PAPER

Piecing together numerical language: children's use of default units in early counting and quantification

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Abstract

When asked to 'find three forks', adult speakers of English use the noun 'fork' to identify units for counting. However, when number words (e.g. three) and quantifiers (e.g. more, every) are used with unfamiliar words ('Give me three blickets') noun-specific conceptual criteria are unavailable for picking out units. This poses a problem for young children learning language, who begin to use quantifiers and number words by age 2, despite knowing a relatively small number of nouns. Without knowing how individual nouns pick out units of quantification – e.g. what counts as a blicket – how could children decide whether there are three blickets or four? Three experiments suggest that children might solve this problem by assigning 'default units' of quantification to number words, quantifiers, and number morphology. When shown objects that are broken into arbitrary pieces, 4-year-olds in Experiment 1 treated pieces as units when counting, interpreting quantifiers, and when using singular–plural morphology. Experiment 2 found that although children treat object-hood as sufficient for quantification, it is not necessary. Also sufficient for individuation are the criteria provided by known nouns. When two nameable things were glued together (e.g. two cups), children counted the glued things as two. However, when two arbitrary pieces of an object were put together (e.g. two parts of a ball), children counted them as one, even if they had previously counted the pieces as two. Experiment 3 found that when the pieces of broken things were nameable (e.g. wheels of a bicycle), 4-year-olds did not include them in counts of whole objects (e.g. bicycles). We discuss the role of default units in early language acquisition, their origin in acquisition, and how children eventually acquire an adult semantics identifying units of quantification.

Introduction

Learning names for things lies at the core of language acquisition. Not only do nouns represent objects, events, and abstract entities, but they are central to acquiring other aspects of language. Without nouns, some words would be very hard to learn: knowing *who* did what to *whom* is crucial to distinguishing words like *give* and *take*, *chase* and *flee*, *borrow* and *lend*, and to verb learning in general (Gillette, Gleitman, Gleitman & Lederer, 1999). Others words, like *some*, *all*, *one* and *two* depend crucially on nouns for their interpretation, since nouns function as sortals. Sortals are words that specify criteria for application (e.g. distinguishing apples vs. oranges), criteria for tracing the identity of referents over time and space (e.g. same apple vs. different apple), and criteria for individuating referents (e.g. one orange vs. two; see Macnamara, 1986; Hirsh, 1982; Wiggins, 1980; Xu & Carey, 1996). Thus, whereas a request like 'count the things in the room' leaves open many possibilities (e.g. counting letters in each book, or specs of dust on the wall), a request like 'count the books in the room' makes clear which units should be quantified. The child

encounters this problem when learning words like *one* and *two*. To figure out these meanings – e.g. what counts as *one blicket* – it seems that the child must first know *what* a blicket is, and where one blicket ends and another one begins.

Interestingly, children begin to use quantifiers, number words, and number morphology by around the age of 2, at a time where they know very few noun meanings (Fenson, Dale, Reznick, Bates, Thal & Pethick, 1994). For example, by around 24 months of age most English-speaking children have begun to produce and comprehend singular–plural morphology (Barner, Thalwitz, Wood & Carey, 2007; Brown, 1973; Cazden, 1968; Kouider, Halberda, Wood & Carey, 2006; Mervis & Johnson, 1991). Not long after, they begin to learn the meanings of quantifiers like *some* and *all* (Barner, Chow & Yang, 2009; Barner, Libenson, Cheung & Takasaki, 2009; Hanlon, 1987), and numerals like *one* and *two* (e.g. Bermejo, 1996; Briars & Siegler, 1984; Frye, Braisby, Lowe, Maroudas & Nicholls, 1989; Fuson, 1988, 1992; Le Corre, Van de Walle, Brannon & Carey, 2006; Wagner & Walters, 1982; Wynn, 1990, 1992). Meanwhile, English-speaking 2-year-olds use only 300 words on average

(Bates, Dale & Thal, 1995), a mere fraction of the vocabulary that they will eventually learn, and a small subset of the words that are used in caregiver speech. As a result, a large proportion of quantifier and number word uses in maternal speech occur with nouns that children do not yet use in their own productive speech (see the Appendix).

Two broad alternatives are consistent with these facts. On the one hand, children's inferences about quantifier and numeral meanings may be based exclusively on their occurrences with informative nouns, which specify units of individuation. Since unknown nouns (i.e. those without meanings for the child) do not supply criteria of individuation, these words may be uninformative as children try to distinguish words like *all* and *some*, and thus may contribute little to the learning process. In the best case, children could make interim guesses about noun meanings to inform subsequent guesses about quantifiers. For example, they might use word-learning constraints like the whole object bias (Macnamara, 1972; Markman, 1989) to guide assumptions about a noun's units of reference, and then use these units to interpret quantifiers or number words that are used with the novel noun (for additional evidence of an object bias in word learning, see Barner & Snedeker, 2006; Dickinson, 1988; Imai & Gentner, 1997; Imai, Gentner & Uchida, 1994; Landau, Smith & Jones, 1988; Samuelson & Smith, 1999; Soja, Carey & Spelke, 1991, 1992; Soja, 1992). In the worst case, if children are unable to relate nominal constraints to counting and quantification, children might throw out such instances altogether, and rely purely on utterances that contain known nouns.

A second possibility is that children include all uses of quantifiers and numerals in their analysis by assigning them 'default units' of quantification. Initially, quantifiers may not rely on nouns to identify individuals, but may instead be interpreted according to units that are specified by the quantifiers themselves. What might these units be? Studies of pre-linguistic numerical development indicate that infants are able to represent and quantify various types of individuals independent of language, including discrete physical objects, sounds, collections, and punctual events (Feigenson, Dehaene & Spelke, 2004; Starkey, Spelke & Gelman, 1983; Wood & Spelke, 2005; Wynn, 1996; Wynn, Bloom & Chiang, 2002; Xu, 2007; Xu, Spelke & Goddard, 2005; Xu & Spelke, 2000). These studies suggest that conceptual criteria that are independent of nouns – such as solidity, continuity, and cohesiveness – may guide the individuation of objects, and that analogous non-linguistic criteria may govern infants' quantification of more abstract perceptual phenomena. By appealing to such criteria when learning to count and use quantifiers, children could bypass nouns altogether, getting a head start on quantifier learning.

Here, we provide evidence that children's quantifier learning is guided by the use of default units, like those that are documented in the infant individuation literature. We show that 4-year-old children use default units when interpreting quantifiers, numerals, and singular–plural morphology. Children's units of quantification are not determined exclusively by nouns, as they are for adults. We conclude that children rely on default units not only when noun meanings are unknown, but that they continue to do so even after they have learned their meanings and the units that they denote.

The starting point for this investigation is a result reported by Shipley and Shepperson (1990). In their study, Shipley and Shepperson presented 2- to 6-year-old children with arrays that included both whole objects (e.g. forks), and pieces of broken objects (e.g. half forks), and asked the children to count them – e.g. *Can you count the forks?* Over 70% of children responded by counting the pieces of broken objects, while adult controls counted two pieces as one fork, or excluded broken pieces from their counts entirely. Thus, when presented with two whole forks and one fork broken in two, for example, children counted the array as *four forks*. This behavior did not differ significantly from when children were asked to count the 'things' in an array, suggesting that the noun played no role in specifying units of quantification. In keeping with this, Sophian and Kalihiwa (1998) showed that 4-year-olds frequently counted each piece of broken objects even when asked specifically to count 'whole' items. Further, Wagner and Carey (2003) report similar results for children's counting of events, suggesting that such units are not limited to discrete physical objects. When children were asked how many times a character painted a flower, they counted the individual brush strokes, rather than the total number of flowers painted. These studies, and others in the literature, find that children's counting of parts is significantly less frequent in 5-year-olds, and is almost completely absent in 6- and 7-year-olds (see also Gutheil, Bloom, Valderrama & Freedman, 2004).

