The role of cardinality in the interpretation of measurement expressions

Abstract

The purpose of this brief article is to investigate four-year-olds' interpretation of attributive measure phrases, such as *3-pound*, and the role of cardinality in mediating children's responses. In two experiments, we demonstrate that children at this age are starting to recognize that such MPs refer to a property of an individual, such as weight per unit (rather than the weight of an entire collection). Accordingly, they distinguish between attributive and pseudopartitive MPs. However, when the opportunity presents itself to treat the number word as referring to the cardinality of a set, some children succumb to this pressure, deviating from adult-like responses. We argue that the fundamental aspect of number word meaning that children take the first few years of life to master – that number words denote exact cardinality of a set of discrete objects – is precisely the aspect they must overcome when interpreting these MPs. However, the evidence shows that four-year-olds are well on their way to doing so.

Keywords: semantics, syntax-semantics, measure phrases, number words, cardinality

1. Introduction

The purpose of this brief article is to investigate the role of cardinality in children's developing ability to interpret expressions of measurement. In recent decades, research on children's developing understanding of number words has focused primarily on their knowledge of the cardinal principle, which says that the final tag in a count list carries special significance by indicating the cardinality of a set (Bloom & Wynn, 1997; Briars & Siegler, 1984; Carey, 2004, 2009a, b; Fuson, 1988; Gelman & Gallistel, 1978; Gelman & Meck, 1983; Le Corre & Carey, 2007; Le Corre, *et al.*, 2006; Syrett, Musolino, & Gelman, *in press*; Wynn, 1990, 1992). There is a good reason for this: reference to exact set size represents a core component of number word meaning, differentiating it from lexical items with similar meaning and distribution (e.g., quantifiers such as *some* and other modifiers such as *many*, or *several*). How and under what circumstances children acquire the correct representation of number words remains an outstanding puzzle in the field of language development.

However, full mastery of number word meaning entails being able to correctly interpret phrases in which number words appear, which might not necessarily serve to pick out a set of objects in the real world with the corresponding exact cardinality. In fact, recent work in language acquisition has targeted instances in which a number word in an utterance does not necessarily signal the presence of that exact set size in the world (Hurewitz *et al*., 2006; Noveck, 2001; Musolino, 2004, 2009; Papafragou & Musolino, 2003). However, each of those cases still involves reference to a set of discrete objects, and the research question concerns whether the grammar is structured in a way as to allow the sentence to be true when the cardinality expressed by the number word is a proper subset of the cardinality corresponding to the relevant set of objects in the context.

Number words can also appear in constructions in which the number word does not signal the cardinality of the set of objects. A prime example is measure phrases (MPs). In a phrase such as *8-pound baby*, the number word does not pick out the number of babies, but rather the total weight of the baby, which is not a set of objects in the world, the members of which can be verbally tagged. Thus, the road to becoming fully adult-like in the interpretation of natural language expressions with number words involves navigating through examples that seemingly diverge from the core aspect of number word meaning children strive so hard to master in the first four years.

In this article, we ask when children begin to correctly interpret such expressions of measurement, and what factors account for the instances when their interpretations diverge from those of adults. Here we focus on one factor in particular – cardinality – by manipulating the count-mass status of the target items. We further narrowed our focus to attributive MPs, such as *8-pound X*. In such cases, the number word is prenominal and prosodically prominent, but does not necessarily serve to pick out a set of discrete objects with an exact cardinality. Moreover, the real-world referent is expressed by the second noun (*X*), rather than the one immediately following the number word. Such cases would thus appear to present a special challenge to the language learner. In two sets of experiments, we shed light on this challenging aspect of language development, demonstrating that while four-year-olds exhibit a developing command of the syntax-semantics mapping of attributive MPs, their performance in experimental tasks tapping into this knowledge is mediated by their tendency to interpret the number word in the MP as referring to cardinality of a contextually-relevant set of objects.

2. Semantic background

Measure phrases (MPs) such as those in (1) are constructed from a combination of a number

word or a weak quantifier and a word expressing a unit of measurement. This measure phrase then combines with a noun to form a measurement expression (Jackendoff, 1977; Klooster, 1972; Schwarzschild, 2006).

(1) a. They are the proud parents of an 8-pound baby.

b. I ordered a 2-shot espresso.

c. They drank several bottles of water.

There are two kinds of MPs: attributive MPs and pseudopartitive MPs. The difference is illustrated in (2).

(2) a. 3-pound strawberries (attributive MP)

b. 3 pounds of strawberries (pseudopartitive MP)

While these MPs are minimally different on the surface (i.e., the presence or absence of the number marking on the MP head *pound(s)* and the word *of*), they differ fundamentally in how they measure out amounts. Attributive MPs express a property of individuals (e.g., weight per unit), while pseudopartitive MPs express a property of the whole (e.g., the entire weight). Thus, in (2), (a) entails that each strawberry weighs three pounds, whereas (b) entails that the entire collection of strawberries weighs three pounds. This difference in measuring out quantities has consequences when subtraction is performed on the quantity. Taking away a subset from a larger set of strawberries changes the overall weight of the collection, but it does not change their weight per unit. Formally, this difference in the two MPs is captured by saying that pseudopartitive MPs are monotonic on the part-whole relation, while attributive MPs are non-monotonic (Barwise & Cooper, 1981; Ladusaw, 1982; Link, 1983; Schwarzschild, 2006).

