A Broken Fork in the Hand is Worth Two in the Grammar: A Spatio-Temporal Bias in Children's Interpretation of Quantifiers and Plural Nouns

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Abstract

We investigated the role of spatio-temporal and kind information in children's early counting and quantification of sets. Previous studies report that children exhibit a spatio-temporal bias when counting, and count parts of broken objects as distinct individuals (Shipley & Shepperson, 1990). We explored whether this bias is restricted to counting, or reflects early linguistic set representations more generally. When tested with a quantity judgment task, nearly 75% of 4-year-olds judged that an object broken in three – e.g., a broken fork – was *more forks* than two whole objects. In an elicitation task, we found that the bias is also present in children's pluralization. Children labeled broken objects using plural morphology 30% of the time (e.g., calling a broken fork "some forks"). These results indicate that a spatio-temporal bias exists for multiple forms of linguistic quantification. We suggest that children's early set representations are defined over spatio-temporal individuals.

Keywords: spatio-temporal individuation; kind-based individuation; quantity judgment.

Introduction

By around two years of age, most children have begun to recite the count list (e.g., *one, two, three…*), and point sequentially at objects in an array when counting. However, these children do not yet understand the *cardinality principle* – that the last word in a count denotes the cardinality of the set as a whole (Gelman & Gallistel, 1978; Wynn, 1990). By 3½ many children shows signs of understanding cardinality, but often make errors in their counts, and have difficulty estimating larger cardinalities without deploying the count routine (Bermejo, 1996; LeCorre & Carey, 2007). Learning how to count clearly extends well beyond reciting the count list.

Shipley and Shepperson (1990) found further evidence that children's understanding of cardinality is initially limited. In their study, 3- to 6-year-olds were asked to count arrays that included instances of broken objects. Unlike older children, 3- and 4-year-olds routinely counted pieces of broken objects as though they were whole objects (e.g., counting a fork broken in two pieces as two forks). Thus, children failed to correctly integrate sortal information when counting, exhibiting what Shipley and Shepperson called a "discrete physical object bias."

A similar bias has also been found in children's enumeration of events, suggesting that children's difficulty with cardinality is not restricted to counting objects. Wagner and Carey (2003) asked 3- to 5-year-olds to count events that had distinct sub-parts and a goal. For example, in one condition children saw a video of a rabbit that made multiple jumps, and eventually landed in a hole. After viewing the video, children were asked either "How many times did the rabbit move?" or "How many times did the rabbit jump into the hole?" Although children generally distinguished between these two types of question, many still counted individual movements when responding to the second question, rather than the completed goals. Thus, children have a bias not only for objects, but also in their individuation of events, suggesting that children have a broader "spatio-temporal" counting bias, rather than a bias that is specific to discrete physical objects.

In their account of the counting bias, Shipley and Shepperson (1990) entertained two possible explanations of children's behavior (p. 125):

(1) young children incorporate part of their first learned counting procedure, a procedure which requires that each object be processed separately, into every counting task

(2) young children have a bias to interact with discrete physical objects which is neither limited to nor derived from counting

In favor of the second hypothesis, Shipley and Shepperson presented evidence that, when asked to name *kinds* of things, 2-year-olds named each token of a kind rather than each type, thus exhibiting a bias even outside of counting contexts. Further, they argued that this bias is a pre-cursor to counting, and facilitates its acquisition by assuring that children include *individuals* in their counts.

If this idea is correct, then the spatio-temporal bias should exist not only for counting, but also for other forms of natural language quantification. The bias may inform not only children's early hypotheses about numeral meanings and counting, but also the meanings of quantifiers and number morphology in language. Here, we explored this hypothesis by testing whether children exhibit the spatio-temporal bias when pluralizing nouns and interpreting the comparative quantifier *more*.