Based on their study, Shipley and Shepperson argued that children treat discrete physical objects as units for counting, thereby facilitating their imitation and interpretation of adult counts. However, because their study was restricted to counting, it left open (1) whether such behaviors are specific to the counting routine, or (2) whether the behaviors reflect children's early meaning hypotheses. In the case of (1), these behaviors may be an artifact of how children learn to count. From an early age, children engage in a counting routine, in which they point at individual things in sequence and label the set with the last word in the count. Early in development, this routine is used even before children understand the meanings of numerals, and before they understand how counting represents cardinality (e.g. Fuson, 1988, 1992). It is therefore possible that the routine is used automatically later in acquisition, too, and overrides children's knowledge of sortals and individuation. In this case, counting parts of broken things may indicate little about children's understanding of numeral meanings, or their use of noun criteria for quantification. Thus, a similar bias would not be expected on quantification tasks that

do not involve counting, and should be limited to the interpretation of numerals. In contrast, if the behaviors reported by Shipley and Shepperson reflect children's meaning hypotheses when learning quantifiers, numerals, etc. – i.e. if children assume default units of reference – then such effects should be found not only in tasks that involve counting, but should be found throughout the grammar. Children should treat parts of broken objects as the relevant units when interpreting quantifiers and determiners like *a*, *some*, *every*, *more*, and *both*, and should even use plural marking when naming a broken object. This behavior should persist for known nouns even when their referents are broken in plain view, and even when children explicitly judge that the counted items are broken.

Experiment 1

The first experiment tested whether children use default units of individuation when counting, when interpreting quantifiers like *a*, *more*, *every*, and *both*, and when producing singular–plural morphology.

Method

Participants

Participants were 45 English-speaking children aged 3;1 to 4;10 (M = 4;3) recruited by phone or through daycares in the Pacific Northwest and the greater Toronto and San Diego areas. Sixteen children (nine girls and seven boys, mean age = 4;3, range = 3;1–4;9) participated in the Who has more? and counting tasks. Four additional children were tested but excluded from the analysis due to failure to understand counting.[1] Twenty-nine children (mean age = 4;4; range = 4;0–4;10) participated in the singular–plural elicitation task. Fifteen children (nine girls and six boys, mean age = 4;2, range = 3;11–4;10) participated in the remaining quantifier tasks (*Touch-every-X*; *Give-an-X*; *Give-both-Xs*). Thirty-two undergraduate students attending the University of Toronto participated in the quantity judgment and counting tasks. Twelve undergraduate students attending the University of California, San Diego participated in the singular–plural elicitation task, and another 15 participated in the remaining quantifier tasks. All adults received course credit for participating.

[1] In this experiment and all others reported in this paper, we assessed children's counting abilities using Wynn's 'Give-a-Number' task (Wynn, 1990). This task was always administered after other tasks, to ensure that it did not influence performance. A total of six children across all three Experiments were excluded due to a failure to give the correct number of objects for requests of 5–8 objects. Thus, by Wynn's criteria, all children in our experiments were 'Counting Principle Knowers'. By limiting our study to counters, we could be sure that children's counts were a valid reflection of how they interpreted requests, and not the product of immature counting abilities.

Materials

In all tasks, participants were presented with arrays of objects selected from among the following kinds: painted styrofoam balls, doll-sized shirts, baby socks, plastic 'croc' shoes, plastic forks, plastic cups, and paper plates. Three sets of stimuli were used. Stimulus Set 1 consisted of whole balls, shirts, socks, shoes, forks, cups, and plates, as well as identical objects that had been cut into three pieces. Stimulus Set 2 included whole shoes, balls, shirts, and socks, as well as identical objects cut into two pieces. Stimulus Set 3 was also made up of whole objects and identical objects cut in two. In this case, the objects were shoes, balls, plates, and forks. In all tasks, the broken objects were arranged such that their parts were aligned so they resembled an unbroken object, with parts separated by approximately 2.5 cm. This was done to make it clear that the pieces could be combined to make a single whole object.

Procedure

Task Set 1 included the *Who has more?* and *Counting* tasks. These tasks were always presented in this order to ensure that the counting tasks did not influence 'more' judgments. Task Set 2 included *Touch-every-X*, *Give-an-X*, and *Give-both-Xs*. The order of these tasks was counterbalanced across participants. Task Set 3 included the *Singular–plural elicitation* task. Figure 1 provides examples of each task. Here, and for all other tasks described in this paper, the order of items was quasi-random. In all cases, half of the participants received one item-order, and the other half received a different item-order.

Who has more? This task was adapted from Barner and Snedeker (2005) to test children's interpretation of the comparative quantifier *more*. Participants were introduced to two action figures: Farmer Brown and Captain Blue. On each trial, two whole objects from Stimulus Set 1 were placed in front of one figure, and one object that had been cut into three pieces was placed in front of the other figure. Participants were told, 'Farmer Brown and Captain Blue have some [shoes]. Who has more [shoes]?' Since one character had more whole objects and the other character had fewer whole objects but more individual things, responses based on the noun's criteria of individuation could be distinguished from those based on default units (i.e. discrete physical objects). Each participant completed seven trials (one for each type of object), and the side of the whole object choice was quasi-random on each trial.

