 4+6 and 7, 8, 12, 15; 6+5 and 8, 9, 14, 16). The ratio between the sum and the last set was 4/5 (e.g., 5+4/11) in half of the trials, and 2/3 (e.g., 4+6/15) in the others. The score was the total of CRs.

General cognitive tasks

Matrix Reasoning Task. Matrix reasoning is a nonverbal intelligence subtest from the WPPSI (Wechsler, 2012). Children were invited to select the one from the visually presented response options that best completed a matrix.

Digit Span. This task is from KABC-II (Kaufman, 2004). The experimenter read a string of numbers at a rate of one per second, and the child had to repeat the string in the same order. Twenty-two trials ranged from 2 to 9 one digits number. Each length contained three series of numbers. The task was stopped when the child failed on all three trials of a given length. The score corresponded to the longest length for which at least three trials were correctly repeated, plus .5 if one trial of the next series length was successful.

Letter Span. Children listened to a series of one-syllable letter names (among B, C, G, K, L, M, N, P, R, S, T, V) and were then asked to repeat them in the same order. Stimuli varied in length from one letter (e.g., K) up to five letters (e.g., P L G R V), with three items per length. After two unsuccessful trials of a given length, the task was stopped. The score corresponded to the higher length for which at least two trials were correctly repeated, plus .5 if one trial of the next length series was successful.

Parental home activity questionnaire

The questionnaire was designed by Skwarchuk, Sowinski, and LeFevre (2014) and assessed home numeracy practices (13 items, e.g., counting, simple sums, number recognition) and home literacy practices (11 items, e.g., word reading, alphabet/word recognition). The parents answered by circling the corresponding frequency of each activity based on a Likert scale ranging from 0 (never) to 4 (very often or once per day). The mean frequency of home numeracy practices was computed.

First-grade arithmetic task

<u>Additions task</u>

Children were presented with 10 simple one-digit number additions (e.g., 3 + 3; 4 + 4; 5 + 5; 2 + 4; 2 + 6; 3 + 7; 6 + 6; 7 + 7; 3 + 9; 5 + 9) and six complex additions with one 1-digit number addend and one 2-digit number (e.g., 5 + 13; 2 + 14; 3 + 16; 7 + 15; 9 + 14; 7 + 18). In simple additions, half of the trials were doubles problems, and in the others, the smaller addend always appeared first (this allowed us to distinguish between a counting-on and a counting-min procedure). Each problem was presented one at a time horizontally on a computer screen projected by PowerPoint 2016 and remained on the screen until the child answered. Children were asked to solve each problem as quickly as possible by using any strategy they wished and to report how they reached the answer. Four examples were presented (e.g., 2 + 2; 2 + 5; 1 + 2; 2 + 3) for children to practice answering as quickly as possible.

Accuracy (Acc) was recorded with 1 point given for each addition answered correctly.

Response time (RT): RT was especially measured to allow to determine the recall strategy if RT 3s (see below). However, it was not considered as an outcome variable.

Strategy used: The experimenter used the paper answer protocol to write the child's answer and strategy. The problem-solving strategies were coded based on Chu et al. (2018); notably, we did not credit for strategies that led to calculation errors but only considered strategies for CR.

Three counting-based strategies were distinguished: *counting all* (i.e., counting both addends with or without a finger, starting from one), *counting on* (i.e., starting from the smaller addend), and *counting min* (i.e., starting from the larger addend).

When the child represented the two addends with fingers and answered immediately without verbal counting and without counting the fingers one by one, the strategy was called a "*vision strategy.*" This strategy appeared mostly for a sum below 10.

When children gave a correct answer without showing any sign of finger or verbal counting, took more than 3 seconds to give their answer, and could not explain how they reached it, the strategy was considered a "*not identified strategy*."

Retrieval was encoded if children did not count or use their fingers, reached the correct answer in less than 3 seconds, and explained that they knew the answers or had this answer in their head.

