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Symbolic representations and cardinal knowledge in 3- and 4-year-old children

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ABSTRACT

This study analyzes the impact of iconic representations of quantity (objects and images) and arbitrary representations (spoken number words) on the performance of 3-, 3.5- and 4-year-old children when building collections of 1–6 items. We used an adaptation of the Give-N task in which children had to use the information about quantity transmitted by collections of bottle caps, round dots on cards and number words. The results show that iconic representations helped children produce sets which cardinal values were larger than their known number words. This pattern of results was found in a transitional stage to learning that a given number word picks out an exact cardinal value, for set sizes 3 and 4 among children in all three age groups. These findings suggest that children would be in different (but proximal) levels of cardinal competency according to the symbolic modality employed to present the quantitative information.

1. Introduction

Children's understanding of cardinality and the mechanisms underlying the acquisition of this knowledge are at the centre of current debates in developmental literature. A large body of research has examined how young children begin to understand the cardinal meanings of the first number words, an acquisition that occurs slowly and in order. There is approximately an 18 month lapse, between 2 and 4 years of age, from the moment in which children are able to produce and label collections of 1 item until the time they can do so with collections of 4 or more items, when children typically learn that the last number word reached when counting a set represents the size of the whole set (cardinal principle) (Condry & Spelke, 2008; Gelman & Gallistel, 1978; Huang, Spelke, & Snedeker, 2010; Sarnecka & Carey, 2008; Sarnecka & Lee, 2009; Wagner & Johnson, 2011; Wynn, 1990, 1992).

At these ages, the development of cardinal knowledge has been investigated by using a variety of experimental tasks such as asking children to state the number of items that are displayed on a card, or picking up a given number of elements from a larger set. From the knower-levels account (Baillargeon & Carey, 2012; Sarnecka, 2015; Wynn, 1992) the expressions "one-knowers", "two-knowers", and "three-knowers" are used to refer to children who succeed in these tasks with the quantities of 1, 2 and 3, respectively. Similarly, the expression "pre-number knowers" is used to refer to children who do not coherently relate number words with cardinal values. Thus, early cardinal knowledge seems to be associated with the ability to use and understand the unique and exact cardinal meaning of the first number words.

However, spoken number words (referred to simply as "number words" in subsequent mentions) are only one way to represent quantity. From early on in life, children interact in their sociocultural environments with other symbolic representations of quantity

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(i.e. objects, images, number gestures, written number words or numerical notations such as Arabic numerals used to indicate quantity in a set) that pose a gradient of cognitive and symbolic challenges for young children. The present study compares the effects of three symbolic representations of quantity, namely, objects, images and number words, on 3-, 3.5- and 4-year-old children's ability to construct collections of different cardinal values. Until now, developmental research has not paid enough attention to symbolic components of number and the role that they play in the first steps of its acquisition (Martí & Scheuer, 2015; Sfard & Lavie, 2005; Sfard, 2000; Walkerdine, 1988).

1.1. Symbolic representations of quantity

Symbolic representations of quantity differ from each other on various levels. Number words and gestures (finger patterns to represent a set size) are ephemeral representations in the sense that they unfold over time and therefore do not have a materiality. In contrast, numerical notations, images (drawings or graphic marks on a card) and collections of objects are permanent representations; they are displayed in space and have a concrete reality which facilitates their handling and preservation (Martí, 2003; Tolchinsky, 2003). Given the role of executive functions in number knowledge (Cragg & Gilmore, 2014; Cragg, Keeble, Richardson, Roome, & Gilmore, 2017), differences in working memory demands may be related to the ephemeral or permanent nature of representations. For example, when children have to produce sets of elements corresponding to the number words provided by an adult, they need to hold the requested quantity in memory and compare it to the number of items produced because the number words vanish as soon as they are spoken.

Another aspect in which symbolic representations of quantity vary is how they represent their numerical referents (Martí, 2003; Tolchinsky, 2003; Wiese, 2003). Iconic representations, number gestures, drawings or objects, are item-based representations because there is a one-to-one correspondence between their elements and the elements of the represented collection. Instead, number words and Arabic numerals establish an arbitrary relation to what they represent: their forms do not map transparently to the number of items in a set.

In addition, symbolic objects and images have a "dual reality" (Gibson, 1979; Ittelson, 1996) in the sense that they have both a physical and representative nature. DeLoache (1995, 2002) has shown that, to symbolically use an object or a picture, one must mentally represent both facets of their dual reality; that is, one must represent the concrete entity itself and simultaneously its relation to its referent (dual representation). Numerous studies have demonstrated that young children comprehend and use the symbolic function of pictures before objects (DeLoache, 1987, 1991; Marzolf & DeLoache, 1994). Although images are physical objects, their conventional function is to be a symbolic representation (as opposed to the three-dimensional objects that may have other instrumental functions), so they present less of a challenge with respect to dual representation. An object (or a set of objects in the case of representing the number of objects in another collection) has salient characteristics that may draw children's attention to its physical and instrumental characteristics, hindering the possibilities of interpreting its representational status (McNeil, Uttal, Jarvin, & Sternberg, 2009; Uttal et al., 2013).

Objects and images also allow for the realization of different activities. For instance, a collection of objects can be manipulated: children can separate the items, form smaller collections, and bring them back together to again form a global collection. Images do not have this flexibility, the drawings or marks depicted in a picture cannot be manipulated individually; they have to be observed as a whole. In the current study, we wondered if the differential properties between two- and three-dimensional representations that introduce a clear impact on the symbolic domain may be relevant to emerging cardinal knowledge.