Experiment 1

The first experiment tested the scope of the spatio-temporal bias by comparing children's counting of broken objects to their interpretation of the comparative quantifier *more*. If children's bias is mainly attributable to the counting procedure, then it should be absent or reduced for *more* judgments. In contrast, if all linguistic sets are initially defined in terms of spatio-temporal information, then the bias should be equally strong for quantifiers like *more*. To evaluate this, we tested 4-year-old children and adult controls with both Shipley and Shepperson's original counting task, and also with a quantity judgment task (Barner & Snedeker, 2005). Participants were asked to judge whether one object broken in three pieces was *more* (e.g., *more shoes*) than two whole objects of the same kind. Finally, children's counting level was assessed using the *Give-a-Number* Task (Wynn, 1990) to assure that they were cardinal principle knowers.

Methods

Participants Children were recruited by phone or through daycare centers in downtown Toronto. The preliminary sample of 4-year-olds consisted of twenty-four children from which eight were excluded as they were not cardinal principle (CP) knowers. The final 4-year-old sample included sixteen children (9 girls and 7 boys) with a mean age of 4 years and 3 months (range = 4; 0 to 4; 9). An adult student sample (n=16) from the University of Toronto also participated for course credit and served as a comparison group.

Materials The whole objects used for the quantity judgment and counting tasks included: plastic shoes, plastic forks, doll-sized shirts, silver styrofoam balls, plastic cups, baby socks, and paper plates. For each kind of whole object there was also an object of its kind that was cut into three pieces, referred to in this paper as "broken objects." For the *Give-a-Number* task, which was used to assess counting competence, eight plastic fish were used together with a plastic red circle.

Procedure In the quantity judgment (QJ) task, children were presented with two action figures: Farmer Brown and Captain Blue. One character was placed on the right side of the table and the other was placed on the left. After the characters were introduced, two whole objects were placed in front of one character and one broken object was placed in front of the other (see Figure 1). Broken objects were single whole objects cut into three pieces; therefore, on every trial there were more whole objects on one side, but more discrete physical objects on the other. The side of the broken object and the item order were both counterbalanced. For every object type (e.g. shoes), children were asked to indicate which character had "more" – e.g., "Farmer Brown and Captain Blue have some shoes. Who has more shoes?" Choosing the side with the two whole objects was coded as a "kind-based" response.

After the QJ task, children were asked to count seven different object arrays. Four arrays (shoes, socks, forks, shirts) included two whole objects and one object cut in three pieces. The remaining three arrays (balls, plates, cups) included four whole objects and one object cut in three. Children's counts were coded as either spatio-temporally based (counting discrete physical objects as equivalent to wholes) or kind-based (counting three pieces of a broken object as one, or excluding broken objects from counts altogether).

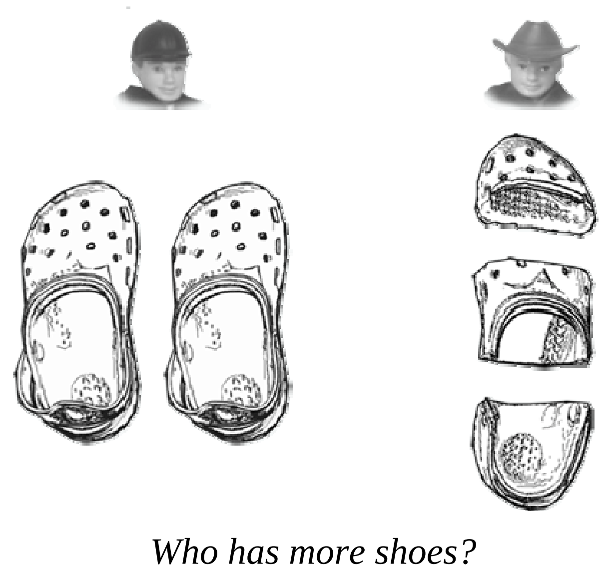

Figure 1. Sketch of a Quantity Judgment trial

Following the counting task children were tested on the *Give-a-Number* task (Wynn, 1990). Children were presented with eight fish and a red circle. In the first trial they were asked to put one fish in the circle. If they gave a correct amount, they were asked for two fish (and then for three, four, five, six, with each successful response). When children failed to provide a correct number they were encouraged to correct their count. If they failed again they were asked for one less fish in the next trial. Children were categorized cardinal principle knowers if they gave correct counts for sets of 5 or above on 2 out of 3 trials for each number. They were called subset knowers if they only succeeded with numbers up to one, two, three or four. Only cardinal principle knowers were included in the analyses, since we were interested in how units of counting are determined once counting itself is understood. The adult participants were tested on the QJ task and the counting task but not the *Give-a-Number* task.