Decomposition was considered if children used close double problems to help them find the answer (e.g., 7 + 8 = 7 + 7 + 1) or decomposed one of the addend to reach a sum of 10 (3 + 9 = 2 + 1 + 9) or used other decompositions to solve complex additions (e.g., 7 + 18 = 5 + 2 + 18) or decomposition of the unit and decade part of the larger addend (e.g., 2 + 14 = 2 + 4 + 10).

Each strategy was given a value expressing the degree of its maturity (Table 3). On this basis, a strategy score was calculated (see Chu et al. (2018) for a similar approach) by summing the frequency of use of each strategy by the child multiplied by each of these strategies' maturity degree. For example, for one child who had 12 correct answers, 10 times using a retrieval strategy and 2 times using the count-min strategy, the score is (10 (retrieval) x 6) + (2 (count min) x 3) = 66 points.

Calculation fluency

Calculation fluency was measured with Tempo Test Automatiseren (De Vos, 2010). 50 addition problems presented horizontally on one page and children had two minutes to answer as many problems as they could with a pencil. The calculation fluency score was the total number of CRs.

Procedure

In preschool , the children were tested individually in a quiet room in their school in two sessions of approximately 45 minutes. The tasks were ordered, alternating between verbal and computerized tests, with a maximum of six tasks in a session. The first session included counting, advanced counting, enumeration, collection comparison, Give-N, and NW comparison. The second session included the matrix reasoning task, digit repetition, approximate addition, and letter repetition.

Parents were invited to complete an anamnestic questionnaire about their child, their own highest education level and a questionnaire about home activity practices. Measures employed were piloted on 30 preschoolers. In the second semester of G1, between March and May, children were individually tested in a quiet room in their school in a session of approximately 20 minutes. The testing gap between T1 and T2 was 24 months (*SD* = 2.35).

Results

The analyses were run on SPSS version 25.0.

Preliminary analyses

Preschool tasks analysis

Cronbach's alphas (computed on the global sample's performance, $N = 242$; see Table 2) was suitable for all the tasks but moderate for the collection comparison and the approximate additions. Independent t-tests showed there were no significant differences between the performance of the group that dropped out ($N = 85$) and the group that continued the research ($N = 157$), except for the collection comparison task (Table 2). There was also no significant gender difference in preschool numerical skills and in first-grade arithmetic outcomes (independent t-tests, all $p > .05$).

Table 2
Task analysis and preliminary results.

	Reliability		Range		Remained group			Dropped-out group			Independent *t-test*			
	N	α	Min	Max	*N*	Mean	*SD*	*N*	Mean	*SD*	*t*	*df*	*p*	*d*
Age			47	64	157	56.82	3.87	85	56.94	4.36	0.22	240	0.827	0.29
Preschool numerical skills														
Counting			5	50	157	26.31	12.58	85	25.33	13.15	-0.57	240	0.571	0.76
Advan-Count	242	.95	0	6	157	3.01	2.54	85	2.76	2.64	-0.70	240	0.486	0.96
Enum	242	.93	0	8	157	4.16	3.16	85	3.81	2.83	-0.88	189*	0.382	0.12
Give-N	242	.89	0	6	157	4.55	1.94	85	4.82	1.84	1.07	240	0.284	0.14
NW-Comp	242	.74	7	24	157	14.76	4.11	85	15.85	4.80	1.76	151*	0.080	0.25
Collection-Comp	242	.54	18	50	157	31.66	5.13	85	33.01	5.15	1.95	240	0.052	0.26
Appro-Add	242	.49	4	16	157	9.38	2.57	85	9.68	2.68	0.87	240	0.384	0.11
General cognitive abilities														
Matrix Reasoning	283	.84	4	19	157	9.46	2.96	85	9.56	2.85	0.27	240	0.788	0.04
Digit Span	283	.89	3.0	8.5	157	5.77	1.01	85	5.72	0.94	-0.36	240	0.722	0.05
Letter Span	283	.77	1	4	157	2.68	0.74	85	2.81	0.72	1.31	240	0.190	0.18
Parental educational level														
Mother			1	7	149	4.95	1.48	80	5.14	1.39	0.96	227	0.340	0.13
Father			1	8	149	5.14	1.46	80	5.18	1.40	0.17	227	0.864	0.03
Home frequency	184	.95												
Numeracy	198	.91	0	4	142	2.36	0.76	75	2.42	0.81	0.50	215	0.617	0.22
Literacy	194	.92	0	4	143	2.05	0.95	75	2.18	0.89	1.03	156	0.303	0.14

