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Supporting the understanding of cardinal number knowledge in preschoolers: Evidence from instructional practices based on finger patterns

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A R T I C L E I N F O

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A B S T R A C T

The acquisition of cardinal numbers represents a crucial milestone in the development of early numerical skills and more advanced math abilities. However, relatively few studies have investigated how children's grasping of the cardinality principle can be supported. It has been suggested that the richness of number inputs children receive influences the acquisition of cardinal numbers. The present study was designed to investigate whether canonical finger patterns representing numbers may contribute to this acquisition. Fifty-one 3-year-olds were randomly assigned to 1 of 2 training conditions: (a) a condition that involved counting and labeling, which has shown efficacy to support the acquisition of cardinality, and (b) a condition in which counting and labeling were enriched with finger patterns. Crucially, we aimed at providing evidence of both training programs in a real-life learning environment where teachers incorporated the training as a group-based activity into their regular schedule of daily activities. Children assigned to the finger-based condition outperformed those who received the counting-and-label training. Findings suggest that finger patterns may have a role in children's cardinality understanding. Furthermore, our study shows that instructional approaches for improving cardinality understanding can be easily and successfully implemented into real-life learning settings.

1. Introduction

At school entry, children already have quantitative competencies that are the foundations of further mathematical development (Merkley & Ansari, 2016). For instance, they show a basic understanding of number symbols and the quantities represented by both number words and Arabic numerals, as well as their relations (e.g., more, less). Among these number symbols, number words are usually the first entities that young children learn. In the current study, we investigate the role that finger patterns (such as holding up the index finger to refer to "1," or the index, middle, ring, and pinky finger to refer to "4") may play in scaffolding the learning of cardinal number knowledge before children enter formal education. Specifically, we evaluate the efficacy of an instructional protocol in which finger patterns are associated with verbal number words.

2. Learning the cardinal meaning of number words

Around the age of 2, most children can recite some numbers in order. Nevertheless, this does not imply that children understand the basic properties or functions of numbers (i.e., cardinality and ordinality). Learning the cardinal meaning of number words—namely, that a number word tells how many there are in a group of objects—is a difficult and protracted process. Indeed, understanding cardinality includes different levels that can be measured by different tasks (Baroody et al., 2017; Fuson, 1988, 1992; Sarnecka & Carey, 2008). Previous studies have mainly used the How-Many and Give-N tasks (Baroody et al., 2017; see also Mou et al. 2021). How-Many tasks require children to determine the number of a given set. When a child counts a set and then responds to the How many question with the last counted word, that is the first level of cardinality called "last-number rule," in

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which that last word does not refer to the whole set and does not refer to the numerosity of that set— that is the cardinality of the set (Fuson, 1992). At the next level, referred to as "count-to-cardinal transition," the last word shifts from a reference to the last counted object to a reference to the cardinality of the whole set— that is the cardinality principle. Give-N tasks require children to produce a set of objects for a given number (Winn, 1990, 1992), which is thought to assess a more advanced level of understanding of cardinality, referred to as cardinal-to-count transition. In this case, performance requires a higher level than last-word responding or the count-to-cardinal transition since children have to count and remember how many to make.

A series of studies have suggested that understanding the cardinal meaning of numbers represents a crucial milestone in the development of early numerical skills and more advanced math abilities (Geary et al., 2018). For instance, preschoolers' knowledge of the cardinal meaning of numbers is predictive of later mathematics achievement (e.g., Chu et al. 2018; Geary & vanMarle 2016; Geary et al. 2018; Nguyen et al. 2016; Spaepen et al. 2018). Geary et al. (2018) examined the relation between preschoolers' age, their understanding of the cardinal meaning of number words (according to the Give-N task), and later mathematical competence, and found that children who grasped an understanding of cardinality earlier also had better number knowledge and arithmetic skills at school entry. According to these authors, an early understanding of cardinality translates into longer experiences with numbers and the relations among them before school entry. Indeed, in a different study, Geary & vanMarle (2018) found that the growth of children's symbolic number knowledge accelerates once they understand the meaning of number words (as determined by performance on the Given-N task). Notably, the delayed understanding of the cardinal meaning of number words throughout preschool increases the risk of long-term mathematical difficulties (Chu et al., 2019).

3. Supporting the understanding of cardinal meaning of number words

Given the role of this knowledge of the cardinal value of numbers on children's accumulated experience with number symbols at the onset of formal school, it is surprising that relatively few studies have investigated how that knowledge can be supported. It is also unclear how best to teach the meaning of number words. Some studies suggest that the richness of number inputs children receive influences such understanding. It is thought that an input in which counting and labeling set sizes are used together facilitates that knowledge (Mix et al., 2012; O'Rear & McNeil, 2019; Paliwal & Baroody, 2018, 2020). Indeed, both processes are prerequisites to understanding what cardinality is (LeCorre & Carey, 2007; Wynn, 1990). For instance, Mix et al. (2012) showed that a teaching approach in which the size of a set is labeled and the elements of that set are immediately counted afterward is more effective than other types of approaches (e.g., counting sets only, labeling set sizes only, and cycles of counting only that alternate with others of labeling only). According to these authors, labeling and then counting the same set allows children to make the connection between the set size and the last word said when counting. Paliwal & Baroody (2018) found that a count-then-label approach (i.e., counting a set, emphasizing the last word counted, and identifying the total) was also effective. Recently, Gibson et al. (2019) found that children learn more from inputs that involve counting and set labeling along with the spatial alignment of neighboring sets and comparison of these sets than from number inputs involving counting sets presented one at a time. These studies suggest that enriched number inputs wherein comparing, counting, and labeling co-occur support children's cardinality learning.