3. Previous research on MPs in child language

Recent investigations of four-year-olds' interpretation of attributive MPs by Syrett &

Schwarzschild (2009) and Syrett (2010) have produced somewhat mixed results concerning children's knowledge of these expressions. In a forced-choice task in which children were given a choice between one card with two cups on it, and two cards with five cups on each, children were more likely than chance to select the individual card when asked to find the *two-cup card* and to select the set of two cards when asked to find the *two cup-cards* (a NN compound with similar surface-level features). Although children correctly appealed to the number of cups on the card to justify their response to the attributive MP, the number word still referred to a set of discrete entities (e.g., the set of cups on the card). Thus, it remains an open question whether four-year-olds can correctly interpret attributives that do not rely upon cardinality of a set.

In a second experiment contrasting attributive and pseudopartitive MPs (*2-cup cards* v. *2 cups of cards*), four-year-olds were able to select the correct referent for the pseudopartitive more likely than chance, but were at chance with the attributive. Once again, however, a question about the role of cardinality arises. It is possible that upon hearing the number word and the MP head, children were drawn to the set of two cups. In the 'pseudopartitive' condition, children retained this choice upon hearing the plural marking (and perhaps *of*). However, in the absence of such information, children in the 'attributive' condition may have found it difficult to overcome their initial selection. While they were pulled away from the two cups, they did not completely switch over to the two cards. The combined set of results leads us to ask to what extent four-year-olds can correctly interpret attributive MPs, and how they will perform when the number does not make reference to the cardinality of a set. The two experiments presented were designed to answer these questions by avoiding a forced-choice scenario pitting the cardinality of the MP head against cardinality of the second noun, and by manipulating the count-mass status of the target items.

4. Experiment 1: Truth Value Judgment Task

4.1. Participants

16 children (8 boys, 8 girls) between the age of 3;6 and 5;3 (mean: 4;3) participated. Data from one additional child was excluded, due to a 'yes' bias across test and filler items. Children were randomly assigned to one of two experimental orders ('count, mass'=9; 'mass, count'=7), balancing for age and gender. Children in both experiments were recruited from area preschools and tested in a quiet room on the premises. All children were normally developing, native speakers of American English.

4.2. Materials and Procedure

The procedure was a Truth Value Judgment Task (TVJT) (Crain & McKee, 1985). One experimenter told the child a series of stories, using supporting images presented on computer slides, while a second experimenter played the role of a puppet, who watched the stories alongside the child. At the end of each story, the puppet said what she thought happened in the story, and the child's job was to say whether she was right or wrong. When the puppet was right, she got to nibble a cookie; when she was wrong, she gulped some milk. Children were occasionally invited to supply justifications for acceptances or rejections.

In an example scenario, Dora is at a farmer's market purchasing strawberries. One farmer is selling huge strawberries (each one weighing 3 pounds), but doesn't have many of them. Another farmer is selling small strawberries and has a lot of them (all together, weighing 3 pounds). Dora needs to decide which strawberries to buy. She thinks about it, and eventually chooses the small strawberries. After the story, the puppet explains that Dora was deciding which strawberries to buy, and that she bought the *3-pound strawberries*. The puppet's utterance for test items always stood in contradiction with the choice favored in the experimental scenario.

Thus, the puppet always used the attributive (e.g., *3-pound strawberries*), but the character in the story never made the choice corresponding to this description (e.g., she bought the *3 pounds of strawberries* instead).

There were two 'count' items (*3-pound strawberries/3 pounds of strawberries*, *2-ton bricks/2 tons of bricks*) and two 'mass' items (*4-foot ribbon/4 feet of ribbon*, *3-foot rope, 3 feet of rope*). There were two orders: one in which the two count items appeared before the two mass items ('count, mass'), and another in which this order was reversed ('mass, count'). In both orders, test items were pseudorandomized with four filler items (designed to elicit both 'yes' and 'no' responses), which involved descriptors in prenominal position (e.g., *red cars*) or a pseudopartitive (e.g., *plate of sandwiches*). Performance with the filler items was at ceiling for all children. We predicted that if children recognized that the attributive described a property of the individual items and not the group, they would reject the puppet's statement.

4.3. Results

Recall that the correct response is *rejection* of the puppet's utterance. Responses to the test items were therefore coded as percentage of 'no' responses, and are presented in Table **1**. In presenting the results, we distinguished between the two experimental orders ('count, mass' and 'mass, count'). We also noticed that within the entire group of children, there were two children within each order who accepted the puppet's response for all test items, but who did not display a 'yes' bias for all items, since they correctly rejected filler items. We therefore included their data in the analysis, but we also present the data without their responses (in parentheses). (10 children correctly rejected the puppet's statement 50% of the time or more, with five children rejecting the puppet's statement on all four trials.) Note that no child ever commented on the oddness of strawberries weighing 3 pounds or of bricks weighing 2 tons.