Note. * Levene's test indicated unequal variances; thus, *df* were adjusted.

First-grade additions task analysis

Accuracy ranged from 4 to 16 CR (mean of 12.27 ± 2.93). The strategy was analyzed for CR only (i.e., 1937/2512 answers), see Table 3. The strategy score ranged from 2 to 96 (mean of 53.35 ± 20.54).

Table 3

Strategy used in problem-solving, coding criteria, and frequency.

Strategy	Value	Criteria Example: 3 + 9	Whole task n	 %
Incorrect or missing	0	Incorrect answer or "*I do not know*."	575	22.89
Counting all	1	Correct: count 1 to 12	239	9.51
Counting on	2	Correct: count 3 to 12	95	3.78
Counting min	3	Correct: count 9 to 12	167	6.65
Vision or not identified	4	Correct: subitizing, no explanation, no behavior, RT > 3s	156	6.21
Decomposition	5	Correct: making base-10 (2+1+ 9) or double knowledge	87	3.46
		or additive decomposition: Unit + Unit + Decade	320	12.74
Retrieval	6	Correct: memorized or RT ≤ 3s	873	34.75
Total			2512	100%

Note. Strategy coding criteria was replicated on Chu et al. (2018), except for vision or not identified.

Longitudinal data analysis

First, factor analysis was conducted to find the latent variable behind the three main arithmetical outcome measures. Then, Pearson correlation analyses measured the relationship between each preschool predictor and arithmetic skills. Next, a regression was run to identify the best set of predictors for arithmetic skills. Dominance analysis was then conducted to compare the importance of the selected predictors. Finally, the last regression was applied to examine whether these predictors remained significant after controlling for cognitive abilities.

Factor analysis for the outcome variables

The three main dependent variables measured accuracy, strategy score, and calculation fluency had strong correlations with one another (accuracy - strategy score: $r = 0.79$; accuracy – fluency: $r = 0.50$; strategy – fluency: $r = 0.57$, all ps < .001). Principal axis factor analysis was conducted on these three variables. The Kaiser–Meyer–Olkin measure was above the commonly recommended value of .6 (Kaiser & Rice, 1974). Only one factor was extracted (with an eigenvalue over 1), which explained 75% of the variance. This factor (arithmetic skills) was then used in all further analyses.

Correlations

Table 4 shows the correlation between each preschool predictor and arithmetic skills. Many preschool symbolic numerical predictors (i.e., advanced counting, Give-N, NW comparison, counting, enumeration, collection comparison) significantly correlated at the level of .01 with the later arithmetic outcome.

Age, letter span, and fathers' education (Edu-Father) were not significantly correlated with the arithmetic outcome and were thus discarded from the regression analyses. Regarding mother's education (Edu-Mother) and home numeracy, which correlated with later arithmetic outcome, we first entered them in the appropriate regressions but found that they never reached the significance level of .05. Furthermore, because of the absence of home numeracy data for 15 participants, including this variable into the regression model would reduce the degree of freedom. Accordingly, the regression models presented here did not consider those two variables.

Table 4

Correlations.