4. Fingers and cardinality understanding

Some studies have focused on the role that fingers and gestures can play in counting skills (see Goldin-Meadow et al., 2014, for a review). For instance, pointing while counting is thought to promote counting accuracy. This gesture helps children to keep track of counted items and coordinate saying the number words and tagging the items (Alibali & DiRusso, 1999). Gelman & Gallistel (2009) found that children begin pointing while counting as early as 2-years of age, although it is not until children are 4-years old that they successfully coordinate pointing and number words (Saxe, 1977). Recently, Gordon et al. (2019) showed that children who had not yet acquired an understanding of cardinality pointed to each item while completing the Give-N task. Pointing while counting has been promoted in instructional studies that have aimed at supporting cardinality learning (e.g., Gibson et al. 2019; Mix et al. 2012).

Considerably less work has been devoted to studying the representational nature of finger patterns and how finger patterns serve to label and communicate the cardinality of sets. The dearth of research is noteworthy given that finger patterns are jointly learned with number words early in development and are part of parents' informal and incidental transmission of numerical knowledge (for instance, parents encouraging toddlers to communicate their age with fingers). In contrast to number words, which are arbitrary symbols, finger patterns show a transparent relation with numerical quantities. For small numbers, there is a one-to-one correspondence between the number of fingers that are held up and the quantity that is represented. There is evidence that labeling sets with finger patterns may be easier for children than labeling the same sets with number words. This is more evident when cardinality knowledge is in a transitional stage— that is before comprehending cardinality (Gunderson et al., 2015; but see Nicoladis et al. 2010). According to Gunderson et al. (2015), because finger patterns show a transparent mapping between the number of fingers and number of items in a set, they may serve as a bridge between nonsymbolic and symbolic representations of numbers. In the same vein, it has been suggested that fingers may provide the "missing tool" (Andres, et al., 2008) or the "missing link" (Fayol & Seron, 2005) that permits the connection between the children's likely innate capacity for numerosity and number symbols, such as number words.

5. The current study

Although some authors have suggested that finger patterns, if practiced early in development, may play a functional role in numerical development by facilitating the learning of cardinality through the assignment of symbols to quantities (Di Luca & Pesenti, 2011; see also Andres et al. 2007; Fayol & Seron 2005; Levine et al., 2019), there is no empirical evidence that finger patterns do support the understanding of the cardinal meaning of number words. Thus, in the current study, we conducted a pretest-training-posttest with 3-year-old at the beginning of their first year of preschool education (children had not yet received mathematical instruction) to investigate that possibility. Children received 1 of 2 training conditions. In one training condition (adapted from the training described in Mix et al. 2012 and Paliwal & Baroody 2018), children received an input involving counting sets of tokens and labeling their corresponding set sizes with number words. The sequence was labeling a set, counting tokens, and labeling (hereafter, label-count-label condition —LCL). Since training involving both counting and labeling (independently of order) has been shown effective in promoting the understanding of cardinality, this condition was considered a sort of control condition to compare the effectiveness of an alternative finger-based instruction. In this training, the same instruction that was provided in the label-count-label condition was enriched with finger patterns (hereafter, LCL-plus-finger condition). Hence, this condition provided children with associations between number words (or labels), finger patterns, and quantities. Based on findings from correlational studies that have suggested an early link between finger patterns and cardinality (e.g., Gibson et al. 2019; Gunderson et al. 2015), we hypothesized that children in the finger pattern condition would experience larger gains or better knowledge of the meaning of number words (after accounting for differences in previous knowledge) than those assigned to the LCL condition. This is because finger patterns may help to strengthen the connection between number words and quantities.

As indicated earlier, 2 types of tasks have been used to measure children's knowledge of cardinality: How-Many and Give-N tasks. Although the Give-N task is thought to assess a relatively advanced cardinality concept, we decided to use this task because the instruction that was designed included components that were similar to those elicited by the How many task (see Methods section). In the Give-N task, children are required to produce a particular number of tokens. Initially, children give 1 object when asked for 1, but give a random number of objects when asked for any other number. These children are called one-knowers (Le Corre & Carey, 2007). Similar patterns are found for 2-knowers, 3-knowers, and 4-knowers. They accurately produce up to 2, 3, and 4 objects, respectively. These stages are also referred to as "subset-knowing." It is only after children become 4-knowers that they successfully generalize that knowledge to larger sets. In other words, they know the exact meaning of any number word, as high as they can count (Sarnecka, 2015). These children have been referred to in the literature as cardinality knowers or CP-knowers (e.g., Le Corre & Carey 2007; Sarnecka & Lee 2009). Nonetheless, a recent study suggests that performance on Give-N tasks reflects more accurately "n-producer" levels (Baroody et al., 2017). Thus, for consistency, we will use this terminology (e.g., 2-giver or n-giver)[1]

Several measures served as control variables to investigate group differences at the pre-test level, as well as their relations with giver level at the beginning of the study. For instance, we included variables that were, directly and indirectly, related to children's ability with finger patterns, such as their knowledge of finger patterns, fine motor skills, and their visual working memory skills (which might contribute to efficiently storing and retrieving patterns). These variables served to account for finger-related aspects that may impact the efficiency of the LCL-plus-finger condition. We also included children's knowledge of verbal numbers since studies on early number development have found that children learn to recite the count list, albeit as a meaningless series, prior to learning that "1" refers to 1 thing or "2" refers to 2 things (Sarnecka & Carey, 2008; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Moreover, we included the child's ability to label the number of dots in a set without counting since such ability is also an indicator of the child's early number and mathematics development (Yun et al., 2011; indeed, some studies have found that improving the child's conceptual subitizing offer a possible way to support the understanding of the meaning of number symbols, e.g., O'Rear & McNeil 2019). Because dots were arranged in a dice-like pattern, this task also served to investigate children's familiarity with other numerical patterns that are typically experienced in the home environment. The role of these control measures as moderators of the effectiveness of the finger pattern condition was also analyzed.