1.2. Iconic and arbitrary representations in cardinal knowledge

A few studies have investigated how different symbolic representations of quantity affect the onset of cardinal knowledge. Bialystok and Cood (1996) asked children of 3, 4 and 5 years of age to produce (by writing or drawing on a blank card) or to select (from a set of printed cards) a representation and then use it to recall the number of items contained in a closed box; the cards depicted Arabic numerals or arrays of dots. In general, results showed that Arabic numerals responses increased with age in both tasks, and that they were more reliable than dots as an indication of quantities less than 10 for children in all age groups.

In a more recent study, Nicoladis, Pika and Marentette (2010) tested 2- to 5-year-old children in the Give-a-Number ("Give-N") and the How Many tasks (Wynn, 1990, 1992) using number words and gestures. For the Give-N task, the experimenter gave 16 toys to the children and asked them to put in a box the quantity of toys corresponding to either the number word she said or the number gesture she made (from 1 to 10). For the How Many task, the experimenter presented the children with a collection of toys and asked them to either say orally how many toys there were or to show the correct number of fingers to represent the quantity of toys. The results indicated that children were more accurate with number words than with number gestures on both tasks, particularly the older children (4- to 5-year-olds) with set sizes 6, 7, 8 and 9.

Taken together, the aforementioned studies suggest a facilitative effect of arbitrary representations (Arabic numerals and number words) in comparison to the iconic ones (arrays of dots and number gestures) for some cardinal values. Recent work shows that 3- and 4-year-olds may first map Arabic numerals to number words (two arbitrary representations of number) and only through this mapping are numerals subsequently tied to the quantities they represent (Hurst, Anderson, & Cordes, 2017).

With regard to iconic representations, only two studies that we are aware of have experimentally investigated how objects and images affect children's understanding of quantity. Petersen et al. (2014) compared the effects of counting practice with picture books versus physical objects on 3.5-year-old children's counting skill and understanding of cardinality. Children who practiced counting with images improved their performance on the Give-N task (numbers 1–6), but children who practiced counting with three-dimensional versions of the depicted objects did not. These authors argued that objects may have caused children to focus their attention on their physical properties at the expense of noticing cardinality as an important attribute of the sets.

In a former exploratory study (Salsa and Martí, 2015), we assessed 4-year-olds' performance when building collections of given cardinal values (2–6) using objects (thin cardboard tokens), images (dots) and number words. We designed an adaptation of the Give-N task in which children had to build collections of cookies using the information about quantity transmitted by the tokens, dots and number words. Similar to Petersen et al.'s (2014) study, children's performance was higher with dots in comparison to tokens and number words. Images had a facilitative effect when children constructed sets of 3 and 4 items, but not in small (1 and 2) and large (5 and 6) sets.

1.3. The present study

This study involves further tests of the relationship between symbolic representations and cardinal knowledge by analyzing the impact of objects, images and number words on 3-, 3.5- and 4-year-old children's performance when building collections of 1–6 items. As in our previous study (Salsa and Martí, 2015), we used the Give-N task but replacing the tokens for bottle caps in order to increase the concrete affordances of the three-dimensional representation. Thus, this study is partly motivated by the longstanding picture-superiority effect that has been reported in several studies focused on symbolic development (DeLoache, 1987, 1991) and recently tested in the number domain (Salsa and Martí, 2015; Petersen et al., 2014).

We expected children to be more accurate when using iconic representations than number words for those set sizes that are in a transitional stage. We expected this for at least two reasons. First, we reasoned that images and objects, being permanent and item-based representations, may help children map between their items and the items of the requested set by promoting one-to-one correspondences. Second, children are able to match small sets of objects to other small sets of objects based on set size around age 2, earlier than they can correctly produce number words for those sets of objects (Huttenlocher, Jordan, & Levine, 1994; Mix, 2008). In consequence, the addition of two groups of younger children (3 and 3.5 years of age) allows us to analyze the impact of symbolic modality on emerging cardinal knowledge, specifically on the cardinal values being learned between 3 and 4 years of age.

2. Method

2.1. Participants

Fifty-four children participated in the present study, 18 in each of three age groups (age range: +/- 1 month): 3-year-olds (M_{age} = 35.49 months), 3.5-year-olds (M_{age} = 41.76 months) and 4-year-olds (M_{age} = 47.49 months). Each age group included nine girls and nine boys. Children were predominantly middle class and were recruited from day-care centers in a large city (name of the city to be completed after review process). The majority of their parents (around 80%) had pursued university-level studies and worked in professional or commercial positions. Informed written consent was obtained from all parents.

2.2. Materials

We used six black bottle caps (1.2 cm height, 3.8 cm diameter) and six white cards (9 × 15 cm) with black dots (2 cm diameter) drawn on them that ranged in number from 1 to 6 and had an random, non-linear arrangement. The target collection consisted of 16 real cookies (6 cm diameter). A puppet (Winnie the Pooh) and a plate (25 cm diameter) were also used.

2.3. Procedure

Children were individually tested in a separate room at their day-care center. Each session lasted around 15 min and began with a few minutes of free play. Once the child was comfortable with the experimenter, he or she was invited to play with the puppet and cookies. The materials were presented on a table, with the experimenter seated orthogonally to the right of the participants. Prior to the administration of the Give-N task, an orientation phase was carried out.

2.3.1. Orientation phase

The objective of this phase was to focus the child's attention on the numerical domain and explain the purpose of the task: to place a certain quantity of cookies on a plate. First, the experimenter asked the child if he or she knew how to count and explained that Winnie the Pooh had not yet learned the numbers. Then, she placed 10 cookies on the table and asked the child to count them aloud to teach the puppet those numbers. If the child did not start counting, the experimenter prompted the child by beginning the count sequence ("One, two…") while pointing out each cookie.