	Arithmetic skills	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Count	**.39****	–													
2. Advan-Count	**.38****	.51**	–												
3. Enum	**.30****	.35**	.41**	–											
4. Give-N	**.29****	.30**	.29**	.43**	–										
5. NW-Comp	**.33****	.51**	.40**	.31**	.35**	–									
6. Collection-Comp	**.25****	.20*	.09	-.04	.11	.26**	–								
7. Appro-Add	.20*	.16*	.16	.17*	.18*	.29**	.18*	–							
8. Age	.12	.14	-.05	.05	.28**	.13	.14	.00	–						
9. Matrix Reasoning	**.37****	.22*	.19*	.29**	.20*	.19*	.07	.21**	-.13	–					
10. Digit Span	**.37****	.29**	.26**	.23**	.36**	.25**	.04	.26**	.15	.26**	–				
11. Letter Span	.06	-.07	.00	.01	.17*	-.06	-.08	.13	.05	.07	.14	–			
12. Home numeracy	**.32****	.18*	.29**	.25**	.18*	.13	.08	.02	.03	.20*	.29**	.18*	–		
13. Edu-Mother	.20*	.21*	.26**	.07	.06	-.01	.03	.05	.03	.17*	.12	.02	.31**	–	
14. Edu-Father	.13	.24**	.17*	.10	.09	.04	-.03	.01	-.05	.14	.28**	-.05	.22*	.52**	–

Note. **correlations in bold are significant at the $p < .01$ level; * $p < .05$

Regressions for predicting the arithmetic outcome

A regression (stepwise method) was run on the seven numerical tasks (counting, advanced counting, enumeration, Give-N, NW comparison, collection comparison, and approximate addition) to find the significant predictors for the later arithmetic outcome.

Counting, advanced counting, Give-N, and collection comparison were the best set of predictors that significantly predicted the arithmetic outcome (Table 5). However, enumeration, number comparison, and approximate addition were not significant predictors (all *p*s > .05).

Table 5

Regression for the arithmetic outcome from preschoolers' numerical skills.

Predictors	β	*t*	*p*	Δ R^2
Count	.200	2.27	.019	.153
Advan-Count	.215	2.59	.010	.043
Give-N	.157	2.09	.038	.030
Collection-Comp	.170	2.36	.019	.022

Dominance analysis

Dominance analysis was then conducted on the four above significant predictors to compare them (Budescu, 1993, Azen & Budescu, 2006). One predictor is considered more important (dominant) than another in a given model when it increases its R^2 more than another (see Table 6). Both counting (X_1) and advanced counting (X_2) completely dominate Give-N (X_3) and collection comparison (X_4) because their additional contributions are larger than those of X_3 and X_4 across all possible subset models. However, there is no dominance established between two pairs, (X_1 and X_2) and (X_3 and X_4), since the averaged additional contributions of X_1 and X_3 are greater than those of X_2 and X_4 when model sizes = 1 but slightly smaller when model sizes = 3. The last row provides the general dominance measures for each predictor, which is the mean of the four averaged additional contributions within each model size. The sum of the four general dominance measures (.081 + .080 + .048 + .039 = .248) is equal to the R^2 of the full model. Based on the general dominance measures, the four predictors were ordered as follows: $X_1 = X_2 > X_3 = X_4$.

Table 6

Dominance analysis with four **s**election predictors using arithmetic skills as the outcome.

		Additional contribution			
Subset model	Model R-squared	Counting (X_1)	Advanced counting (X_2)	Give-N (X_3)	Collection comparison (X_4)
Null, *k* = 0 average		0.153	0.143	0.089	0.060
X_1	0.153	-	0.043	0.035	0.030
X_2	0.143	0.053	-	0.045	0.044
X_3	0.089	0.099	0.099	-	0.046
X_4	0.060	0.123	0.127	0.075	-
k = 1 average		0.092	0.090	0.052	0.040
X_1X_2	0.196	-	-	0.024	0.030
X_1X_3	0.188	-	0.032	-	0.027
X_1X_4	0.183	-	0.043	0.032	-
X_2X_3	0.182	0.038	-	-	0.038
X_2X_4	0.187	0.039	-	0.033	-
X_3X_4	0.135	0.080	0.085	-	-
k = 2 average		0.050	0.053	0.030	0.030
$X_1X_2X_3$	0.220	-	-	-	0.028
$X_1X_2X_4$	0.226	-	-	0.022	-
$X_1X_3X_4$	0.215	-	0.033	-	-
$X_2X_3X_4$	0.220	0.028	-	-	-
k = 3 average		0.028	0.033	0.022	0.028
$X_1X_2X_3X_4$	0.248	-	-	-	-
General Dominance		0.081	0.080	0.048	0.039
Percentage (Rescaled dominance)		33%	32%	19%	16%

Note. k is equal to the number of additional predictors in the model.