[1] We thank an anonymous reviewer for this suggestion.

Crucially, in the current study, we aimed at providing evidence of both training protocols in a real-life learning environment where teachers incorporated the training as a group-based activity into their schedule of daily activities—that is teachers carried out the training. The implementation of interventions/trainings/instructional protocols from empirical studies has frequently found challenges. Administration protocols and experimental settings are often tightly controlled to mimic the lab conditions that resulted in positive findings, hence, affecting the translation of findings into real-life applications. For instance, all of the cardinality training protocols with children that were mentioned in this manuscript required individual administration and lengthy training periods that do not fit the time constraints of real-life preschool settings. Indeed, some studies have reported that many teachers feel that interventions and instructional protocols supported by experimental literature do not work in their classrooms because researchers usually fail to tailor the approach and administration protocols to the context of the real world (Gersten & Woodward, 1990; McDonald et al., 2006).

6. Method

6.1. Study sample and training design

Participants were 51 children enrolled in the first year of preschool education (50% girls, age range from 34-months to 45-months, $M = 39.8$, $SD = 3.4$) in a school that served a middle socioeconomic status area from a midsize city in Spain. Parental consent was obtained from all of the children attending 2 different classrooms. Their corresponding class teachers agreed to take part in the study ($M_{age} = 38$, $SD = 4{,}2$). Both (female) teachers had a bachelor's degree in Early Childhood Education and had more than 10-years of teaching experience (13 and 19). Children were randomly assigned to each of the classrooms at the beginning of the school term and one of the classrooms was randomly selected for the LCL-plus-finger training. The breakdown of children's giver level, as determined by the Give-N task, indicated that 74% of children were 1-2-3-givers, 14% were 4-givers, and 12% were 5-givers or more at the beginning of the training (see Results section: Table 1). Data from 5-givers or more were not included in analyses[2], as these children showed knowledge of cardinality. No differences between groups were found in terms of age (t [43] = 1.44, $P > 0.05$) and pretest measures (see Results section: Table 1).

6.2. Measures

6.2.1. Give-N task

In this task (see Le Corre & Carey 2007; Wynn 1992), a set of 15 small balls (3-cm in diameter) were given to participants and a plastic animal (a bear) was placed in front of them. Children were asked to give the bear exactly N balls, beginning with 1 ball. Once they gave the bear N balls, they were asked "Is that N? If the child agreed, then, the next trial began. If the child disagreed, then, the experimenter prompted the child to give the correct amount by saying "But the bear wanted N balls, could you give the bear N balls?" If the child succeeded at giving a number N, they were asked to give the next consecutive number (N + 1), with 10 being the highest number requested[3]. If the child failed to give N, the next request was for N – 1. The highest number of objects that children accurately gave the experimenter on at least 2 of 3 attempts was coded as their number-giver level. Pre- and post-test

[2] The pattern of findings was replicated when these children were included in the analyses.

[3] Although in the widely-used titration method the highest number requested is 6, Krajcsi et al. (2019) suggest that numbers at least up to 10 should be tested.

Table 1
Descriptive data and statistics for pre-test differences between training conditions*.

	Label-count-label (LCL) (n = 23)				LCL plus finger pattern (n = 22)				LCL vs LCL plus finger pattern
	Min	Max	M	SD	Min	Max	M	SD	
Pre-t Cardinality	1	4	2.39	1.03	1	4	2.55	0.86	-0.543[b]
Post-t Cardinality	1	10	3.30	2.05	1	10	5.32	2.46	-
Pre-t Finger recog	0	1	0.54	0.26	0	1	0.63	0.28	-1.10[a]
Post-t Finger recog	0.30	0.90	0.62	0.17	0.30	1	0.81	0.23	-3.27**,[b]
Counting list	0	29	9.65	8.08	0	39	6.55	7.88	1.30[b]
Visual memory	0	13	5.04	3.62	0	11	4.73	2.71	-0.22[a]
Fine motor skills	1	8	4.04	1.97	0	10	4.86	2.78	-1.17[a]
Dots pattern recog	0.20	1	0.53	0.23	0.10	0.80	0.52	0.20	-0.06[a]
1-2-3-givers (n)	19	-	-	-	19	-	-	-	-
4-givers (n)	4	-	-	-	3	-	-	-	-

Note:
* $P < 0.01$,
** $P < 0.001$, 2-tailed.
[a] denotes t-test comparison;
[b] denotes Mann-Whitney U test.

Cronbach's alpha (0.77 and 0.87, respectively) indicated a good internal consistency.