After counting, the experimenter placed the empty plate and 16 cookies on the table and said "You're going to help Winnie the Pooh to put cookies on the plate. Remember, he does not know how to count yet. If Winnie wants you to put one cookie for you and one for me, how many cookies do you have to put on the plate?" If the child did not respond or responded incorrectly, the experimenter said "If Winnie wants to put one cookie for you and another for me, he puts like this (while placing two cookies on the plate). This one is for you and this one is for me" (while pointing out each cookie).

2.3.2. Give-N

Each child solved the task using the three symbolic modalities, dots, caps and number words; the order of their presentation was counterbalanced so that half of the children of each age group began the task with caps and the other half with dots. The number word modality was always presented third in order to control the impact of number words on children's performance with the iconic representations. Three orders of presentation of the quantities were used, one for each modality, none of these orders in ascending or descending progression. Therefore, the task consisted in three blocks of six trials, one for each symbolic modality (a total of 18 trials). In each block the child had to evaluate the cardinal values (1–6) represented by the given symbolic modality and build (by picking up cookies from a larger set) successive collections of an equivalent quantity of cookies.

The experimenter explained "You have to put on the plate the number of cookies that Winnie asks for. Winnie will show you the number of cookies you have to put on the plate using these bottle caps (or these drawings). You have to use the caps (or drawings) to know how many cookies you need to place on the plate". After each trial, the cookies on the plate were removed and placed back in the set so that it always contained 16 items throughout the task. When changing the symbolic modality, the experimenter said, "Now Winnie will show you the number of cookies you have to place on the plate using these drawings (caps or saying a number)". With number words the experimenter explained: "Winnie will say a number (the experimenter approaches the puppet as if he whispered something in her ear). If Winnie says 'four', how many cookies are going to place on the plate?" The child's errors were not corrected.

2.4. Coding and analysis

The experimental sessions were videotaped and then transcribed textually for coding and analysis. In each trial, the child's response was recorded, whether it was correct -he or she placed the correct quantity of cookies on the plate- or incorrect. Children could obtain a score of 0–6 correct responses in each symbolic modality. Incorrect responses were classified into either "proximal error" (one cookie more or fewer) or "distant error" (two or more cookies more or fewer). If the child spontaneously used an identifiable strategy to solve the task (e.g., counting) that was also recorded.

For statistical analysis, we applied nonparametric tests since the Kolmogorov-Smirnov (K-S) test revealed that the data were not normally distributed ($z = .013$, $p = .021$). Preliminary analyses (Mann-Whitney U test) showed no effects of gender (dots: $U = 322.50, p = .445$; caps: $U = 274.50, p = .106$; number words: $U = 335.50, p = .584$) or order of presentation of caps and dots (dots: $U = 265$, $p = .077$; caps: $U = 328$, $p = .512$; number words: $U = 292$, $p = .171$), so these variables will not be discussed further. The SPSS statistical software package, version 20, was used for the analyses.

3. Results

There were two main questions addressed in the analyses. First, we assessed the effects of symbolic modality within each age group (3, 3.5 and 4 years) and then across age groups. Second, we examined the effects of symbolic modality according to the size of the sets, within and across age groups. These analyses were made on the number of correct responses; percentages are used in the text to facilitate the interpretation of the comparisons between symbolic modalities.

3.1. Symbolic modality in the Give-N task

Fig. 1 shows the number of correct responses with caps, dots and number words of each age group. The statistical analysis of comparison of frequencies (Friedman test) confirmed the effect of modality in all three age groups, 3 years ($\chi^2(2) = 9.47, p = .009$), 3.5 years ($\chi^2(2) = 20.19, p < .001$), and 4 years ($\chi^2(2) = 12.40, p = .002$). Pairwise comparisons (Wilcoxon signed rank test) showed that 3-year-olds' correct responses with dots (50%) were significantly higher than their correct responses with number words (35%) ($Z = -2.85, p = .004$), with a large effect size (Cliff's Delta = .53). There was no difference between dots and caps (44%) ($Z = -1.32, p = .186$) nor between caps and number words ($Z = -1.64, p = .101$).

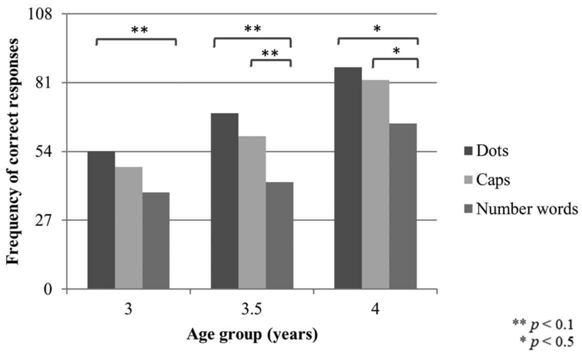

Fig. 1. Frequencies of correct responses on the Give-N task using dots, caps and number words (by age group).
Note. Maximum score: 108 correct responses per symbolic modality in each age group (18 children for group and 6 trials for each child corresponding to the different cardinal values).

In the case of the 3.5-year-olds' group, both iconic representations of quantity, dots (64%) and caps (56%), had a large and significant effect in comparison to number words (39%) ($Z = -3.33, p = .001$ and $Z = -3.03, p = .002$, respectively; Cliff's Delta = .79 and .68), and no significant differences were found between dots and caps ($Z = -1.88, p = .059$).