Counting. This task was modeled after Shipley and Shepperson (1990) to test whether children use default units when counting. Each participant completed seven trials, one for each type of object. On four trials, participants were presented with an array including two
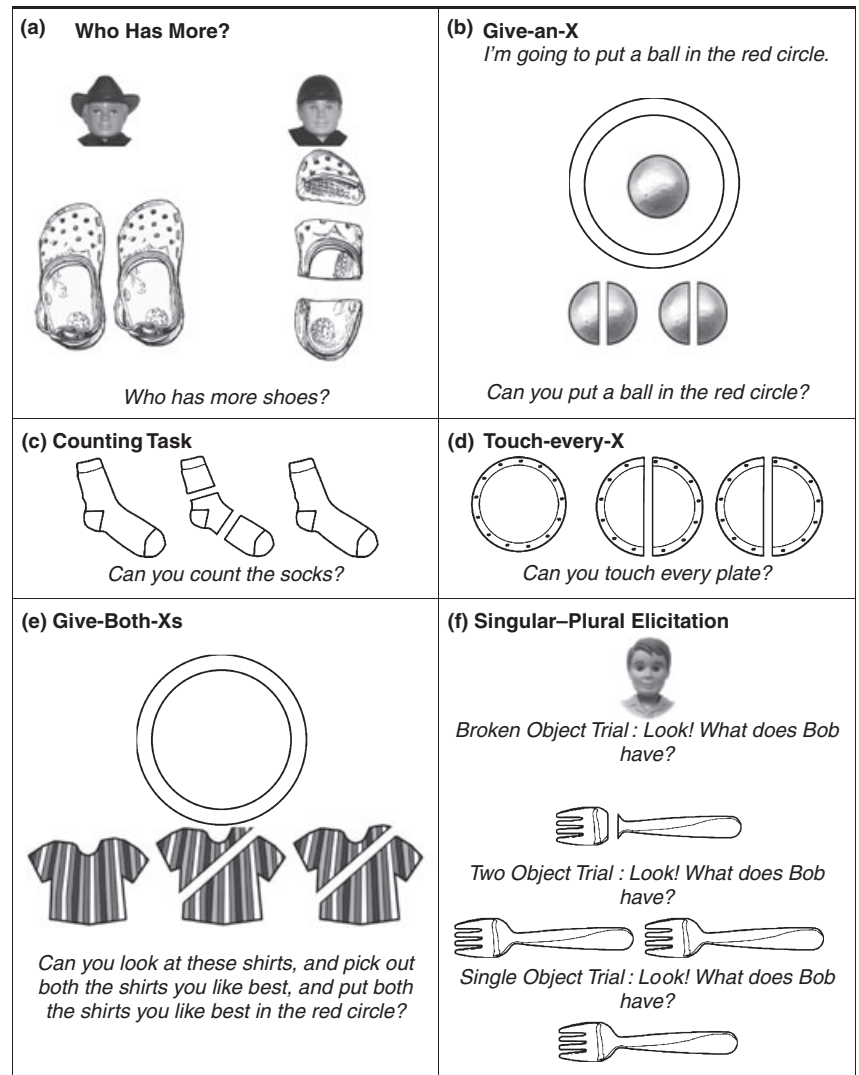
Figure 1 *Sketches of Experiment 1 stimuli and procedures.*

whole objects and one object cut into three pieces (five discrete physical objects in total). On three trials, they saw four whole objects and one cut object (seven discrete physical objects in total). Objects were those in Stimulus Set 1. On each trial participants were asked, 'Can you count the [shoes]?'

Touch-every-X. This task tested children's interpretation of *every.* Participants were presented with arrays that included one whole object and two broken objects from Stimulus Set 2. Across four trials, participants were asked, 'Can you touch every [shirt]?' We asked whether participants would touch three individual objects (consistent with the noun's units) or five (consistent with using discrete physical objects as units).

Give-an-X. This task tested children's interpretation of singular nouns. Participants were presented with one whole object and two broken objects from Stimulus Set 2. They were then told, 'I'm going to put a [shirt] in the red circle.' After placing the whole object in the circle, the experimenter asked, 'Now can you put a [shirt] in the red circle?' Since the remaining items were broken objects,

the children could satisfy the request either by giving a piece of a broken thing, or by giving two pieces that together made up a whole object.

Give-both-Xs. Participants were shown one whole object and two broken objects from Stimulus Set 2, and were asked, 'Can you look at these [shirts], and pick out both the [shirts] you like best, and put both the [shirts] you like best in the red circle?' To satisfy the request, children could give one whole object and two pieces of a broken object (or both pieces of each broken object), consistent with the noun's units, or one whole object and one piece of a broken thing (or two of the four pieces of broken objects), consistent with using discrete physical objects as units.

Singular–plural elicitation. On each trial, participants were asked to label one of three sets of objects from Stimulus Set 3: (1) one whole object, (2) two whole objects, or (3) one object cut into two pieces. In each case, the array was placed in front of a single action figure (Bob), and the participant was asked, 'Look! What does Bob have?' Each type of array was presented once

for each of the four object kinds used, for a total of 12 trials. Of interest was whether children used singular or plural forms to describe broken objects.

Results

When counting, interpreting quantifiers, and using singular–plural morphology, 4-year-old children treated discrete physical objects as units of quantification up to 74% of the time, rather than using the units specified by familiar nouns.

First, on the counting task, children counted parts of objects on 56.3% of trials (11 out of 16 children exhibited the behavior). This was significantly more often than adults, who never did so ($t(15) = 5.13$, $p < .001$). This result replicates the finding of Shipley and Shepperson (1990), who found that children counted the parts of broken objects 56% of the time when the parts of broken objects were aligned, as they were here (see also Wagner & Carey, 2003; and Sophian & Kailihiwa, 1998). As in these previous studies, we found that the counting of parts was negatively correlated with age, $r(14) = -.537$, $p < .05$.

Second, children based quantity judgments (e.g. *Who has more shoes?*) on discrete physical objects on 74.1% of trials. For example, when asked who had more shoes, children chose the character who had one shoe broken into three pieces, rather than the character with two whole shoes (see Figure 2). Adults made such judgments on 0.4% of trials, which was significantly less frequent ($t(15) = 9.37$, $p < .001$). On this task, there was no correlation between age and adult-like quantification, $r(14) = .05$, $p > .4$, presumably because there was so little variability between children. Every child included broken parts on at least one trial (including children as old as 4 years, 9 months).

To compare performance on these two tasks, we performed a 2×2 analysis of variance with Age Group (Adults vs. Children) as a between-subjects factor and
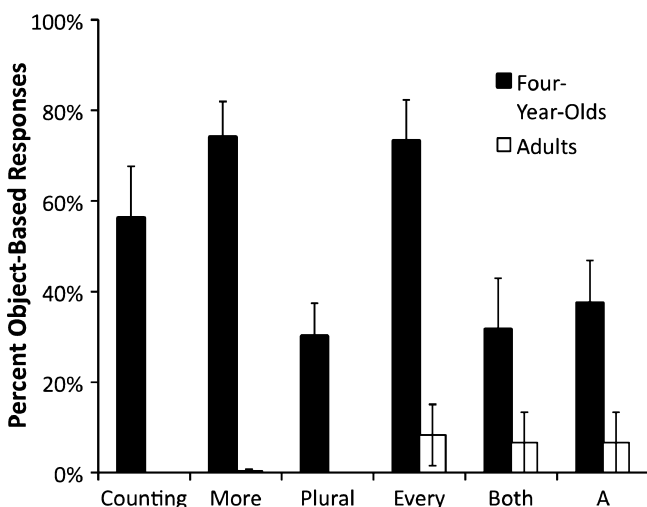
Task (Quantity Judgment vs. Counting) as a within-subjects factor. The dependent variable was the average percentage of trials on which participants based judgments on whole objects, rather than on parts of broken objects. The analysis showed a significant main effect of Task ($F(1, 46) = 9.93$, $p < .05$) and of Age Group ($F(1, 46) = 112.58$, $p < .001$), and a significant interaction between the two ($F(1, 46) = 8.94$, $p < .05$). Children included parts of broken objects as units of quantification more often for quantity judgment than for counting ($t(16) = 2.16$, $p < .05$), unlike adults. This provides clear evidence that this behavior is not restricted to counting.

Similar effects were found for the words *every*, *both*, and *a*. A 2×3 ANOVA with Age Group (Children vs. Adults) as a between-subjects factor and Task (*Every* vs. *Both* vs. *A*) as a within-subjects factor showed significant main effects for Age Group ($F(1, 27) = 17.52$, $p < .001$) and for Task ($F(2, 54) = 7.18$, $p < .005$) and a significant interaction between the two ($F(2, 54) = 6.02$, $p < .05$). When asked to touch 'every [shoe]' children touched each discrete physical object on 73.3% of trials (two out of 15 children never gave this response). When asked to put 'a [shoe]' into a circle, children included a broken piece on 37.5% of trials (four out of 15 children never gave this response). Finally, when asked to choose 'both of the [shoes] that you like best' children selected two pieces on 31.7% of trials. A total six out of 15 children exhibited this behavior for *both*, fewer than for other words.