Results

Quantity judgment and counting results are presented in Figure 2. An ANOVA was performed with Age (Adults vs. Children) and Item Order (Order 1 vs. Order 2) as between-subjects factors, and Task (Quantity Judgment vs. Counting) as a within-subjects factor. The dependent variable was the average percentage of trials with kind-based judgments. The analysis revealed a significant main effect of Task ($F(1,28) = 4.71$, $p < 0.05$) and a significant interaction between Age and Task ($F(1,28) = 4.71$, $p < 0.05$). In the quantity judgment task 4-year-olds showed a spatio-temporal bias, and used a kind-based strategy only 26% of the time. This bias was significantly greater than in the counting task, in which they used a kind-based strategy 43% of the time ($t(15) = 2.16$, $p < 0.05$). Adults always used a kind–based strategy and thus differed from children for both the quantity judgment task ($t(30) = 9.44$, $p < 0.0001$) and the counting task ($t(30) = 5.13$, $p < 0.0001$).

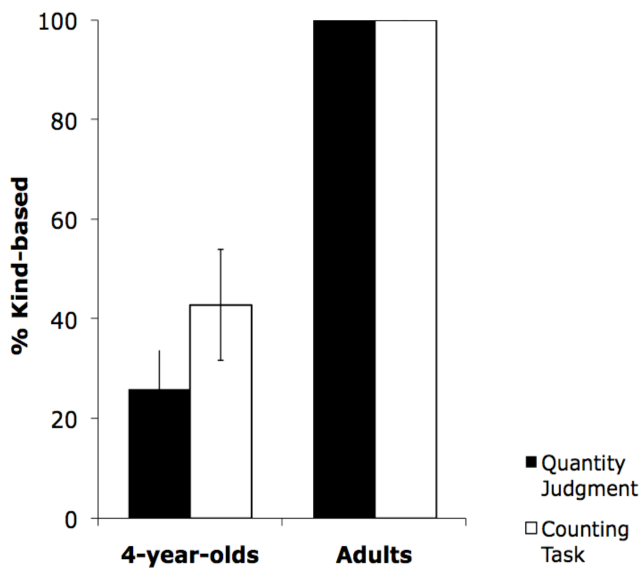

Figure 2. Use of a kind-based strategy in Quantity Judgment and Counting in adults and children.

To determine the relation between performance on the two tasks, we calculated their concordance on a trial-by-trial basis. Responses for each item (e.g., shoe) were coded as concordant if (1) they were both based on discrete physical objects, or (2) they were both kind-based. The average percentage of concordance across items was 70% for 4-year-olds and 100% for adults (See Figure 3). The difference in overall concordance between age groups was significant ($t(30) = 3.60$, $p < 0.005$). In children, the concordance between items was highly consistent, and ranged from 63% to 75% (concordance was identical across items for adults, since they were 100% correct on both tasks). High levels of concordance suggest that performance on the QJ task was associated with performance on the counting task. Crucially, this high level of concordance existed despite the fact that children never explicitly counted when doing the QJ task.

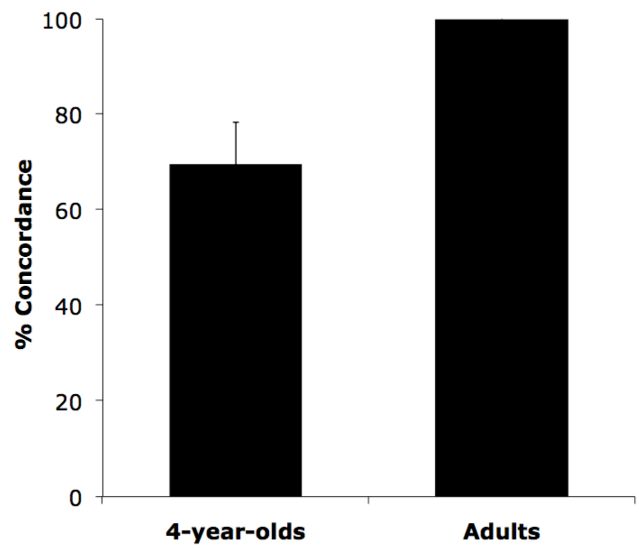

Figure 3. Concordance between quantity judgment and counting (Experiment 1).