Lastly, at 4 years of age, symbolic modality comparisons indicated once again a higher performance with dots (81%) and caps (76%) in comparison to number words (60%) ($Z = -2.59, p = .010$ and $Z = -2.42, p = .015$; Cliff's Delta = .60 and .53), and no differences were found when comparing performances with both iconic representations ($Z = -1.23, p = .218$).

With regard to age-related changes, we compared the number of correct responses with each symbolic modality across age groups using a Kruskal-Wallis test. A significant effect of age was revealed for all symbolic modalities, dots ($\chi^2(2) = 21.08, p < .001$), bottle caps ($\chi^2(2) = 22.80, p < .001$), and number words ($\chi^2(2) = 21.69, p < .001$). Pairwise comparisons carried out with the Mann-Whitney U test showed that performance with dots increased with age: 3.5-year-olds (64%) were more successful than 3-year-olds (50%) ($U = 86, p = .012$), while 4-year-olds' performance (81%) was higher than the other two younger groups (3-year-olds: $U = 32, p < .001$; 3.5-year-olds: $U = 77, p = .005$). The effect size for these comparisons was large, between .46 and .80 (Cliff's Delta).

The same pattern of results was found with caps and number words. However, it was only found to be so for 4-year-old children. This age group was more accurate in giving a quantity conveyed by either caps (76%) or number words (60%) than 3.5- (56% and 39%) ($U = 48$ and $U = 54.50$, both $ps < .001$) and 3-year-olds (44% and 35%) ($U = 34$ and $U = 40$, both $ps < .001$) (effects size for these comparisons were between .66 and .79). However, there were no significant differences between 3.5- and 3-year-olds with caps ($U = 113, p = .102$) and numbers words ($U = 138, p = .348$).

Finally, we conducted an analysis of children's errors. We calculated the proportions of proximal errors (+/- 1) and of distant errors (> 1) over the total of errors in each symbolic modality, within age groups. Our main purpose was to examine whether different representations of quantity resulted in an approximate, though not exact, response to the requested quantity. Statistically significant differences were found between the proportions of proximal errors with dots and number words in all age groups, 3 years (48% versus 23%, $Z_{calculated} = 3.04, p < .05$), 3.5 years (62% versus 21%, $Z_{calculated} = 4.28, p < .05$) and 4 years (71% versus 33%, $Z_{calculated} = 3.56, p < .05$). There also were significant differences between the proportion of proximal errors with caps and number words at 3.5 (56% versus 21%, $Z_{calculated} = 3.93, p < .05$) and 4 years (73% versus 33%, $Z_{calculated} = 3.31, p < .05$), but not at 3 years of age (48% versus 23%, $Z_{calculated} = 1.52, p > .05$). More importantly, no differences were found between proximal errors with dots and caps in any age group (3-year-olds: $Z_{calculated} = 1.45, p > .05$; 3.5-year-olds: $Z_{calculated} = 0.53, p > .05$; 4-year-olds: $Z_{calculated} = 0.12, p > .05$).

In summary, these results show that preschool children, between 3 and 4 years of age, tended to be more successful at the Give-N task with iconic representations than with number words; even when their responses were incorrect, they tended to be more approximate to the requested cardinal value with dots and caps. With respect to iconic representations, 3-year-olds were generally more accurate when mapping dots onto a number of items in a set.

3.2. Set size and symbolic modality

In this section we analyze the number of correct responses by set size (1–6) and symbolic modality (Table 1). First we proceeded

Table 1
Number of correct responses for each set size and statistic results across symbolic modalities (by age group).

Age groups	Set size	Dots	Bottle caps	Words	Cochran test (Q)	p =
3- year- olds	1	18	17	17	1.00	.607
	2	15	13	16	2.33	.311
	3	12	8	4	8.16	.017
	4	5	6	1	6.25	.044
	5	2	3	0	2.80	.247
	6	2	1	0	2.00	.368
3.5-year- olds	1	18	18	18	–	–
	2	18	17	15	4.66	.097
	3	17	14	3	21.73	.001
	4	10	8	4	6.50	.039
	5	4	2	2	1.14	.565
	6	2	1	0	2.00	.368
4- year- olds	1	18	18	18	–	–
	2	18	18	17	2.00	.368
	3	18	15	15	3.60	.165
	4	16	16	8	12.80	.002
	5	7	10	3	5.69	.058
	6	10	5	4	5.11	.076

Note. Maximum score: 18 correct responses per set size and symbolic modality. Cochran test for set size 1 was not performed for the 3.5- and 4-year-olds' groups because all the variables were not dichotomous with the same values.

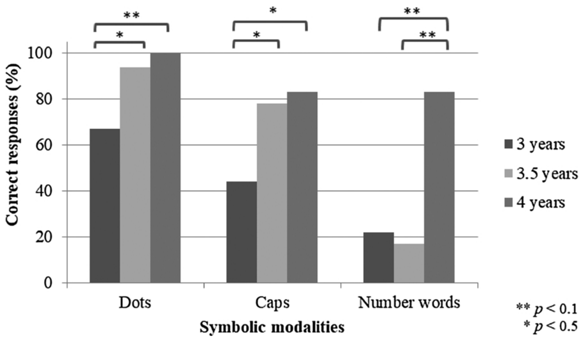

Fig. 2. Set size 3: Percentage of correct responses in each symbolic modality by age group.

generally, comparing the three modalities with the Cochran test (Q) within age groups, and in the cases that it indicated significant effects we conducted pairwise comparisons using the McNemar test.