In contrast to the children, only one adult participant gave object-based responses on these tasks. Overall, adults gave object-based responses on 8.3% of trials for *every*, 6.7% of trials for *a*, and 6.7% of trials for *both*. Planned comparisons showed significant differences between 4-year-olds and adults for *every* trials ($t(28) = 5.80$, $p < .001$) and *a* trials ($t(27) = 2.71$, $p < .05$), and a marginally significant difference between Age groups for *both* ($t(28) = 1.97$, $p < .06$). Among the children there were no significant correlations between age and performance, presumably because our sample contained a very restricted range of ages (and a standard deviation of 3.3 months).

No significant differences were found in the performance of 3- and 4-year-olds on the singular–plural elicitation task and there was no correlation between performance and age (see below). Accordingly, the two groups were combined for analysis. Surprisingly, children produced plural morphology when naming a single broken object on nearly a third of trials (30.2% of the time). This was significantly more often than when naming one whole object (3.4%; $t(28) = 3.5$, $p < .001$), though less often than when naming two whole objects (92.2%; $t(28) = 7.7$, $p < .001$). Adults pluralized on 100% of trials for two whole objects and 0% of trials with a single whole or broken object. Thus, their rate of pluralization differed significantly from children only on broken object trials ($t(36) = 3.7$, $p < .01$). Although children did not pluralize consistently when referring to broken objects, it is nonetheless very surprising that

Figure 2 *Percentage of object-based responses made by adults and 4-year-olds on Experiment 1 tasks.*

4-year-olds used the plural a third of the time for broken objects. Overall, 41% of the children pluralized sometimes for broken objects, including the oldest children in our sample. There was no sign of the behavior fading with age, as indicated by a non-significant correlation between age and adult-like use of the plural, $r(27) = .14$, $p > .4$.

Discussion

The results of Experiment 1 indicate that 3- and 4-year-old children treat parts of broken objects as units of quantification when counting, when interpreting words like *a*, *more*, *every*, and *both*, and when producing singular–plural morphology. These data are consistent with the hypothesis that children treat discrete physical objects as default units not only when counting, but also when interpreting and producing other quantifiers and number marking. Children often count and quantify discrete physical objects, rather than whole shoes, forks, balls, etc.

However, two problems confront this analysis. First, although it is possible that children use default units to interpret quantifiers, it is also possible that they do not fully understand what things like shoes and forks are. For example, for 4-year-olds, the sortal SHOE may denote any discrete physical object with shoe properties (e.g. associated parts, shapes, colors, textures), independent of the object's structure or its capacity to fulfill a particular function. On this view, quantifiers may not specify units that are at odds with those of nouns; the nouns may specify the units of individuation after all, but simply pick out the *wrong* units.

A second problem is noted by Giralt and Bloom (2000), who argue that children's counting is not restricted to quantifying discrete physical objects, but that children quantify things in a more abstract fashion. As evidence for this, they note that children are capable of counting holes (e.g. in pieces of cardboard) and also parts of objects, such as feet and ears (see also Wagner & Carey, 2003). Especially interesting to the current study is the counting of parts (since previous studies find that although children can count abstract things like events, they nonetheless exhibit similar use of default units, counting arbitrary parts of events rather than completed events; Wagner & Carey, 2003). The counting of parts suggests that although being a discrete physical object is often sufficient to guide quantification, it may not be necessary. Criteria specified by known nouns (e.g. words that distinguish parts of things like ears and feet) may also be sufficient. By allowing either type of cue to guide individuation, children could get a head start on counting and quantifier acquisition, while also learning how nouns guide quantification.

This hypothesis, that children use parallel sets of sufficient criteria to guide quantification, generates two novel predictions. First, it predicts that two things glued together should count as *two* (e.g. *two shoes*) if each part separately satisfies the criteria specified by a noun (i.e.

each is a shoe). Second, these glued together objects should count as *one* (e.g. *one shoe*) if the parts do not individually satisfy the criteria specified by the noun – i.e. if they are arbitrary parts of an object. Thus, two parts of a single shoe pressed together should not count as two shoes, even if children have previously identified the very same pieces as 'two shoes' in a counting task.

Experiment 2 explored these predictions using two tasks. The first task tested children with pairs of whole objects that had been glued together. If children understand the conceptual criteria for being a shoe and these criteria are sufficient for being counted as a unit, then children should count two shoes that are glued together as *two shoes*, despite the fact that they constitute a single object (whose parts move together). The second task extended this reasoning, and tested whether any two parts combined into one would count as two things (even when previously counted as two), or whether counting combined objects truly draws on the conceptual understanding of nouns.
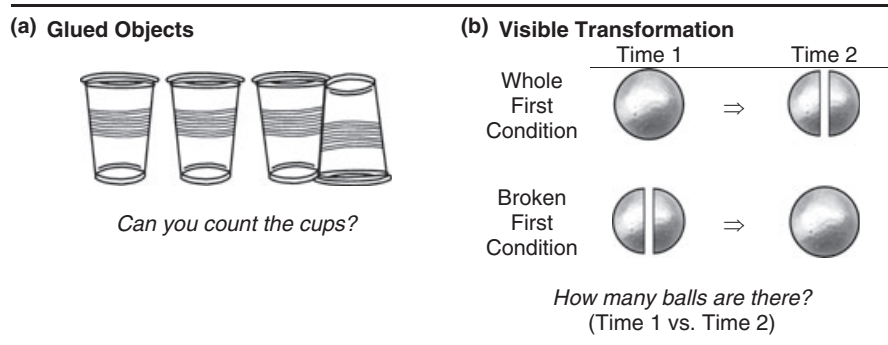
Experiment 2

Method

Participants

Participants were 32 English-speaking children aged 3;11 to 4;11 (M = 4;4) recruited by phone or through daycare centers in the greater San Diego area, and in daycare centers in the Pacific Northwest. Fifteen of these children (five boys and ten girls) participated in the Glued Objects Task. All children who participated in glued objects also participated in the *every*, *a*, and *both* tasks in Experiment 1. The glued objects task always followed the Experiment 1 tasks. The remaining 17 children participated in the visible transformation task. These participants ranged in age from 4;2 to 4;11 (M = 4;6).[2]

Procedure

Glued Objects Task. This task included trials in which two whole members of an object kind (shoes, balls, forks, or cups) were glued together to form a single discrete physical object (see Figure 3a). The objects were glued together so that the sides of the objects were touching, allowing the child to see both whole object components. However, as the glued objects were presented, they were held by the experimenter and moved around in the air, demonstrating to the child that the two items moved as a connected whole, a signature of object-hood beginning in infancy (Spelke, 1990). The glued objects were presented in arrays with one or two additional whole objects. As in

[2] Gender information is not available for the 17 children who participated in this task.

**Figure 3** *Sketches of Experiment 2 stimuli and procedures.*

the counting task in Experiment 1, participants were asked, 'Can you count the [forks]?' After completing three trials with glued objects, participants completed three counting trials with broken objects (shirts, plates, and socks). This allowed us to directly compare performance on broken object and glued object trials.