Regressions with controlling cognitive abilities

Finally, hierarchical multiple regression was conducted to examine whether the four above selected predictors still predicted the arithmetic outcome after controlling general cognitive abilities. In the first block, entry of matrix reasoning and digit span were forced, and then the four predictors were introduced in the second block using the enter method. Cognitive abilities explained 21.8% of the variance of the arithmetic outcome, $F(2, 156) = 21.42$, $p < .001$ (Table 8). Advanced counting and collection comparison still predicted the arithmetic outcome, $F(6, 156) = 12.94$, $p < .001$, but counting and Give-N were not significant. These predictors accounted for an additional significant 12.3% of the variance.

Table 8

Hierarchical multiple regression for arithmetic outcome controlling cognitive abilities.

	B	***SE B***	***β***	***t***	***Sig. (p)***
Step 1					
Constant	-2.49	0.41		-6.03	< .001
Matrix reasoning	0.09	0.24	.296	3.99	< .001
Digit span	.28	.070	.289	3.91	< .001
Step 2					
Constant	-3.38	.54		-6.27	< .001
Matrix reasoning	.08	.02	.234	3.34	.001
Digit span	.18	.07	.186	2.4	.014
Count	.01	.01	.139	1.73	.087
Advan-Count	.07	.03	.178	2.27	.024
Give-N	.04	.04	.071	0.96	.340
Collection-Comp	.03	.01	.171	2.52	.013

Note: R^2= .218 for step 1, and R^2= .341 for step 2; ΔR^2 = .123 for step 2

In short, the dominance analysis showed that the predictor weights for arithmetic skills were 33% (counting), 32% (advanced counting), 19% (Give-N), and 16% (collection comparison); however, only advanced counting and collection comparison significantly predicted arithmetic outcome after controlling cognitive abilities.

Discussion

Our study examined the associations between numerical abilities from preschool (mean age of 4.8) and arithmetic achievement two years later (at the end of G1) in a Vietnamese sample. Seven different numerical tasks were considered as potential predictors, including three that were barely considered before, i.e., advanced counting, Give-N, and NW comparison task. The arithmetic outcome covered both quantitative (accuracy, fluency) and qualitative (strategy) aspects, a global measure that was rarely considered before. We will summarize the results obtained and discuss them.

Analyses of the results first showed that all seven numerical tasks proposed in preschool significantly correlated with arithmetic skills two years later, supporting the idea that all these aspects were relevant and worthy of assessment. However, the approximate addition task showed a smaller correlation, and this task proved to be not very valid (low Cronbach's alpha). Accordingly, this task, does not seem interesting to consider in further research.

Second, multiple regression analysis showed that among these seven factors, the best combination of predictors of further arithmetic skills was the counting, advanced counting, Give N, and collection comparison. Using dominance analysis, we found that the sequential aspect tested by the two counting tasks was a more dominant predictor than cardinal knowledge and nonsymbolic magnitude understanding. These results support the finding that counting processes are critical for later arithmetic skills (Aragón et al., 2016, Locuciak & Jordan, 2008, Nguyen et al., 2016). This finding is also consistent with the study of Aunola et al. (2004), in which counting skills (tested by both verbal counting and advanced counting) were a significant predictor of grade 2 arithmetic achievement.