In the 3-year-olds' group, results from the Cochran test were significant for quantities 3 and 4. However, the McNemar test only indicated an advantage for quantity 3 for dots (67% of correct responses) over number words (22%) ($p = .021$; Cliff's Delta = 0.44), without differences between caps (44%) and number words ($p = .180$) or between the iconic representations ($p = .375$). In fact, as seen in Table 1, the correct responses for quantity 4 were very low in the three symbolic modalities.

At 3.5 years of age, symbolic modality again had significant effects on performance when children built sets of 3 and 4 items. Pairwise comparisons showed that dots (94% of correct responses) and caps (78%) facilitated the construction of sets of 3 items in comparison to number words (17%) (both $ps < .001$, Cliff's Delta = .77 and .61, respectively), without differences between dots and caps ($p = .375$). In regard to sets of 4 items, there was an advantage of dots (56%) over number words (22%) ($p = .016$), with a medium size effect (Cliff's Delta = .33). No statistically significant differences were registered between caps (44%) and dots ($p = .727$) and between correct responses with caps and number words ($p = .180$).

At age 4, symbolic modality had an impact on performance only with quantity 4. According to subsequent pairwise contrasts, performance with dots (89%) and caps (89%) were significantly higher than performance with number words (44%) ($p = .021$ and $p = .008$, respectively, Cliff's Delta = .44), recording no differences between dots and caps ($p = 1.00$).

Finally, in order to take a closer look at children's performance with set sizes 3 and 4, we carried out an analysis of age differences within each symbolic modality. For quantity 3 (Fig. 2), the Kruskal-Wallis test showed an effect of age in the three modalities, dots ($\chi^2(2) = 9.98$, $p = .007$), caps ($\chi^2(2) = 7.24$, $p = .027$), and number words ($\chi^2(2) = 20.02$, $p < .001$). This pattern of results was only found between 3- and 4-year-olds [dots ($U = 108$, $p = .008$), caps ($U = 99$, $p = .017$), and number words ($U = 63$, $p < .001$)]. Age-related changes between 3- and 3.5-year-olds were observed with dots ($U = 117$, $p = .038$) and caps ($U = 108$, $p = .043$) but not with number words ($U = 153$, $p = .678$), and between 3.5- and 4-year-olds only with number words ($U = 54$, $p < .001$), not with dots ($U = 153$, $p = .317$) and caps ($U = 153$, $p = .678$). Then, the older children were more accurate than the younger children with all symbolic representations; the use of iconic representations, compared with number words, facilitated the mastery of quantity 3 between 3 and 3.5 years of age.

For quantity 4 (Fig. 3), the Kruskal-Wallis test also showed significant effects of age in dots ($\chi^2(2) = 13.52$, $p = .001$), caps ($\chi^2(2) = 12.36$, $p = .002$), and number words ($\chi^2(2) = 7.35$, $p = .025$), a pattern which appeared in the pairwise comparisons between 3- and 4-year-olds [dots ($U = 63$, $p < .001$), caps ($U = 72$, $p = .001$), and number words ($U = 99$, $p = .008$)]. Unlike the quantity 3, with 4 there were no differences between the two younger groups, 3- and 3.5-year-olds [dots ($U = 117$, $p = .096$), caps ($U = 144$, $p = .500$), and number words ($U = 135$, $p = .154$)]. The use of iconic representations, and not number words, significantly improved performance between 3.5- and 4-year-olds: dots ($U = 108$, $p < .028$), caps ($U = 90$, $p < .005$) and number words ($U = 126$, $p < .163$).

In sum, iconic representations clearly improve performance in the Give-N task with the quantities that are in the process of

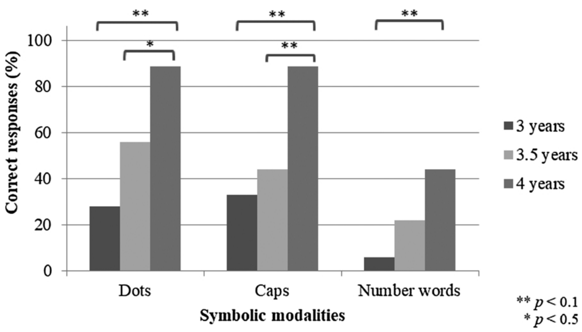

Fig. 3. Set size 4: Percentage of correct responses in each symbolic modality by age group.

acquisition in specific points of cardinal knowledge, quantity 3 between 3 and 3.5 years and quantity 4 between 3.5 and 4 years of age. Images, in comparison to objects, seemed to be a more effective medium to convey information for learners in transition with respect to a cardinal concept (set size 3 for 3-year-olds and set size 4 for 3.5-year-olds).

4. Discussion

Most of the research concerning the development of cardinal knowledge has focused on verbal representations of quantity, analyzing when and how children understand number words and are able to, for example, construct a collection of N elements according to the number word given by an experimenter (Condry & Spelke, 2008; Huang et al., 2010; Sarnecka, 2015; Wynn, 1990, 1992). In the present study we tested whether distinct symbolic representations of quantity (not only words but also images and objects) have an impact on preschool children's emerging cardinal knowledge. In fact, symbolic components of number have not received enough attention in studies exploring the development of number (Martí & Scheuer, 2015; Sfard & Lavie, 2005; Sfard, 2000; Walkerdine, 1988) but, as we stated in the introduction, children engage in everyday interactions in which the cardinal value of sets are communicated through a great diversity of symbolic modalities.

Our findings highlight two striking patterns. First, children across age groups were more accurate when using images and objects than number words in the Give-N task. As a general rule, this was true for both correct and incorrect responses: not only did children give more correct responses when using iconic representations but their answers were also closer to the requested cardinal value when they made mistakes (proximal errors). These results raise the possibility that preschool children's ability to use images and objects as representations of quantity may precede their ability to use number words in a cardinal manner.