Counting with Visible Transformation Task. For this task, each participant saw a pair of trials that featured the visible transformation of an object (shoes, balls, or plates). Stimuli are shown in Figure 3b. In one condition, which we will call 'Whole First', children initially saw two objects, one of which was cut into two pieces, but held together such that it was not visibly broken. The child was asked, 'How many [shoes] are there?' Following their response, the experimenter pulled the two pieces apart, and the participant was again asked, 'How many [shoes] are there?' In the second condition, which we will call 'Broken First', the pieces were initially held apart, children were asked how many there were, and the pieces were pressed together before they were again asked how many there were. Thus, in both conditions the child was asked to report the number of things both before and after a transformation.

Results

Results are shown in Figure 4. On the Glued Objects Task, where two whole objects were glued together, both 4-year-olds and adults counted each segment of a glued object as a distinct thing (95.8% vs. 100% of trials, respectively), resulting in no significant difference between the groups ($t(14) = 1.00$, $p > .3$). In contrast, on broken objects trials, 4-year-olds performed like the children in Experiment 1, and counted parts on 91.7% of trials, on average.[3] This differed significantly from adults, who counted parts on only 4.2% of trials ($t(26) = 9.21$, $p < .01$). Children's tendency to count two objects as *two* when the objects are glued together indicates that they can use the conceptual criteria of a noun to guide counting, when these criteria are satisfied.

[3] All children exhibited these non-adult behaviors. Performance was not significantly correlated with age for this task or the transformation task.

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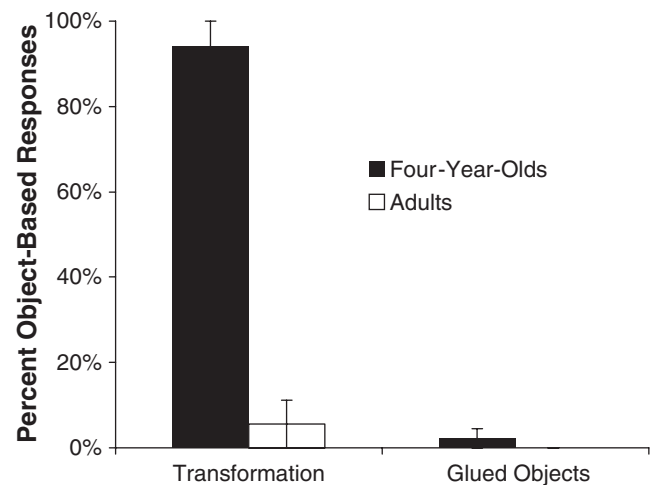
Figure 4 *Percentage of object-based responses by adults and 4-year-olds on Experiment 2 tasks.*

On the Visible Transformation Task, there was no difference in counting behavior whether objects were first seen as broken or whole for either the adults or the children (Broken First vs. Whole First; $ps > .05$). Consequently, we collapsed across the two conditions for analysis. Overall, 4-year-olds counted discrete physical objects on 100% of whole object trials (resulting in adult-like counts) and 94.1% of broken object trials (resulting in mainly non-adult-like counts). Children nearly always counted broken objects as 'two' when their parts were separated, and always counted them as 'one' when the parts were pressed together, regardless of whether they initially saw the object as whole or broken only seconds earlier. Adults gave object-based responses on 100% of whole object trials and 5.5% of broken object trials. The number of object-based responses on broken object trials differed significantly between the two age groups (Wilcoxon $W = 170.50$, $n_1 = 17$ $n_2 = 18$, $p < .001$).

Discussion

The results from the Glued Object Task in Experiment 2 indicate that when the parts of a discrete physical object are non-arbitrary and have their own names (e.g. two

whole shoes) they are counted individually. Not all discrete physical objects with fork properties count as *one fork*. Instead, children *can* use the criteria specified by nouns to pick out units when those criteria are fully satisfied. However, the Visible Transformation Task shows that when two arbitrary parts of an object are combined into one thing, they are counted as *one*, even if the same parts were previously counted as *two* only seconds earlier. Together, the results from these tasks suggest that, in addition to default units, children can also use the criteria specified by nouns to guide quantification. These criteria, however, are not *necessary* for individuation. This is shown not only by Experiment 1, but also by the finding that children count two parts of an object as *two* even after counting the united parts as *one* (e.g. when visibly transformed).

These findings generate a final set of predictions. If children use noun criteria to guide counting of glued objects they should also exclude objects with different names, or broken parts that are nameable. For example, children should ignore shoes when counting broken cups, and should similarly refuse to count nameable parts of things (e.g. wheels) when asked to count whole things of which they are parts (e.g. bicycles). We know that children rarely count parts of objects when they are physically connected to the things being counted (Wagner & Carey, 2003). However, it is unknown whether children exclude nameable parts from their counts when they are broken into separate physical objects, or if they ignore noun information and include these parts as they include more arbitrary parts.

Children's treatment of nameable parts is relevant not only to early stages of quantificational development, but also to how they eventually learn that noun criteria are necessary for guiding quantification. By learning that parts get their own names (rather than inheriting the names of whole things), children might acquire the general principle that only whole objects count as units for quantification. Although children's counts of broken things become increasingly adult-like by the ages of 5 and 6 years (Sophian & Kailihiwa, 1998; Shipley & Shepperson, 1990), they may begin earlier by learning that parts of objects often get their own names, and are therefore counted separately. We tested this idea in Experiment 3.

Experiment 3

Experiment 3 tested whether children exclude detached nameable parts from their counts of objects. In addition, it included two final tasks to verify that children understand the meanings of nouns at age 4, and that they do not include any random objects when performing quantification tasks.

In the first task, we asked children to count broken objects with nameable parts (e.g. bicycles with detached wheels). In the second task, children were asked to count objects in the context of other distractor objects that belonged to different kinds altogether. Thus, the first two tasks probed whether children exclude parts from a count when they belong to another kind.

In the third task, which we will call the What's Wrong Task, children were asked to label both broken and whole objects, and then to say whether anything was wrong with each of them (see Shipley & Shepperson, 1990, for evidence that some children spontaneously label broken objects as broken). This task was included to verify that children know the full conceptual criteria of nouns (i.e. what counts as a single instance of each kind), but fail to treat these criteria as necessary when counting and using quantifiers. Only if a child knows that a piece of a shoe is broken can we conclude that their willingness to include it in object counts is due to the use of default units, rather than incomplete knowledge of the noun's conceptual criteria.

Method

Participants

Twenty-six English-speaking children aged 4;0–5;0 (*M* = 4;5, 13 girls and 13 boys) participated in the Nameable Parts and Distractor Object tasks. Two additional children were excluded from analysis due to failure to understand counting. Sixteen 4-year-olds (five girls and 11 boys, mean age = 4;7, range = 4;1–5;0) participated in the What's Wrong Task. Participants were recruited by telephone or through daycare centers in the San Diego and Toronto areas. Thirteen undergraduate students participated in the Nameable Parts and Distractor Object tasks for course credit.

Materials

Examples of stimuli are shown in Figure 5.

Materials for the Nameable Parts Task were laminated photos of eight object kinds that had nameable parts: trash cans (lids), clowns (arms), tables (legs), bicycles (wheels), umbrellas (handles), butterflies (wings), rabbits (ears), and lambs (legs).

Materials for the Distractor Object Task were the seven objects in Stimulus Set 1, with the broken objects cut into two pieces.