Counting as a robust contributor to the later arithmetic outcome

Counting skills are indeed a natural scaffold for calculation and arithmetic strategies as most of the solving strategies for addition are counting-based procedures at the beginning of the learning process (Fuson et al., 1982; Johansson, 2005). Furthermore, the repeated use of verbal counting favors problem–answer associations in long-term memory, making it possible to resolve additions by retrieving the answer from memory (Siegler & Shrager, 1984).

Sequential elaboration (i.e., advanced counting, the "*breakable chain*") is more complicated than acquiring a simple number word sequence. Advanced counting corresponds to a lengthy process from the age of 4 to 7 or 8 years old (Fuson et al., 1982); it requires complex thinking (Nguyen et al., 2016) and conceptual understanding of the ordering principle that the child can count at any point in the sequence (Secada et al., 1983). The first graders who have not yet mastered advanced counting skills must rely on a counting-all strategy, using their fingers to solve additions; this is often the basis of later computational difficulties (Carpenter & Moser, 1984).

Contributing role of cardinal knowledge

Cardinal knowledge (Give-N task) also predicted arithmetic skills (but not after controlling matrix reasoning and digit span). This finding is in line with that of Chu et al. (2018), who showed that children who were at least two-knowers at the beginning of preschool (3- to 4-year-olds) used a mix of more sophisticated strategies (retrieval, decomposition, and counting-min strategy) in G1 than those who were one-knowers or had no understanding of cardinality. Notably, in our study, the children we tested were a little bit older than those of the other studies (Chu et al., 2018; Geary et al., 2018), and two-thirds were already cardinal-principle-knowers (i.e., could correctly handle the Give-N task for a number equal to five or above), which could explain why the Give-N task was a less discriminant predictor here than in Chu et al. (2018).

It should, however, be noted that in the child's development, all these processes develop in parallel and in interaction. Therefore, it is also necessary to consider these significant predictors as integrated knowledge of number sense activated during arithmetic resolution. For instance, counting is an essential contributor to learning numerical magnitudes (Siegler, 2016, for a review). The counting experience leads them to the cardinality principle, an abstract understanding that the number of objects in a set corresponds to the last number used to count the objects in it, contributing to understanding the cardinal meaning of symbolic numbers (Siegler, 2016). A recent longitudinal study (Geary, vanMarle, Chu, Hoard & Nugent, 2019) found that children who knew more count words at the beginning of preschool also performed better on the Give-N task. Recently, Sella, Lucangeli, and Zorzi (2018) also showed that the comparison of number words (i.e., below 9) is related to cardinality knowledge measured using the Give-N task. Congruent with those data, our study found quite large correlations between the performance measured in the counting tasks, the enumeration task, the Give-N task, and the NW comparison task.

Contributing role of nonsymbolic magnitude knowledge and other predictors

ANS acuity was also selected as a significant predictor of later arithmetic outcome, even after controlling for general cognitive skills. Chu et al. (2018) showed that children's ANS acuity in kindergarteners (5- to 6-year-olds) was related to their strategy sophistication in G1 whereas their ANS acuity in preschool (3- to 4-year-olds) was not. Children's ANS acuity improves with development (Halberda, Mazzocco & Feigenson, 2008) and could be refined by the advanced practice of exact numbers (Noël & Rousselle, 2011). It is possible that children's understanding of arithmetic is dependent on a certain level of maturation of the ANS (Chu et al., 2018). The growth of numerical magnitude knowledge is the core of numerical development (Siegler, Thompson & Schneider, 2011) that serves in arithmetic learning (Siegler, 2016). This finding supports Halberda et al.'s (2008) study but contradicts others (Bartelet et al., 2014). In their meta-analysis of longitudinal studies of predictive relations between nonsymbolic numerical magnitude discrimination and math achievement test scores, Chen and Li (2014) obtained a weighted mean value of $r = .17$ (Siegler, 2016, for a review). Further study needs to reexamine whether the contribution of ANS to later arithmetic ability changes by age and by the growth of symbolic numerical knowledge.