This first pattern of results–an advantage of iconic representations over arbitrary ones–appears to contradict a previous study by Nicoladis et al. (2010), which used similar methods and found that number words seem to be easier to understand and use than number gestures. However, this contradiction can be explained by important differences in the nature of the iconic representations employed in both studies. Images, objects and number gestures are item-based representations, in the sense that each symbolic item maps onto one item in a set. Nevertheless, images and objects are displayed in space and have a permanence which facilitates their handling and use. In the current study, this physical permanence could have prompted children to have solved the Give-N task through one-to-one correspondences between the items of the representation and the items of the collection requested to build. The findings that children have made more proximal errors with iconic representations, in comparison to number words, could also suggest that they may be using one-to-one correspondences as a strategy to solve the task.

One-to-one correspondence is at the core of number concepts and provides a way to determine equivalence–whether this correspondence is established directly between individual items by pairing or indirectly by enumerating one set and then the other (Fuson, 1988; Mix, Moore, & Holcomb, 2011; Piaget, 1941). With this perspective, the inclusion of images and objects in the Give-N task creates a context that encourages comparisons between sets and promotes the construction of numerically equivalent collections by correspondences that can be easily inspected, repeated, and modified. This inclusion could also impact on working memory demands. Even with small quantities, the Give-N task requires children to hold the requested number in working memory and compare this cardinal number to the number of items produced. Images and objects, by activating one-to-one correspondences, probably reduce this memory demand. Thus, it is possible that the mapping of these types of representations of quantity onto other sets of objects through one-to-one correspondences opens the door to the successful use of arbitrary representations.

The mentioned affordances of images and objects have promoted the use of counting as another strategy to solve the task. Although children rarely spontaneously counted aloud or visibly to produce their responses (10% of the trials for the three age groups), from the total amount of times they used counting, 87% of them were when constructing the collections with iconic representations. Moreover, this strategy led children to produce correct responses. Hence, an interesting direction for future work would be to add a verbal counting component to the task. For example, children could be explicitly encouraged to count the dots or the caps as the experimenter places them on the table, or count the items in the iconic representations first, followed by the requested set, and check for equivalence by matching them. An experimental manipulation that might elicit the link between item-based representations and number words is likely to help children discover the cardinal value of sets with greater gains than in the present study.

Our second pattern of results shows that the greater accuracy with iconic representations, compared to number words, was more apparent with set sizes 3 and 4 in the three age groups. Specifically, 3- and 3.5-year-olds had no difficulties in solving the task with set sizes 1 and 2, in all explored symbolic modalities; they presented a lot of difficulties when working with set sizes 5 and 6, in all modalities as well. When these children had to construct collections of 3 items, they had a low performance with number words, which was significantly improved by the use of dots at 3 years of age, and by dots and caps at 3.5 years. When they had to construct collections of 4 items, both 3- and 3.5-year-olds performed poorly with number words, and only 3.5-year-olds had a significant improvement when using dots.

At 4 years of age, children appeared to be more advanced in the process of elaboration of cardinal knowledge. They had a high performance with set sizes 1, 2 and 3 in all modalities, while experiencing an improvement when they had to construct collections of 4 items with both iconic representations. Even though the differences did not reach statistical significance for set sizes 5 and 6 (see Table 1), probably due to the relatively small sample, children tended to benefit more from iconic representations than number words and therefore managed to achieve a higher performance. For set size 5, 4-year-olds performed better with caps than with dots; for set size 6, they performed better with dots than with caps. This striking pattern of results needs further examination in future research. An interesting way to explore this data would be through an intra-individual analysis comparing the responses per child by symbolic modality in every cardinal value.

This second pattern of results suggests two interesting facts. On one hand, images and objects broaden the range of quantities preschool children master in comparison to number words, the symbolic modality traditionally used in the Give-N task. Before children learn the cardinal meanings of the number words "three" and "four", they would be able to access non-verbal representations of those set sizes and correctly construct collections of those cardinal values based on images and objects. Thus, iconic representations help children produce sets which cardinal values are larger than their known number words. These findings would seem to relativize the idea of cardinal knowledge levels (Baillargeon & Carey, 2012; Sarnecka, 2015; Wynn, 1992), according to which children at a particular knower-level have little to no knowledge of the cardinal meanings of numbers above their highest known number. Our data showed that a child would be in different (but proximal) levels of cardinal competency according to the symbolic modality employed to present the quantitative information. Other studies have reported similar results. Barner and Bachrach (2010) found that children classified as "two-knowers" tended to say "three" when they were shown 3 objects more often than when shown 4 objects, suggesting that children at a given knower-level seem to have some knowledge of the next number word above their knower-level.

On the other hand, the distinction between two- and three-dimensional representations seems to play a role in performance as a function of the set size. In effect, when 3-year-old children were requested to construct sets of 3 items, only dots facilitated performance in comparison to number words. The same pattern of results occurred when we considered the effects of symbolic modality on performance with set size 4 at 3.5 years of age. Therefore, images appear to have a boosting effect on the early stages of cardinal knowledge, when children are just beginning to elaborate a specific cardinal value, before three-dimensional objects start having the same effect.

DeLoache (1987, 1991) has shown that images have a facilitative impact on young children's performance in symbolic tasks, in comparison to three-dimensional objects. Also, in a recent study (Salsa and Martí, 2015), we have found that the use of pictures facilitated 4-year-olds' performance in a cardinal task. The concept of dual representation can shed light on these results: being nonsalient and uninteresting as objects, images have a high representational status (they are easily comprehended as representations of something else). Furthermore, Gelman, Chesnick, and Waxman, (2005) have argued that the more interesting an object is in its own right, the lower representational status it has and is therefore more likely to be understood as an individual (e.g., Garfield) rather than as a member of a larger category, or set (e.g., one of many cats). This is relevant because research on early understanding of number suggests that children exhibit a better understanding of cardinality when they can construe the items to be counted as a set (Mix, Huttenlocher, & Levine, 2002).