In the What's Wrong Task, children were presented with laminated photographs of cups, socks, forks, and shoes. For each kind, the following set of images was presented to children: two whole objects, two halves that were cut in a jagged line, and one distractor picture that was similar in shape to the whole object picture but was completely black.

Procedure

Nameable Parts Task. Participants were first familiarized with the whole object pictures that were used as stimuli.
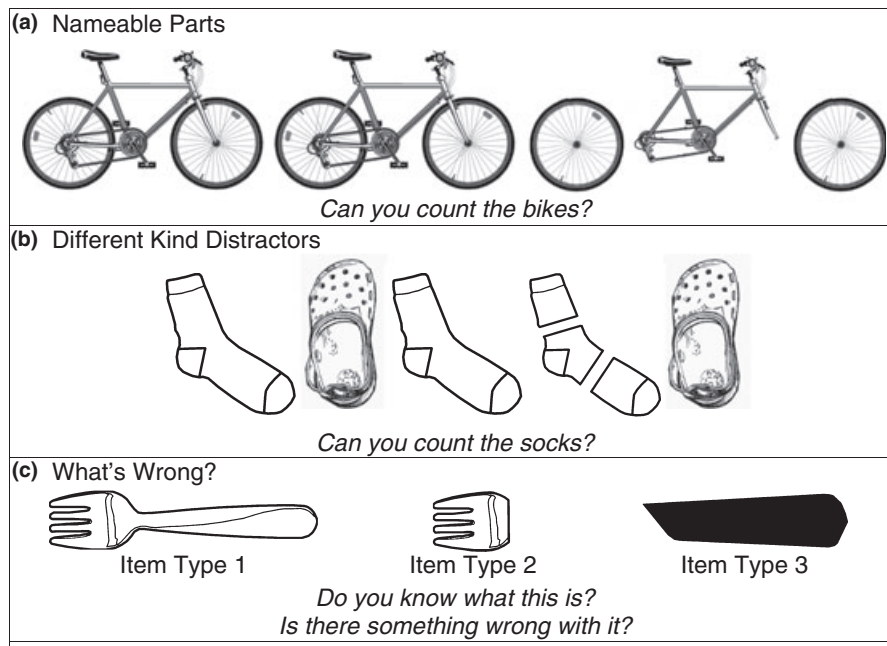
Figure 5   *Sketches of Experiment 3 stimuli and procedures.*

Each whole picture was presented to the participant, who was asked to label the item. If they were unable to label the item, the experimenter provided the label and asked the child to repeat it.

Next, participants were presented with arrays of each object kind. Arrays included 1–3 whole objects and 1–2 objects that had been cut so that the nameable parts were discrete objects (broken objects had between two and five parts in total. The total number of discrete objects depicted in an array ranged from four to 11). As in all other broken object tasks in this paper, the pieces were presented with a small space between them, but in alignment with each other so that participants would be able to tell that they combined to make a single whole object. Participants were asked to count the objects, which were identified by the target noun (e.g. 'Can you count the bikes?'). After the trials, participants were asked to label the object parts, to determine whether they were familiar with the names for these pieces.

Distractors Task. Participants were presented with arrays of two or three whole objects of the target kind, one object of the same kind broken into two pieces, and one or two whole distractor objects of a different kind. Each array consisted of five or six discrete physical objects, and two or three instances of the target object kind. As in earlier experiments, participants were asked to count objects of the target kind (e.g. 'Can you count the forks?'). Each participant was given seven trials, one with each stimulus type in Stimulus Set 1. Each stimulus type also served as a distractor on a trial of a different type.

What's Wrong Task. Participants were initially familiarized with the four kinds of whole objects used in this

task: cups, socks, forks, and shoes, in the same manner as in the Nameable Parts Task.

On test trials, children were presented with laminated images of whole objects, objects that had been cut in half, and black distractor shapes that only vaguely resembled each whole object. Images were placed in front of the child one at a time, and children were asked to name the object. If they did so, they were next asked if there was anything wrong with the picture. If a child said there was something wrong with the image, they were asked, 'What is wrong with it?' On each trial, if a participant failed to name the object or said there was nothing wrong with it, the experimenter continued to the next trial. Five pictures were shown for each of the four object kinds, for a total of 20 trials.

Results

Children, like adults, excluded nameable parts and irrelevant objects from their counts. A 2 (Task) × 2 (Age Group) ANOVA analyzed the percentage of responses on which children and adults excluded nameable parts (same kind) or different-kind distractor objects from their counts. There was no main effect of Task ($F(1, 36) = 1.60$, $p > .05$) and a small, but marginally significant, effect of Age Group, driven by adults' categorical performance on both tasks ($F(1, 36) = 3.69$, $p = .06$, partial eta squared = .09). On the Nameable Parts Task, children excluded nameable parts from their counts on 84.5% of trials, compared to 98.1% for adults, which was not significantly different ($t(36) = 1.75$, $p > .05$). Similarly, there was no difference in the two groups' exclusion of distractor objects (98.1% vs. 100% respectively; $t(36) = -.993$, $p > .05$). A post-test that asked children to label
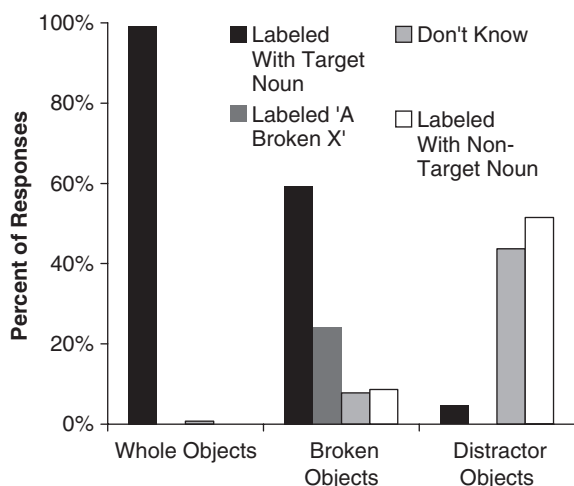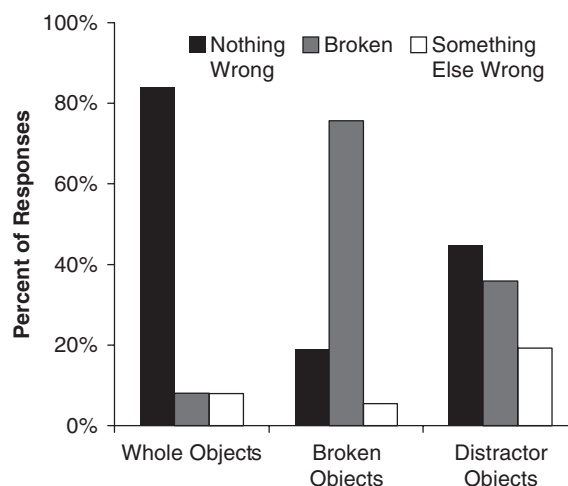
Figure 6 *What's Wrong task results. Responses to the question, 'What does Bob have?' for each trial type.*

Figure 7 *What's Wrong task results. Responses to the question, 'Is there anything wrong with this?' for each trial type.*

the parts of broken objects found that the four items that most frequently elicited broken object counts (umbrella handles, trash can lids, table legs, and butterfly wings) were together about half as likely to be named correctly (46% of trials), relative to the four remaining items (bicycle wheels, clown arms, lamb legs, rabbit ears) which were used with correct labels 88% of the time.[4] However, as can be seen in footnote 4, children correctly labeled broken parts less frequently than they correctly excluded them from counts, raising the possibility that nameable parts are excluded not because children know their names, but because the parts have distinct (and nameable) functions that children recognize. The current study cannot disambiguate between these two possibilities.