6.2.2. Recognition of finger patterns (finger representations)

The stimuli were photographs taken with a digital camera showing the palm of the right hand of a person from a 50-cm distance. The photographs were taken in a black background and edited to adjust color and luminosity. The children were asked to indicate the number of fingers that were raised. Pictures included canonical finger patterns that a Spaniard child[4] would typically show when referring to numbers 1–5, that is, raising the index finger for one, the index finger and the middle finger for 2, and continuing with the natural order of fingers for larger numbers. Children were briefly presented (2-s) with each picture and instructed to say how many fingers were presented. The final task comprised 10 stimuli (2 for each numerosity). Children received 1 point for each correct response. Accuracy (percentage of correct responses) was taken as the measure of children's finger pattern recognition skills. Pre- and post-test Cronbach's alpha (0.77 and 0.73, respectively) indicated acceptable internal consistency.

6.2.3. Recognition of dot patterns

The design of this task is the same as the previous one, but, in this case, children were presented with pictures of black dots (on a white background) arranged in patterns like those on dices, and they had to indicate the number of dots on each picture (how many dots do you see in this picture?). Accuracy (percentage of correct responses) was taken as the measure of children's dot pattern recognition skills. The internal consistency of this task was not optimal (Cronbach's alpha = 0.57), probably due to different processes involved in small (numbers 1,2 may involve subitizing) and large numbers (numbers 3–5 likely involve counting if children are not familiar with these dice patterns). Nonetheless, as shown below (see Results section), such differences serve to support the aim of the study and theoretical rationale for the benefit of finger-based representations.

6.2.4. Knowledge of verbal counting list

In this task, children were tasked to recite the counting sequence. The score was the largest number that children recited without an error.

[4] Authors (in preparation). Finger counting and finger monitoring in children and adults: country-level specifics.

6.2.5. Visual working memory

The Picture Memory subtest of the WPPSI-IV (Wechsler, 2012) was used to assess visual working memory (31 items across both Block A and B). The subtest requires memorizing pictures and identifying them on subsequent pages. Children viewed a stimulus page of 1 or more pictures for a specified time and then were asked to select the pictures from options on a response page. Each item was scored dichotomously (i.e., 0 or 1). Test administration began with an entry point suitable for a child's age (Block A in the current study) and was terminated when the ceiling and basal were established. A high score indicates better visual working memory. The Cronbach's alpha value indicated a good internal consistency (.83).

6.2.6. Fine motor skills (finger configurations)

Children's fine motor skills were measured with the Imitating Hand Positions subtest of the NEPSY-II (Korkman et al., 2007). This task is designed to evaluate children's ability to imitate hand and finger configurations with the preferred hand. Children were tasked to reproduce the same finger or hand configuration as the examiner presented (e.g., the following instruction was given to the participants: "Make a V like this" and the experimenter raised the index and middle finger showing a "V"). They were given 20-s to reproduce the configuration. One point for each correct response was given and after 3 consecutive mistakes, the task ended. The maximum number of finger configurations that were presented was twelve. A high score indicates better visual working memory. The Cronbach's alpha indicated an acceptable internal consistency (0.76).

6.3. Training

Regardless of assignment, each teacher implemented a structured 3-week early numeracy program in their classrooms. The program was based on activities that are typically used at the preschool level (e.g., singing songs, counting games with flashcards involving toys, animals, or concrete objects). Teachers were asked to administer the numeracy activities at the beginning of the class and to avoid additional numeracy activities and/or number scaffolding during the remaining time in school. Both programs were identical in terms of activities and sequence of implementation. Each session (about 20–25 min) started with a song related to numbers 1–5, followed by a counting activity where children were shown a series of flashcards with different objects and quantities up to 5. During the first week, children practiced counting collections of 1–3 items; during the second week, counting only included collections of 3–5 items; and during the third week, collections of 1–5 items. Both teachers were previously (and independently) instructed on how to administer the activities. Fidelity to the program was based on subjective reports at the end of each week. These reports included questions regarding the numerical content in songs, books, and materials that had been used over the week, and the likelihood that numerical input had been provided during mealtimes, circle time, and other structured activities. Incentives were not provided to teachers. Both teachers received the same schedule of activities specifying the order and duration of each activity. Differences between training programs related, exclusively, to how teachers provided support (in the LCL-plus-finger training, the teacher enriched the LCL training with finger patterns).

6.3.1. Activities in the label-count-label condition (LCL)

At the beginning of each session, children sang a song about numbers. The structure of the song was: "Hello one, hello one ¿Where are you? Here I am, here I am, how are you?"—while children were presented with a flashcard depicting one object. The same structure was applied for subsequent numbers. This activity aimed to get children familiar with labeling. The next activity in the program related to counting and was adapted from Mix et al. (2012) and Paliwal & Barrody (2018). Children were presented with flashcards. On each flashcard, the teacher first labeled the set's quantity (e.g., "Look at this card. This card has 3 cars. Can we all say 3 cars? Three cars!" Next, children were asked to count the same set aloud with the teacher (e.g., "Let's count them together. One, 2, 3! There are 3 cars!"—while the teacher pointed to each item as it was counted). Then, children were asked to count aloud (pointing and labeling in their flashcards) and verbalize the total number of items in the card (e.g., "Now it is your turn. Let's count. One, 2, 3. How many cars are there?"). The teacher assisted children in both counting and labeling whenever needed.