Nonetheless, in direct connection with the dual representation hypothesis, it is necessary to bear in mind that our version of the Give-N task does not request at any time for the children handle the objects, and very few children tended spontaneously to manipulate the bottle caps one by one. Petersen et al. (2014) have recently found that picture books are better than physical objects at supporting children's understanding of cardinality, and they have argued that objects may be distracting because they enable cardinal-irrelevant behaviours such as handling and playing. Other studies have also shown that perceptually rich objects may hinder counting performance (Petersen & McNeil, 2012) and understanding of mathematical concepts (McNeil et al., 2009). In consequence, an important goal for future research will be to deepen the analysis of the effectiveness of images and objects as representations of quantity by varying the perceptual properties of the objects (e.g., size, color, height) or by giving children specific instructions to manipulate them. In this way it will be possible to evaluate whether the difference between two- and three-dimensionality would have a larger impact on preschool children's performance on the Give-N task.

Finally, our study is potentially limited by the employment of a single task (Give-N) when it is widely accepted that variations in task demands affect children's performance (Le Corre & Carey, 2007; Sarnecka & Carey, 2008). A crucial direction for future work will be to explore the influence of symbolic modality adapting other tasks, such as How Many, Point-to-X or What's on this Card, in order to examine whether the advantage of iconic representations over number words would have a high within-child consistency across numerical tasks even with small set sizes. In the same direction, these results would gain more strength if the traditional Give-N task was used first to determine children's knower-levels and then their performance with images and objects could be analyzed based on knower-level.

5. Conclusion

The comprehension of numerical cognition could be broadening if cognitive and developmental psychologists focused more attention on children's performance with different symbolic representations of quantity, instead of using verbal measures alone. The present work shows that children between 3 and 4 years of age initially map between iconic representations and the number of items in a set, taking advantage of the permanence and item-based nature of images and objects to master the first steps in cardinal knowledge. This impact is more apparent in a transitional stage to learning that a given number word picks out a specific, unique and exact cardinal value, for set sizes 3 and 4 among children in the current study.

These findings have potential practical implications. In both experimental designs as well as in learning contexts, when preschool children have to work with symbolic representations, it is necessary to take their specific affordances into account in order to know how they may help and hinder performance on the numerical domain beforehand.