Figures 6 and 7 show the results of the What's Wrong Task. When asked to label whole objects, children consistently used the appropriate noun (99.2% of trials). When labeling distractor objects, they either used different nouns (51.6% of trials) or said they did not know the label (43.8% of trials). When asked to label broken objects, 83.6% of children labeled the objects with the target noun. Of these responses for broken objects, 24.4% included words like 'broken' or 'cut'. These words were never spontaneously used to describe whole objects or distractors.

When children were explicitly asked whether there was anything wrong with each object, they were significantly more likely to report that the broken objects were broken (75.7% of trials) relative to whole objects (8.0% of trials, $t(15) = 7.53$, $p < .001$) or distractors (35.9% of trials, $t(12) = 3.15$, $p < .01$).

[4] Percentage of time correctly named vs. percentage of part-counts: Umbrella handles (36% vs. 16%), trash can lids (44% vs. 16%), table legs (28% vs. 16%), and butterfly wings (100% vs. 24%), bicycle wheels (100% vs. 8%) clown arms (100% vs. 0%), lamb legs (100% vs. 4%), rabbit ears (100% vs. 8%).

Discussion

The results of Experiment 3 indicate that children can exclude parts of objects from their counts when they are non-arbitrary and nameable (e.g. ears of a rabbit). Similarly, children restricted their counts to objects (and parts) of the correct *kind*, and ignored distractor objects, or objects of another kind. Finally, they clearly recognized that broken objects were broken, suggesting that they know what counts as a whole shoe, for example. Thus, using the terminology of the sortals literature (e.g. Macnamara, 1986), the 4-year-old children in our studies appeared to know and use the noun's *criteria of application* when counting (i.e. the information that distinguishes apples from oranges). Also, based on the results of Experiments 2 and 3, they likely know the nouns' *criteria of individuation* (i.e. the information that distinguishes one whole apple from two apples). Children differ from adults because they do not treat both sets of noun criteria as necessary when counting and using quantifiers. This account explains why nameable parts are excluded from counts (because they fall under another noun's criteria of application), but arbitrary parts of objects are not (because default units are used instead of the noun's own criteria of individuation).

General discussion

Three studies indicate that 4-year-old children draw on default units of individuation when interpreting numerical language. In Experiment 1, we found that children treat pieces of broken things as units when counting, when interpreting words like *more*, *every*, *both*, and *a*, and when labeling sets using singular–plural morphology. For example, a shoe broken into three pieces was judged to be *more shoes* than two whole shoes. In Experiment 2, consistent with Giralt and Bloom (2000), we found that

although being a discrete physical object is sufficient to support individuation, it is not necessary. Children can also use the conceptual criteria provided by nouns to guide the counting of parts, when those parts have their own names. For example, when familiar objects with known labels were glued together, children used the individuation criteria provided by nouns to pick out units for counting, rather than defaulting to counting discrete physical objects. However, when arbitrary parts of objects that did not have their own names were pressed together, children did not count them as *two*, but as *one*. This was true even though children saw the objects pressed together in plain view, and even though they previously counted the parts as *two*. Finally, Experiment 3 suggested that learning the names for parts may help children overcome their reliance on default units. When the parts of broken objects were nameable (e.g. wheels of a bicycle), children were less likely to include them in their counts of the objects from which they were broken (e.g. bicycles).

The 4-year-olds in our study were presented with familiar objects with known labels, yet failed to treat the noun criteria as necessary for determining units of quantification. These results are consistent with what we will call the Default Units hypothesis: when children learn new words and grammatical morphology they draw on pre-linguistic representations of individuals (e.g. discrete physical objects) to define their linguistic units of quantification. This hypothesis is not only consistent with the results reported here and by other studies of early object and event quantification (Giralt & Bloom, 2000; Shipley & Shepperson, 1990; Wagner & Carey, 2003), but also with the extant literature on how children learn the meanings of nouns. Consider, for example, the Whole Object Assumption (see Carey, 1978; Macnamara, 1972; Markman, 1989, 1990; Mervis, 1987). According to Markman (1990), children 'assume that a novel label is likely to refer to the whole object and not to its parts, substance or other properties' (pp. 58–59). Thus, when they learn the word *rabbit*, for example, they assume that the word refers to the whole animal and not its ears, its fur, or its color alone. The evidence provided here and by Markman and colleagues is consistent with this hypothesis. Children clearly know, by age 4, what counts as a whole shoe or fork. They do not think that *shoe* refers to the laces of a shoe, its sole, its front, or its color.

However, the Whole Object Assumption cannot explain how children select units for quantification. At best, if the hypothesis were extended to explain how quantifiers and numerals are interpreted, it would predict that *three* should refer to a single whole object, like nouns do. At worst, it would predict that children should only count whole objects, and not their parts. Although children may very well exhibit such behaviors when making their first hypotheses about quantifier meanings, they clearly do not use the Whole Object Assumption once they have learned what quantifiers mean. *Two* does not refer to a whole object, but to a *set* that contains two members. Also, as Giralt and Bloom (2000) point out, the Whole Object Assumption is silent about abstract individuals like actions, puddles, and holes, and cannot explain how children learn and interpret the names for object parts, or how they count objects that have been glued together (see also Kobayashi, 1998; Wagner & Carey, 2003).

The Whole Object Assumption, like the current proposal, assigns a special status to discrete physical objects in language acquisition. However, whereas the Whole Object Assumption is unable to explain our results and various others in the literature, the current proposal is more general, and can explain how children interpret known quantifiers, number words, and nouns, as well as how they learn new nouns. For example, in keeping with observations in the word learning literature, the Default Units hypothesis correctly predicts that children will select a discrete physical object as the referent of a novel singular noun. Further, since default units, by our hypothesis, are grounded in pre-linguistic representations of individuals, they include not only discrete physical objects, but also other types of individuals that are perceived and quantified in early infancy (e.g. actions, sounds, and collections that undergo common motion; see Feigenson *et al.*, 2004; Starkey *et al.*, 1983; Wood & Spelke, 2005; Wynn, 1996; Wynn *et al.*, 2002). Finally, the hypothesis predicts that as children learn the meanings of nouns, the conceptual criteria that they provide will become sufficient for individuation (e.g. when naming parts of things) even as default units continue to be used when objects are broken, or when the criteria of the noun are otherwise not fully satisfied. The Default Units hypothesis thus provides a unified account of how children learn not only quantifiers, numerals, and number morphology, but also novel nouns.