6.3.2. Activities in the LCL-plus-finger condition

In this condition, the activities and sequence of actions were the same as those described above. The song aimed at getting children familiar with labeling was: "Finger one, finger one ¿Where are you? Here I am, here I am, how are you?"—while the teacher raised her index finger. The same structure was applied for subsequent numbers. During counting practice, children were presented with both the flashcard and finger patterns. Thus, when children were prompted to look at the flashcard ("Look at this card. This card has 3 cars"), the teacher simultaneously raised 3 fingers. Then, the teacher asked the children "Can we show 3 fingers and say 3 cars? Three cars!" Next, children were asked to count the same set aloud with the teacher (e.g., "Let's count them together. One, 2, 3! There are 3 cars!"—while the teacher pointed to each item as it was counted and verbalized the total number of objects while simultaneously showing the corresponding finger pattern. Then, children were asked to count aloud (pointing and labeling in their flashcards) and verbalize the total number of items in the card while showing the corresponding finger pattern (e.g., "Now it is your turn. Let's count. One, 2, 3. How many cars are there? Show me your fingers"). The teacher assisted children in both counting and labeling, as well as finger configurations whenever needed.

6.4. Procedure

At the beginning of the school year (September of the year the children turned 3 years old), children completed a battery of tasks assessing cardinality skills, knowledge of the counting sequence, visual working memory capacity, recognition of finger patterns and dice patterns, and fine motor skills. These tasks were administered by trained research assistants. Children were administered the training immediately after the testing. After 3 weeks of training (1 session per school day), trained research assistants administered post-tests regarding the child's cardinality skills and recognition of finger patterns. Children were tested individually in their respective preschools in separate rooms. Pretest testing took approximately 30 min per child. All recruitment and testing procedures were approved by the Institutional Review Board at the university of the first author. Following advice from the IRB committee, the training was flipped after administering the post-test so children in both groups were exposed to both types of numerical scaffolding once the study was over.

Table 2
Age-adjusted correlations.

		2	3	4	5	6
1	Pre-t Cardinality	0.381*	0.251	0.171	-0.019	0.404**
2	Dots pattern recog	-	0.204	0.209	0.259	0.642**
3	Counting list		-	0.002	-0.078	0.366*
4	Visual memory			-	0.280	0.217
5	Fine motor skills				-	0.194
6	Pre-t Finger recog					-

Note:
* $P < 0.05$;
** $P < 0.01$.

7. Results

7.1. Preliminary analyses

Table 1 provides the basic descriptive statistics for both groups on the critical pre- and post-test measures and control measures. Both groups showed similar performances at pre-test (group-comparison statistics are also shown in Table 1).

A correlational analysis of the measures that were collected at the beginning of the study revealed that children who were more proficient at identifying finger patterns also had higher giver levels (partial correlation coefficients for the pre-test measures controlling for age are shown in Table 2). The analysis also showed that children who recognized a higher percentage of finger patterns also recognized a higher percentage of dot patterns and had better counting skills. The analysis also revealed that the length of the accurate counting list did not correlate with children's giver level, which adds to existing research suggesting that being able to recite the counting list does not mean that children can recognize the cardinality of numbers (Sarnecka & Carey, 2008; Sarnecka & Lee, 2009; Wynn, 1990, 1992).

Note that the relations between children's giver level and recognition of finger and dot patterns may be affected by children's familiarity with these patterns. For instance, whilst 3-givers in the current study are (theoretically) able to label 1- 2- and 3-dot/finger patterns via subitizing, it is unlikely that they can subitize larger patterns (i.e., the size of a 5-dot/finger pattern cannot be estimated without counting unless some familiarity exists with these patterns). Fig. 1 provides a clear snapshot of this familiarity with finger patterns at this particular developmental stage. It shows the largest[5] finger and dot pattern (left and right panel, respectively) that children recognized per giver level during the pre-test, which may be interpreted as an indication of exposure or familiarity with finger and dot patterns. It can be observed that the median largely corresponds to children's giver level in both finger and dot pattern recognition. Nonetheless, some differences emerge. Half of the 1-givers were already able to recognize 2 fingers and, whilst most 3-givers were able to recognize finger patterns above their giver

[5] The correlation between the proportion of patterns that were recognized and the largest pattern that was recognized was $r = 0.91$ and $r = 0.90$ (for finger and dot patterns, respectively). The largest pattern relates to the pattern that was recognized 2 out of 2 trials.

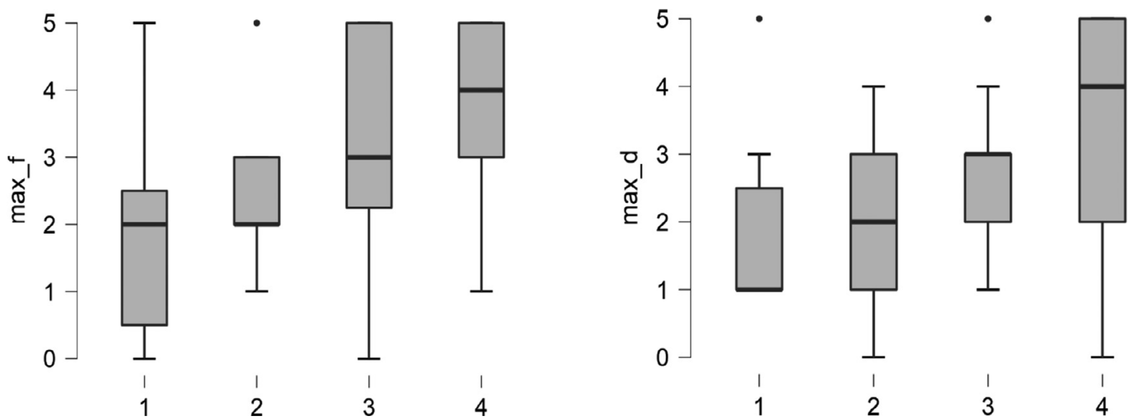

Fig. 1. Box-plots of largest finger (left panel) and dot pattern (Y-axis) per pre-test giver level (X-axis).