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References

Baillargeon, R., & Carey, S. (2012). Core cognition and beyond: The acquisition of physical and numerical knowledge. In S. Pauen (Ed.). *Early childhood development and later outcome* (pp. 33–65). Cambridge, England: Cambridge University Press.
Barner, D., & Bachrach, A. (2010). Inference and exact numerical representation in early language development. *Cognitive Psychology, 60*, 40–62. https://doi.org/10.1016/j.cogpsych.2009.06.002.
Bialystok, E., & Cood, J. (1996). Developing representations of quantity. *Canadian Journal of Behavioural Science, 28*, 281–291. https://doi.org/10.1037/0008-400X.28.4.281.
Condry, K., & Spelke, E. (2008). The development of language and abstract concepts: The case of natural number. *Journal of Experimental Psychology, 137*, 22–38. https://doi.org/10.1037/0096-3445.137.1.22.
Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education, 3*, 63–68. https://doi.org/10.1016/j.tine.2013.12.001.
Cragg, L., Keeble, S., Richardson, S., Roome, H. E., & Gilmore, C. (2017). Direct and indirect influences of executive functions on mathematics achievement. *Cognition, 162*, 12–26. https://doi.org/10.1016/j.cognition.2017.01.014.
DeLoache, J. S. (1987). Rapid change in the symbolic functioning of very young children. *Science, 238*, 1556–1557. https://doi.org/10.1126/science.2446392.
DeLoache, J. S. (1991). Symbolic functioning in very young children: Understanding of pictures and models. *Child Development, 62*, 736–752. https://doi.org/10.2307/1131174.
DeLoache, J. S. (1995). Early understanding and use of symbols: The model model. *Current Directions in Psychological Science, 4*, 109–113. https://doi.org/10.1111/1467-8721.ep10772408.
DeLoache, J. S. (2002). Symbolic artefacts: Understanding and use. In U. Goswami (Ed.). *Blackwell handbook of childhood cognitive development* (pp. 206–226). London: Blackwell Publishing. https://doi.org/10.1002/9780470996652.ch10.
Fuson, K. C. (1988). *Children's counting and the concept of number.* New York, NY: Springer-Verlag Publishinghttps://doi.org/10.1007/978-1-4612-3754-9.
Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number.* Cambridge, MA: Harvard University Press.
Gelman, S. A., Chesnick, R., & Waxman, S. R. (2005). Mother-child conversations about pictures and objects: Referring to categories and individuals. *Child Development, 76*, 1129–1143. https://doi.org/10.1111/j.1467-8624.2005.00876.x-i1.
Gibson, J. (1979). *The ecological approach to visual perception.* Boston, MA: Houghton Mifflin.
Huang, Y., Spelke, E., & Snedeker, J. (2010). When is four far more than three? Children's generalization of newly-acquired number words. *Psychological Science, 21*, 600–606. https://doi.org/10.1177/0956797610363552.
Hurst, M., Anderson, U., & Cordes, S. (2017). Mapping among number words, numerals, and nonsymbolic quantities in pre-schoolers. *Journal of Cognition and Development, 18*, 41–62. https://doi.org/10.1080/15248372.2016.1228653.
Huttenlocher, J., Jordan, N. C., & Levine, S. C. (1994). Assessing early arithmetic abilities: Effects of verbal and nonverbal response types on the calculation performance of middle-and low-income children. *Learning and Individual Differences, 6*, 413–432. https://doi.org/10.1016/1041-6080(94)90003-5.
Ittelson, W. H. (1996). Visual perception of markings. *Psychonomic Bulletin & Review, 3*, 171–187.
Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition, 105*, 395–438. https://doi.org/10.1016/j.cognition.2006.10.005.
Martí, E. (2003). *Representing the world externally: Children's acquisition of external systems of representation.* Madrid: Machado.
Martí, E., & Scheuer, N. (2015). Semiotic systems, culture an early mathematical knowledge. *Studies in Psychology, 36*, 1–17. https://doi.org/10.1080/02109395.2014.1000008.
Marzolf, D. P., & DeLoache, J. S. (1994). Transfer in young children's understanding of spatial representations. *Child Development, 65*, 1–15. https://doi.org/10.2307/1131361.
McNeil, N., Uttal, D., Jarvin, L., & Stenberg, R. (2009). Should you show me the money? Concrete objects both hurt and help performance on mathematics problems. *Learning and Instruction, 19*, 171–184. https://doi.org/10.1016/j.learninstruc.2008.03.005.
Mix, K. S. (2008). Children's equivalence judgments: Crossmapping effects. *Cognitive Development, 23*, 191–203. https://doi.org/10.1016/j.cogdev.2007.03.001.
Mix, K. S., Huttenlocher, J., & Levine, S. C. (2002). *Quantitative development in infancy and early childhood.* New York, NY: Oxford University Presshttps://doi.org/10.1093/acprof:oso/9780195123005.001.0001.
Mix, K. S., Moore, J. A., & Holcomb, E. (2011). One-to-one play promotes numerical equivalence concepts. *Journal of Cognition and Development, 12*, 463–480. https://doi.org/10.1080/15248372.2011.554928.
Nicoladis, E., Pika, S., & Marentette, P. (2010). Are number gestures easier than number words for preschoolers? *Cognitive Development, 25*, 247–261. https://doi.org/10.1016/j.cogdev.2010.04.001.
Petersen, L. A., & McNeil, N. M. (2012). Effects of perceptually rich manipulatives on preschoolers' counting performance: Established knowledge counts. *Child Development, 84*, 1020–1033.
Petersen, L. A., McNeil, N. M., Hall, C. J., Carrazza, C., Devlin, B. L., Tollaksen, A. K., & Boehm, A. G. (2014). Counting practice with pictures, but not objects, improves children's understanding of cardinality. P. Bello, M. Guarini, M. McShane, & B. Scassellati (Eds.). *Proceedings of the Thirty-Sixth Annual Conference of the Cognitive Science Society*.
Piaget, J. (1941). *The child's conception of number.* London: Routledge and Kegan Paul, LTD.
Salsa, A., & Martí, E. (2015). Objects, pictures and words. Effects of representational format on four-year-olds' quantity knowledge. *Studies in Psychology, 36*, 71–91. https://doi.org/10.1080/02109395.2014.1000031.
Sarnecka, B. (2015). Learning to represent exact numbers. *Synthese,* 1–18. https://doi.org/10.1007/s11229-015-0854-6.
Sarnecka, B., & Carey, S. (2008). How counting represents number: What children must learn and when they learn it. *Cognition, 108*, 662–674. https://doi.org/10.1016/j.cognition.2008.05.007.
Sarnecka, B., & Lee, M. (2009). Levels of number knowledge during early childhood. *Journal of Experimental Child Psychology, 103*, 325–337. https://doi.org/10.1016/j.jecp.2009.02.007.
Sfard, A. (2000). Symbolizing mathematical reality into being: How mathematical discourse and mathematical objects create each other. In P. Cobb, K. E. Yackel, & K. McClain (Eds.). *Symbolizing and communicating: Perspectives on mathematical discourse, tools, and instructional design* (pp. 37–98). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
Sfard, A., & Lavie, I. (2005). Why cannot children see as the same what grown-ups cannot see as different? Early numerical thinking revisited. *Cognition and Instruction, 23*, 237–309. https://doi.org/10.1207/s1532690xci2302_3.
Tolchinsky, L. (2003). *The cradle of culture and what children know about writing and numbers before being taught.* Mahwah, NJ: Lawrence Erlbaum.
Uttal, D., Amaya, M., Maita, M. R., Liu Hand, L., Cohen, C., O'Doherty, K., et al. (2013). It works both ways: Transfer difficulties between manipulatives and written subtractions solutions. *Child Development Research,* 1–13. https://doi.org/10.1155/2013/216367.
Wagner, J., & Johnson, S. (2011). An association between understanding cardinality and analog magnitude representations in pre-schoolers. *Cognition, 119*, 10–22. https://doi.org/10.1016/j.cognition.2010.11.014.
Walkerdine, V. (1988). *The mastery of reason.* London: Routledge.
Wiese, H. (2003). Iconic and non-iconic stages in number development: The role of language. *Trends in Cognitive Sciences, 7*, 385–390.
Wynn, K. (1990). Children's understanding of counting. *Cognition, 36*, 155–193. https://doi.org/10.1016/0010-0277(90)90003-3.
Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology, 24*, 220–251. https://doi.org/10.1016/0010-0285(92)90008-P.