Discussion

The first experiment found that 4-year-old children exhibit a spatio-temporal bias not only for counting but also in their interpretation of the comparative quantifier *more*. Children judged, for example, that one shoe broken in three was *more shoes* than two whole shoes, and did so without counting. This result indicates that the bias is present in absence of the counting routine, and may be present in all tasks that involve estimation or comparison of amount. When quantifying sets, individual set members are defined in terms of spatio-temporal criteria, and not in terms of kind information alone.

Experiment 2

Both counting and interpreting the quantifier *more* involve determining the cardinality of sets. In one case, a numeral is assigned to the cardinality, and in the other case the cardinalities are ordered in magnitude to determine which has *more*. This raises the question of whether the spatio-temporal bias is limited to tasks that involve estimating and performing computations over cardinalities, or whether it is general to all tasks that require the representation of sets.

To explore this question, we asked children to simply name a set using singular or plural morphology, in the context of either one whole object, a pair of whole objects, or one object cut in half. Since plural nouns are neutral with respect to the magnitude of sets, the task did not require children to represent the precise cardinality of sets, nor to compare these cardinalities.

Methods

Participants The sample consisted of twenty-nine children (mean age = 4;4) including 8 3-year-olds (mean age = 3;6; range = 3;1 – 3;11) and 21 4-year-olds (mean age = 4;8; range = 4;4 – 4;10). Participants were recruited and tested in daycare centers in the Comox Valley, British Columbia.

Materials The whole objects were plastic shoes, forks, cups, and plates. For each of the whole objects, there was also an item of its kind that was cut into two pieces.

Procedure Children were first presented with an example of each whole object to familiarize them with their names and canonical appearance. They were then asked to identify each object: "Do you know what this is?" Any errors were corrected by indicating the object's name in citation form – "*Can you say 'shoe'*?" – in order to avoid using singular or plural cues. Participants were then presented with a single action figure named Bob, who was placed in the center of the testing table. After Bob was introduced, the child was presented with either a single whole object, two whole objects, or one object broken in two. Each type of object was presented in each form, and the order of items was counterbalanced across participants. On each trial, the experimenter asked the child: "Can you tell me what Bob has?" Responses were coded as singular or plural.

Results

Results for Experiment 2 are presented in Figure 4. An ANOVA was conducted with one within-subjects factor, Trial Type (2 whole objects vs. 1 whole object vs. 1 cut object), and two between-subjects factors, Item Order and Age (3-year-olds vs 4-year-olds). The dependent variable was percentage of plural responses. There was a main effect of trial type ($F(2,50) = 42.06$, $p < 0.0001$), but no main effect of Item Order or Age and no significant interactions. Children almost always pluralized on 2 whole object trials (92.24% of the time), which was significantly more than on 1 whole object trials (3.45%; $t(28) = 18.13$, $p < 0.0001$). Thus, they exhibited a near adult-like use of singular-plural morphology on these trials. Nonetheless, children pluralized on broken object trials nearly a third of the time (30.17%). This differed significantly from both the 2 whole object trials ($t(28) = 7.66$, $p < 0.0001$) and the 1 whole object trials ($t(28) = 3.5$, $p < 0.003$).

Discussion

When asked to name broken objects, children exhibited a spatio-temporal bias, suggesting that the bias extends even to simple naming tasks in children as old as 4. Still, the bias was not as strong as for counting or quantity judgment, suggesting that these specific types of computation exacerbate children's bias. This suggests that the bias may have multiple components, including both the establishment of set representations and an evaluation of their cardinalities.