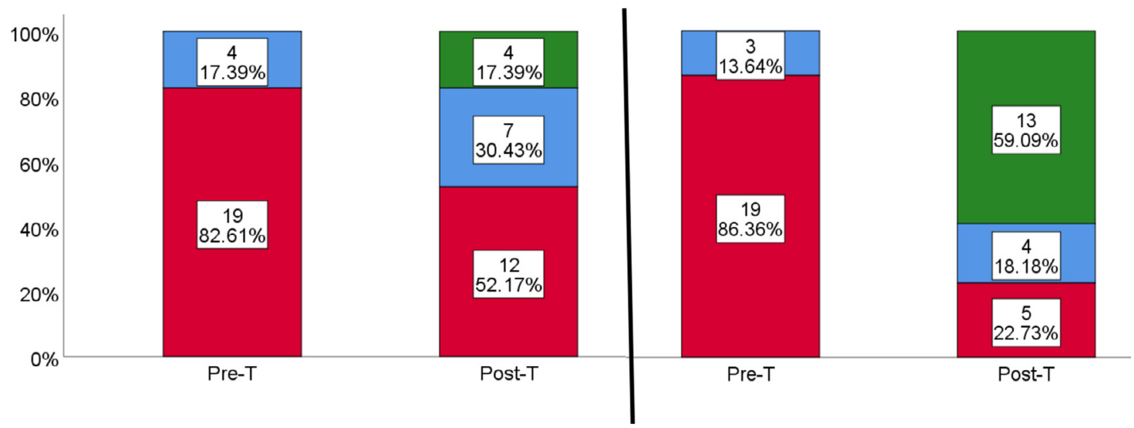

Fig. 2. Mobility across cardinality knowledge levels per training condition. *Note*: Left (LCL condition); Right (LCL-plus-finger condition). Green (cardinality knowers); Blue (4-givers); Red (1-2-3-givers). Vertical axis indicates percentage of children. Pre-T and Post-T indicate pre-test and post-test, respectively (Color version of the figure is available online.)

level, they struggled with 4- and 5-dot patterns. Given that data from the current study were collected at the onset of preschool education, this suggests that children are exposed to finger patterns well before they enter preschool education and that they probably attach number words to particular finger patterns via incidental learning.

7.2. Effect of LCL-plus-finger training on children's giver-level

We first conducted an analysis of variance (ANCOVA) with children's performance on the Give-N task (giver level) at the end of training as the dependent variable, and group (LCL-plus-finger vs LCL) as the main factor. Children's pre-test giver level served as a covariate in the analysis to strengthen the power to detect training effects. Results revealed a significant main effect of group. Children in the LCL-plus-finger group outperformed those in the LCL group ($F(1, 42) = 8.38$, $P < 0.01$, partial $\eta^2 = 0.17$), suggesting that the LCL-plus-finger training was effective in terms of improving children's performance on the Give-N task. The value of the partial η^2 indicates a large effect size. A pair of pairwise t-tests revealed that children assigned to the LCL-plus-finger training improved their giver level after 3 weeks of training, $t(21) = -5.27$, $P > 0.001$, whereas the gains of children in the LCL group only approached the standard levels of significance, $t(22) = -2.06$, $P = 0.05$.

Fig. 2 provides a clearer snapshot of children's mobility across giver levels. It is seen how the LCL-plus-finger instruction boosted the number of children that transitioned to the 5- or more-giver level in comparison to the LCL group (59% vs 17%, respectively; 1-tailed $z = -2.9$, $P < 0.01$). Furthermore, when we look at 1-2-3-givers, it can be observed that the majority of children in the LCL-plus-finger instruction transitioned to a higher giver level, whereas roughly half of the 1-2-3-givers transitioned to a different level in the LCL group.

Next, we sought to investigate baseline interactions or whether the LCL-plus-finger instruction was more effective for children with better performances on any of the measures that were collected at the beginning of the study. A separate analysis was conducted for each variable. The analyses did not reveal significant interactions, which indicates that the effectiveness of the finger pattern instruction was not affected by individual differences in any of the variables measured at the onset of the study. Put differently, the protocol was effective for children with good finger-related and number-related skills as well as for those with weaker skills.

As expected, children in the LCL-plus-finger instruction showed better knowledge of finger patterns than their counterparts at the end of the training (see statistics in Table 1). Eighty percent of children in this condition were able to recognize at least 80% of the stimuli that were shown. A pair of Wilcoxon signed-ranks tests confirmed that children assigned to this condition improved their knowledge of finger patterns ($Z = -3.07$, $P < 0.01$), whereas their counterparts in the label-count-label group did not ($Z = -1.63$, $P > 0.05$).

8. Discussion

A major milestone in early childhood is the understanding of numeral cardinality. This knowledge provides the foundation for mathematical development. Prior work has shown that children who grasp this understanding earlier also have better performances in basic math tasks at the onset of formal education (Geary et al., 2018). This suggests that programs designed at supporting early learners' understanding of cardinality may contribute to school readiness. Although few studies have analyzed which instructional approach is best for supporting such understanding, there is agreement that an important aspect is the richness of the numerical input that children receive. Labeling sets according to their numerical size, counting each object in a set, and providing cues that underscore that numbers are ordered have been found to support children's knowledge of numeral cardinality.