In our study, nonsymbolic magnitude knowledge did not relate to general cognitive abilities while symbolic numerical abilities were strongly related to cognitive abilities. Therefore, some abilities (counting and Give-N) were excluded from the regression after controlling for cognitive abilities. Advanced counting remained significant even when controlling covariates; it allows us to confirm our overhead view that advanced counting is one complex ability beyond general reasoning and thinking, cardinal knowledge, and symbolic and nonsymbolic quantitative magnitude knowledge.

Some tasks were not selected as good predictors of future arithmetical skills. This was the case for enumeration, NW comparison, and approximate addition. However, for the two former, significant correlations were obtained between performance in these tasks and future arithmetic skills. This failure to select enumeration as a good predictor is consistent with other studies (Aragón et al., 2016; Chu et al. 2018, Martin et al., 2014) and inconsistent with others (Bartelet et al., 2014; Major et al., 2017). Both of the latter tested the enumeration speed, which could explain the contrary findings. Regarding NW comparison, there is no previous study using this specific task. However, this finding is in line with other studies that tested the magnitude of Arabic numbers (Major et al., 2017); however, it contradicts others (Bartelet et al., 2014; Martin et al., 2014). This result's difference might be because our study tested NW comparison whereas the other studies used Arabic number comparison, and almost all the studies tested 6-year-olds whereas we tested children younger than that.

Let us note, however, that the results presented here are based on correlations and cannot prove any causation links. Further studies, using the training of one of these specific predictors and examining its impact on addition skills, could test this causal aspect. Honoré and Noël (2016) compared the impact of training using symbolic versus nonsymbolic, number magnitude tasks in preschoolers. They found that symbolic training led to a significantly larger arithmetic improvement than nonsymbolic training (and the control condition). Similarly, Friso-van den Bos, Kroesbergen, and Van Luit (2018) showed that counting training enhanced arithmetic ability (relative to a control group). However, a recent meta-analysis study (Szúcs & Myers, 2017) shows no conclusive evidence that specific ANS training improves symbolic arithmetic.

Implications

Among the seven numerical tasks assessed, advanced counting is the more dominant predictor for the later arithmetic outcome, even after controlling cognitive abilities. However, if it is very usual for parents to ask or teach their children to count as far as possible (e.g., Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010), this is much less the case for advanced counting. Thus, advanced counting should be taught explicitly and reinforced throughout parent-child home activities or school activities. For instance, Ramani and Siegler (2008) have demonstrated that playing a linear number board game that requires counting from a number different from one with preschoolers improved their number knowledge such as magnitude comparison and numeral identification.

Limitations

As children were very young when tested in T1 and their attention skills quite limited, we could not propose a comprehensive cognitive battery of tests. Further studies could consider measuring children's working memory abilities, as this component contributes to arithmetic development (see, e.g., Noël, 2009).

Another limitation is related to the lack of reliability of the collection comparison task. A similar low Cronbach's alpha was reported by Karagiannakis and Noël (2020). According to Karagiannakis et al. (2020, p.22), this is because "*participants not only process the numerical dimension of the stimuli but also process (automatically) other physical dimensions (such as the convex hull, the area of the dots) which could be congruent or incongruent with the numerical dimension*" (see, also Gebuis et al., 2016). Consistent with that interpretation, we found that the Cronbach's alpha was higher if it was calculated on the 28 congruent items (α = 0.71) while it was extremely low when calculated on the 28 incongruent items (α = 0.19). Indeed, in that latter case, some children may compare the numerical dimension, the convex hull dimension, the density, the mean size of the items, etc. Unfortunately, these limitations cannot be avoided.

Conclusions

The current study showed that counting ability and especially advanced counting, measured in early preschool, is the most robust predictor of arithmetic skills two years later (even after controlling for global cognitive skills). More globally, both sequential abilities, counting and advanced counting; cardinal meaning conceptual knowledge (Give-N but not by cardinal principle knowledge tested by how many tasks); and nonsymbolic ability (by collection comparison) were the best set of predictors for later arithmetic achievement.

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