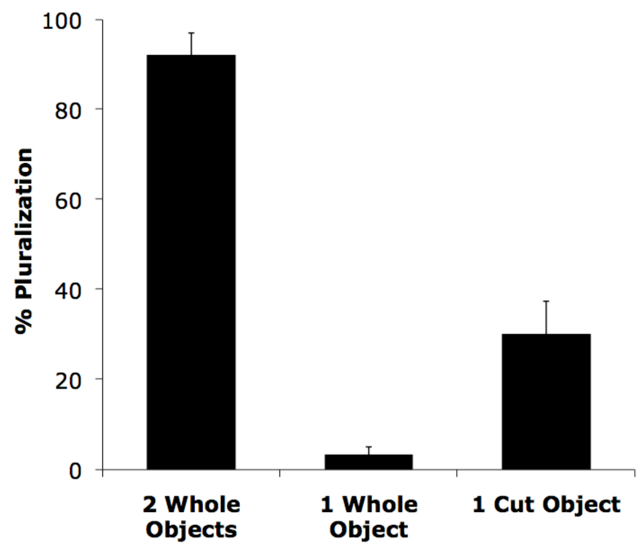

Figure 4. Percent of pluralized responses across trial types in the elicitation task.

General Discussion

The results of this study support the hypothesis that the spatio-temporal bias is not restricted to counting, but may be general to early linguistic set representations. In 4-year-olds the bias was found not only for counting (around 50% of the time), but also for quantity judgment (75% of the time) and pluralization (30% of the time). These results indicate that tasks that require the computation or comparison of cardinalities (like counting and quantity judgment) may amplify a bias that is also present in tasks that involve only labeling sets (like the plural elicitation task). Still, the fact that children as old as 4 incorrectly apply the plural to broken objects suggests that this bias may reflect a fundamental assumption that children make about linguistic set representations in development.

The sortal "shoe" specifies a function and set of physical criteria for satisfying the function (such as shape, solidity, etc.). By 4 years of age children have learned many nouns, and can easily recognize when a shoe (or fork, or ball) is broken. Consistent with the reports of Shipley and Shepperson, many children in our study made remarks about the objects being broken, but nonetheless exhibited the spatio-temporal bias. For example, in the plural elicitation task of Experiment 2, the most common response was not to pluralize, but to call broken objects "a broken shoe" or "a broken fork". These results suggest that children do not have trouble recognizing when objects are "good" shoes, forks, or balls. The trouble, instead, is that the units of quantification for numerals, quantifiers, and plural morphology are initially defined without appeal to deeper conceptual criteria.

This finding can be understood by distinguishing between two components of a noun phrase that contribute to its final interpretation. On the one hand, the lexical item – e.g., *shoe* – supplies item-specific conceptual information that distinguishes shoes from cups, and whole shoes from parts of shoes. These item-specific properties guide the application of the noun, and thus guide categorization. On the other hand, there is the syntactic frame of the noun, which specifies its status as a count noun (e.g., as singular or plural), thus supporting the use of a numeral. These syntactic structures are not item-specific, but are general to a broad class of items, and therefore contribute a uniform meaning to all noun phrases. For example, count syntax specifies number as the measuring dimension for all count nouns (Barner & Snedeker, 2005). Consequently, noun phrases merge kind information with number morphology and syntax, permitting reference to kinds of things.

In adults, noun phrases are clearly compositional. The conceptual features of lexical items combine with the syntactic features of count syntax to specify units of counting that are based on sortal information. In contrast, children's early noun phrases may not be fully compositional in this manner. Although children are aware of the conceptual criteria that guide categorization, this information does not initially determine the units that count as individuals in the syntax. Instead, numerals, number morphology, and quantifiers initially impose spatio-temporal units on noun phrase quantification.

Such an analysis can explain why children exhibit a spatio-temporal bias despite recognizing broken objects as such. However, it leaves open why this bias develops in the first place. According to Shipley and Shepperson (1990), the bias might exist because it is adaptive, and facilitates the early stages of integer acquisition by specifying default units for counting.