In the present study, we analyzed whether canonical finger patterns representing numbers 1–5 contributed to such understanding. To that end, a group of 3-year-olds was randomly assigned to a program that involved counting and labeling, enriched with finger patterns, and their number-giver levels (performance on the Give-N task) were compared to that of a group of children who were assigned to a program that only included counting and labeling and has shown efficacy to support the acquisition of cardinality (Mix et al., 2012; O'Rear & McNeil, 2019; Paliwal & Baroody, 2018, 2020). Results showed that children assigned to the finger pattern condition (LCL-plus-finger) outperformed those who received the label-count-label instruction (LCL). This finding adds to existing literature providing evidence that children's understanding of numeral cardinality—a process that usually takes place over a time of months (Sarnecka & Lee, 2009; Wynn, 1990, 1992), can be effectively supported and accelerated early in development. Furthermore, our study contributes to recent findings from correlational studies (Gibson et al., 2019; Gunderson et al., 2015) providing unequivocal evidence that finger patterns—as iconic numerical representations that may be incidentally learned in the home environment— are relevant for children's knowledge of the cardinal value of number words (as measured with the Give-N task).

8.1. How finger patterns can scaffold children's understanding of cardinality

One way that finger patterns may contribute to cardinality knowledge is because they possess the symbolic properties of number words but also have iconic properties preserving cardinal value (Di Luca & Pesenti, 2011; Wiese, 2007). Unlike number words, finger patterns share non–arbitrary characteristics with the sets of objects they refer to (i.e., there is a one-to-one correspondence between the number of fingers that are held up and the number of elements in a set). In the present study, children assigned to the LCL-plus-finger condition were presented with multiple iterations where finger patterns were attached to both number words and arrays of objects, which could contribute to establishing a robust link (or a clearer mapping) between number words, finger patterns, and quantities. Since finger patterns reflect a transparent mapping between the number of fingers and number of elements in a set, and there is evidence that preschool-age children may be able to detect numerical equivalences between sets (e.g., Mix 2008), then, finger patterns could serve as a bridge between cardinal labels of the number words and the size of the set resulting from the count (see Gunderson et al. 2015 for a similar reasoning).

It is worth mentioning that some authors have argued that the iconicity of finger patterns is not present early in development. For instance, Nicoladis et al. (2010) showed that children between the ages of 2 and 5 are more accurate at interpreting arbitrary number words than iconic finger patterns. According to these authors, children are not sensitive to one-to-one correspondence in finger patterns. These patterns would be learned as unanalyzed arbitrary symbols. Nonetheless, these results do suggest (as these authors point out in recent studies) that children do not spontaneously use the iconicity of finger patterns. Children may come to attend to the one-to-one correspondence available in iconic finger patterns under certain circumstances, such as children participating in early math activities (e.g., Nicoladis et al. 2018) or exposure to multiple finger patterns for the same quantity (e.g., Nicoladis et al. 2019). Therefore, it may be assumed that children assigned to the LCL-plus-finger instruction in the current study relied on the iconicity of finger patterns and likely engaged in one-to-one correspondence processes between the number of fingers and the quantities that were depicted.

Another potential explanation of the current findings is that finger patterns improve children's ability to label sets without counting. As noted above, to establish a connection between counting and cardinality, children need to experience overlap between the cardinal label of a set and the last word that is verbalized when counting that set (see Mix et al 2012). However, this overlap is only possible for small sets that can be labeled without counting (i.e., within the subitizing range). For instance, 3-year-olds are usually able to identify sets up to 3 without counting. In this sense, finger patterns could extend the subitizing range, referred to as conceptual subitizing (see Clements & Sarama 2014). Indeed, children in the finger pattern instruction improved significantly the proportion of finger patterns that were recognized after the training (80% of the children in the finger pattern condition were able to recognize finger patterns higher than 3). Thus, children probably had more opportunities to align and compare these finger patterns to the last count word in the counting sequence and the cardinal labels. This could help children to generalize the insights obtained from experiences with subitizable sets to larger sets.

This interpretation is consistent with findings from 3 recent instructional studies that suggest that children's ability to label sets without counting may accelerate their understanding of numeral cardinality (O'Rear & McNeil, 2019; Paliwal & Baroody, 2018, 2020). In these studies, a training program focused on counting and labeling was preceded by training focused on subitizing sets of objects. According to Paliwal & Baroody (2018), recognizing the cardinal value of a set makes it easy to connect it to the last count word. O'Rear & McNeil (2019) showed that increasing children's ability to label set sizes (dice patterns) without counting improved their understanding of cardinality after 3 weeks of training. Such gains in children's ability to recognize dice patterns without counting probably improved the range of subitizing to quantities that cannot be typically estimated without counting for a particular cardinality knowledge/giver level— that is conceptual subitizing. Thus, providing finger patterns probably had the same effect in our study, as children were presented with finger patterns above their typical subitizing range.

Nonetheless, O'Rear & McNeil (2019) did not find differences in cardinality understanding (as determined by a composite measure that was based on performance on both the Give-N task and a variant of How-May task), between children assigned to a program that included 3 weeks of training focused on subitizing (followed by a 3-weeks training focused on counting and labeling) and those assigned to a 6-week training program focused on counting and labeling. One possible explanation is that, in our study, children assigned to the LCL-plus-finger condition benefited from labeling and counting— that is matching the last count word to the labeled set size since the beginning of the training. In this vein, further research would be needed to investigate whether other than finger patterns (e.g., dots arranged canonically, like pips on a die) render similar results.