Here, we propose that children use two sets of criteria for individuation, each of which is initially sufficient but not necessary. As already noted, we find that, for 4-year-olds, a thing can be quantified linguistically as 'a fork' so long as it is a discrete physical object and has some subset of fork properties (e.g. shape, color, material, texture, etc.), or is clearly broken from a whole fork. Children include broken pieces of objects when counting and when interpreting quantifiers, despite explicitly recognizing that these pieces are not whole objects (i.e. that they are broken). Nonetheless, children can also use their knowledge of nouns to guide counting. They count two glued objects as *two*, they exclude nameable parts from their counts of whole objects, and they do not count distractor objects of different kinds. Thus, for children, either default units or the units specified by a noun are sufficient for individuation, although satisfying a noun's full conceptual criteria is not initially necessary. As a result, when learning quantifiers, numerals, and number marking, children may use either set of criteria to formulate and test hypotheses about their meanings. By using default units, children could begin learning

numerical language early in acquisition, before they have discovered how the nouns in their language individuate. Such a strategy would not only give a head start to acquisition, but would also result in adult-like behaviors most of the time.

Although positing default units might be a good strategy in language acquisition, it is ultimately abandoned by adults. Adults, unlike 4-year-olds, do not count arbitrary parts of things as whole objects. This fact raises two questions that are left unanswered by the current study. First, what causes children to abandon default units later in life? What information leads them to conclude that the criteria provided by nouns are both necessary and sufficient? Second, where does the default units assumption come from in the first place? Is it merely a word learning constraint, designed to solve a particular problem? Or do children's behaviors reflect previously attested properties of language?

Regarding the first point, our study provides a possible clue. As children acquire a lexicon that supplies names for objects and their parts, they learn that the parts of things often do not receive the same labels as their 'hosts'. Parts often get their own names, and when they don't they are described using unitizers like *chunk*, *bit*, *slice*, *portion*, and *piece* (e.g. piece of a shoe). The adult-like use of these words requires rich knowledge about the part–whole structure represented by nouns. For example, for nouns like *shoe* that are typically used in count syntax, the word *piece* picks out a part of a shoe. It cannot pick out whole shoes. Learning this could signal to children that pieces of things are labeled differently from whole things: arbitrary parts of shoes should be counted as *pieces of shoes* rather than as *shoes*.

Regarding the origin of default units, the meaning that children assign to quantified noun phrases, though not entirely adult-like, is not alien to English. It is often noted that, in many cases, both mass nouns and count nouns allow their referents to be divided, while still falling under their denotations, a property that Cheng (1973) called 'divisity of reference' (see Gillon, 1999, for review; see also Prasada, Ferenz & Haskell, 2002). For example, a portion of water divided into two results in 'water over here' and 'water over there', just like a set of horses divided into two results in 'horses here' and 'horses there'. However, for adult speakers of English, a horse divided into two does not result in 'a horse here' and 'a horse there'. Similarly, mass nouns like *furniture* do not allow arbitrary divisity. Unlike a piece of chocolate, which can be divided to get two pieces of chocolate, you cannot cut a piece of furniture in two to get two pieces of furniture (see Barner & Snedeker, 2005). Crucially, however, there are many singular count nouns that do allow divisity, consistent with the semantics that children exhibit in the experiments described above. A rock divided in two is *two rocks*. A string cut in two is *two strings*. Similarly for *hedge*, *chocolate*, *paper*, *cloud*, *puddle*, *party*, *group*, etc. Such examples indicate that chil-

dren must learn, item-by-item, which nouns permit divisity and which do not, regardless of their grammatical class. Thus, children may begin by assuming that count nouns pick out individuals, but may need to learn how each noun defines units of quantification, and whether these units are subject to divisity (see Bale & Barner, 2009; Barner & Snedeker, 2005, 2006; Barner, Wagner & Snedeker, 2008; Chierchia, 1998; Gillon, 1999; Prasada *et al.*, 2002). In the interim, their quantifiers and number words may take on the default semantics, whereby parts are arbitrarily divisible, until children acquire language for describing parts.

To conclude, we have presented evidence that children use default units of individuation when interpreting quantifiers and number words. Default units may help children to begin learning numerical language before they have mastered the meanings of the nouns in their input. These default units operate in parallel with children's emerging use of noun criteria, and are supplanted as children learn that the noun's criteria are not only sufficient, but also necessary for individuation. This may happen as children learn that parts often get their own names, or as they learn that measure words like *piece* and *chunk* label parts. Studies currently in progress are investigating the use of default units in other languages, such as Mandarin Chinese, where classifiers and measure words are more frequent, and are often necessary for counting.

Appendix

This analysis examined how frequently English-speaking children use nouns that appear with quantifiers or number words in caregiver speech.

Participants

Participants were six children from the CHILDES database (MacWhinney, 2000), including Anne, Aran, Becky, Carl, Domin, and Warr (Theakston, Lieven, Pine & Rowland, 2000). For each child, transcripts were included for ages up to 24 months of age (resulting in between three and 13 transcripts for each child). All transcripts consisted of mothers playing freely with their children.

Procedure

We calculated the total number of times each mother used the following quantifiers: *a*, *all*, *another*, *both*, *every*, *none*, *other*, and *some*. Also, we calculated the frequency with which they used the number words *one* through *ten*. Using these data, we then calculated the percentage of these utterances in which the quantifier or number word modified a noun that the child produced over the course of the transcripts.
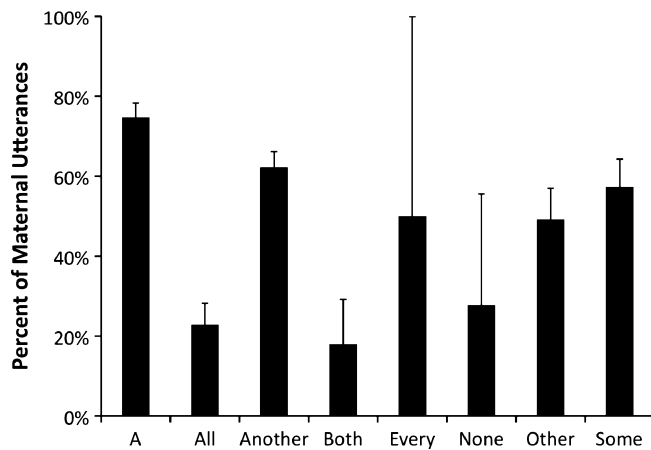
Figure A1 *Percent of maternal quantifier uses that modified nouns also produced in child speech.*
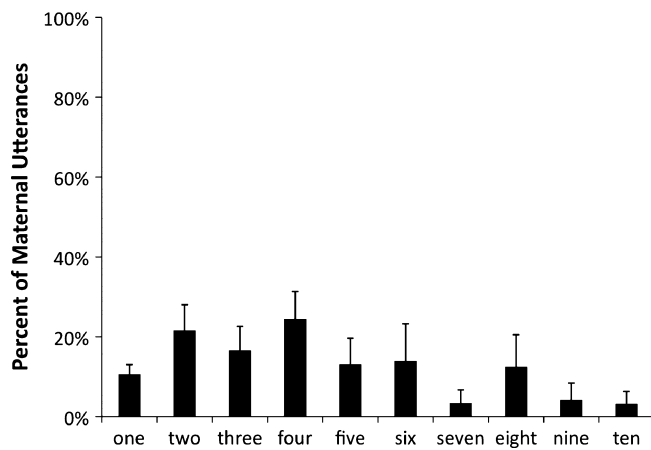
Figure A2 *Percent of maternal number word uses that modified nouns also produced in child speech.*

Results

Overall, number words and quantifiers modified nouns produced by the child in 53.6% of maternal utterances. For quantifiers this number was 67.9% and for number words it was 14.7%. These data varied considerably between quantifiers (see Figures A1 and A2).

Acknowledgements

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