Extending this, the bias could also help children get an early start to acquiring quantifiers and plural morphology, without requiring an understanding of every noun with which these structures are used. All nouns are initially novel to children learning language. As a result, the exact nature of the individuals to which a noun refers might not be certain before the word has been heard a number of times. If children were to wait until they understood a noun's meaning before making hypotheses about the meanings of quantifiers and plural morphology, they would need to throw out substantial information in early acquisition (i.e., many instances of quantifiers and plural morphology would go unanalyzed). However, if children assumed that quantification is defined, canonically, over spatio-temporal individuals, then they could begin acquiring quantifiers and number morphology independent of item-specific lexical knowledge. In short, children face a tradeoff between "accuracy" and "speed" when acquiring set representations. By initially ignoring the specifics of how kind information and syntactic structures intermingle to generate compositional meanings, children could get an early start on quantifiers, numerals, and plural morphology, using a spatio-temporal individual heuristic.

This account explains the potential benefits of a spatio-temporal bias, but leaves open its origin. One possibility is that it is learned associatively, by observing that in most cases kind information and spatio-temporal criteria overlap. After all, learning contexts that involve broken objects, or words that denote collections of discrete physical objects, are not likely frequent for young children.

Another possibility is that spatio-temporal information is privileged by design, since all languages have representations of individuals, but no newborn can anticipate what kinds of individuals they will encounter in their life. The primacy of spatio-temporal information in object individuation is well documented in studies of early human cognition. For example, using a violation of expectancy paradigm, Xu and Carey (1996) showed that 10-month-old infants use spatio-temporal information but not kind information to track occluded objects, whereas older 12-month-olds use both kinds of information. In their study, infants watched as two kinds of objects (a duck and a truck) emerged one-at-a-time from behind an occluder and then disappeared (such that they were never seen simultaneously). When the occluder was raised infants saw either one remaining object (unexpected outcome) or both of the objects (expected outcome). The results showed that 12-month olds but not 10-month olds were surprised by the unexpected outcomes, suggesting that only 12-month olds used kind-based information to infer the existence of distinct individuals and trace their identity over time and space. Before infants represent an entity as a kind of thing, and thus bind kind information to an individual, they first rely on spatio-temporal information to locate the individual in time and space. Although infants in Xu and Carey's study were too young to have begun acquiring quantifiers or numerals, the knowledge that infants exhibit when learning about objects could also be used for learning about linguistic structures. In absence of item-specific kind information (e.g., knowing the criteria that distinguish a duck from a truck), a spatio-temporal heuristic provides a quick path to learning about objects and how they interact in the world.

As noted by Shipley and Shepperson (1990), similar heuristics are seen elsewhere in language development. For example, children exhibit a whole object bias (Markman, 1989), and assume that novel words refer to whole things rather than to their parts. Also, at 4 years of age, children often assume that singular nouns refer to single objects, rather than to collections (see Bloom & Kelemen, 1995). These biases, like others that are deployed in word learning (e.g., the shape bias; Landau, Smith & Jones, 1992), are limited in scope, but may speed the development of vocabulary and syntactic development (see Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002 for evidence that training the shape bias speeds word learning). Like the discrete physical object bias, these word learning heuristics offer a quick entry into an otherwise intractable induction problem (see Markman, 1989).

Future studies should investigate the processes by which older children overcome the spatio-temporal bias. At 6 years of age, when the bias begins to diminish (Shipley & Shepperson, 1990; Wagner & Carey, 2003), children's vocabulary of abstract nouns is increasing, and they are also entering school, where formal mathematical training begins. In each case, representations of quantity become decoupled from spatio-temporal constraints. For example, the acquisition of fractions makes clear that whereas whole numbers refer to whole objects, partial things require the use of fractions. Similarly, enumerating events often involves packaging multiple actions into a single unit that is defined by intentional, rather than spatio-temporal criteria (Wagner & Carey, 2003).

Future studies should also explore the development of the spatio-temporal bias in younger children, to test whether the bias is initially stronger not only for counting, but also for tasks that involve quantifiers and other forms of number morphology. Although children in our study correctly use singular nouns 75% of the time for broken objects, younger children who are just learning plural morphology and quantifiers may lean more heavily on spatio-temporal criteria for individuation.

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