Although this is theoretically feasible, as dice patterns and finger patterns share iconic properties, our study suggests that finger patterns and dice patterns are not 2 sides of the same coin at early stages in development. For instance, children seemed more familiar with finger patterns and, crucially, they were able to recognize finger patterns above their giver level[6]. This suggests that finger patterns, and their corresponding cardinality labels, serve as conceptual subitizing early in development and that such knowledge may support the acquisition of cardinality spontaneously before children enter preschool education. These findings also lend credence to the hypothesis that the role of fingers in understanding the concept of number goes beyond that of a mere external aid and that children (and parents or caregivers) get familiar with finger patterns as a way to communicate the size of a set early in development (Gunderson et al., 2015).

Although our findings are consistent with the idea that the richness of number inputs affects the understanding of numeral cardinality, we also found some discrepancies with previous studies. For instance, our study showed that children assigned to the LCL condition did not experience gains in their giver level (the result only approached the standard levels of significance), whilst other studies that have used a similar program have reported positive findings (e.g., Mix et al. 2012; O'Rear & McNeil 2019; Paliwal & Baroody 2018). One possible explanation is that our study was conducted at the beginning of the first year of preschool education and the 3-week program focused on sets between 1 and 5. The positive effects of LCL instruction may emerge over a longer period. Furthermore, in previous studies, children were trained on a one-to-one basis with an experimenter in a separate room, whilst in our study, the program was implemented in a real-life learning setting (group-based activities that were embedded in the regular daily schedule and administered by regular teachers).

8.2. Ecological validity

Our study shows that instructional approaches for improving basic number properties can be easily and successfully implemented into real-life learning settings. This is important since there is a bulk of empirical findings on how children process basic number concepts and other early numeracy skills that have not been translated into real-life implementations. Other studies that have tested specific instructional protocols in the classroom have neglected the characteristics and requirements of real-life learning settings. In other words, any intervention/training/instructional method needs to be practicable (i.e., teachers have to be able to administer the program themselves and the program has to be embedded in the typical routines and activities). For instance, studies that have provided evidence of effective instructional methods for supporting children's understanding of cardinality are based on one-to-one administration or extended training periods that do not reflect the typical learning context in preschool education—characterized by limited curriculum time and very brief opportunities for one-to-one engagement. Thus, studies with young children that embed interventions/training/protocols as part of group-based activities and where teachers carry out such programs may provide more robust translational evidence as well as contribute to improving teachers' dispositions and commitment to research efforts.

8.3. Limitations of the current study

First, although the LCL group served as a control group (based on findings from previous studies), we did not include a proper control group. We assumed that, at best, children in a control group would perform at the level of children in the LCL group (even though there is evidence that children assigned to LCL instruction perform better than those in a control group; e.g., Mix et al. 2012; Paliwal & Baroody 2018). Second, even though the teachers were encouraged to avoid providing numerical input out of the defined training period, we only had subjective reports on whether they achieved this aim. Our requirement could indeed clash with the typical behavior that is expected from preschool teachers as numerical input is usually provided throughout the day and independently of whether class routines involve math and numbers. In this vein, it might be argued that our requirement of avoiding numerical input may limit the ecological validity of the study. Nonetheless, this was necessary to interpret more clearly the training effects. And third, we also acknowledge that only 2 classes participated in the study. Although this is a valid proof-of-concept study and our findings provide robust evidence of the effectiveness of providing finger patterns to support children's understanding of the meaning of number words, additional RCT studies would be needed (expanding the number of teachers/classes).

9. Conclusions

The results of the current study show that a program that combines finger patterns with labeling and counting can effectively support and accelerate children's learning of numeral cardinality, or at least increases the number-giver level (as measured with the Give-N task). Although some studies have focused on other non–representational roles of fingers (e.g., pointing while counting), our findings support educational practices encouraging the representational role of finger patterns as a potential bridge between number words and the amounts they represent. It is worth mentioning that the present study does not intend to demonstrate that without finger patterns children cannot develop an understanding of numeral cardinality. We do not affirm that fingers are a necessary tool for such milestone but rather that finger patterns can be useful to scaffold and support that knowledge (Crollen et al., 2011; Di Luca & Pesenti, 2011; Lafay et al., 2013).

Credit author statement

All authors contributed equally to the conception and design of the study, organized the database, performed the statistical analysis, and wrote the manuscript. Josetxu Orrantia was responsible for funding acquisition.

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[6] Six In an ad-hoc analysis, we focused on 1-2-givers and their ability to recognize patterns above their corresponding giver level to investigate whether finger patterns preceded the understanding of cardinal value of number words at the beginning of the study. To that end, the largest recognized dot and finger patterns were dichotomized (larger and smaller than a child's cardinality level). Concurrent performances (i.e., 2-givers recognizing a 2-dot/fingers pattern) were not taken into account, as they were not informative regarding whether the label of the pattern was subitized or the pattern was retrieved from memory via conceptual subitizing. A pair of binomial tests revealed that children were not able to recognize dot patterns larger than their giver level ($n = 16$; 50% vs 50%, $P > 0.05$, 1-tailed). In contrast, the analysis provided support to the hypothesis that children's familiarity with finger patterns precedes their giver level ($n = 16$; 25% vs 75%, $P < 0.05$ 1-tailed).

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