Table 1: results of Experiment 1, presented as mean percentage of 'no' responses (the correct answer)

	all items	'count' items	'mass' items
all children (excluding four)	51.6 (68.6)	59.1 (79.3)	44.0 (57.9)
'count, mass' order (excluding two)	63.9 (82.1)	61.1 (78.6)	66.7 (85.7)
'mass, count' order (excluding two)	39.3 (55.0)	57.1 (80.0)	21.4 (30.0)

Overall, the children appeared to pattern at chance level, not systematically rejecting the puppet's statement, as would be expected ($t(15)=.32$, $p=.76$) (all t tests two-tailed). (See the top left cell.) The same pattern holds for the overall responses to the 'count' items ($t(15)=.82$, $p=.42$) and to the 'mass' items ($t(15)=-.25$, $p=.81$). However, when the four children who consistently responded 'yes' to all of the test items are excluded from this analysis, we see that children are more likely than chance to reject the puppet's statement overall ($t(11)=2.59$, $p<.05$) – a pattern driven by the 'count' ($t(11)=3.02$, $p=.01$), but not the 'mass' items ($t(11)=.90$ $p=.39$). Things become more interesting when we take into consideration the difference between the two experimental orders in rejections of the 'count' and 'mass' items. Children who responded to statements about the 'count' items before statements about the 'mass' items patterned the same for both item types ($t(8)=-.32$, $p=.76$). By contrast, children who responded to the 'mass' items before the 'count' items were slightly more likely to correctly reject the puppet's statement with the 'count' items than with the 'mass' items ($t(6)=1.99$, $p=.09$).

4.4. Discussion

With the exception of children's responses to the 'mass' items in the 'mass, count' condition, children were generally inclined to reject the puppet's utterance, or approached doing so. Upon encountering the results, we wondered why children in the 'mass, count' order would exhibit

such a low rate of rejection for (i.e., accept) the 'mass' items. In fact, when we reconsidered the actual test items, the children's responses did not appear to be entirely unreasonable. When the puppet indicated that the character chose the *3-foot rope* or the *4-foot ribbon*, we had predicted that the correct response would be to interpret the MP as referring to the width of the rope or ribbon, since the description favored this interpretation. But it is also possible to have a piece of rope or ribbon where the MP refers to the length. Thus, children who accepted this utterance were not necessarily behaving in a non-adult-like way.

An intriguing idea for further research suggested by one reviewer would be to apply the attributive MP to cases that do not involve such ambiguity. Here we saw no difference in responses to the rope and ribbon items, but it is possible that by introducing objects such as string or wire, which are typically measured by length and not width, or by highlighting the role of the specific dimension for the function of the object, we could remove any uncertainty about the dimension to which the MP applies, and further probe children's understanding of these MPs. The response to the 'mass' items makes children's rejection of the 'count' items that much more striking: they seemed to be aware that these MP referred to a property of the individual members of the set, and not the quantity as a whole. It is possible that the improved performance in the 'count, mass' order derives from the emphasis being placed on each individual in the set having the property in question – something that is not possible with the mass items. We return to this possibility in the next experiment.

Overall, the findings from Experiment 1 suggest that preschoolers are beginning to interpret attributive MPs as referring to a property of the individuals and not a property of the entire group, but that the ability to do is dependent on aspects of the context and conceptual features of the objects. Children therefore seem to be aware to some degree that this expression

measures out something like weight per unit, and not weight of the overall quantity, and that the number word in the MP does not necessarily pick out the cardinality of a set. An open question is whether this difference carries over to scenarios probing monotonicity on the part-whole relation, and to what extent cardinality could play a role in this aspect of their interpretation. We explore these questions in Experiment 2.

5. Experiment 2: Subtraction Vignettes

5.1. Participants

20 children (8 boys, 12 girls) between the age of 4;0 and 5;11 (mean: 4;7) and 24 adults participated. Participants were randomly and evenly assigned to one of two experimental conditions (n=10 in each), and within these two conditions to one of two experimental orders (n=5 in each).

5.2. Materials and Procedure

Participants were presented with seven short vignettes (four test and three filler items) involving subtraction of a quantity. Images capturing key components of the plot accompanied each vignette and were presented on slides on the computer screen. The stories were recounted aloud by the experimenter to child participants. Adults read the stories from text on the slides.

In each vignette, the participant was shown an amount of some object, which was described with either an attributive (e.g., *3-pound strawberries*, *4-inch ribbon*) or a pseudopartitive MP (e.g., *3 pounds of strawberries*, *4 feet of ribbon*), depending on the condition. In the 'attributive' condition, it was pointed out that each member of the set (in the count condition) or the relevant mass item had the property expressed by the measure phrase. In the 'pseudopartitive' condition, it was pointed out that the entire quantity had the property expressed by the measure phrase. Two of the vignettes involved a set of discrete 'count' items

(strawberries, bricks), while two involved a 'mass' item (ribbon, rope). The filler items involved the highly frequent adjectives *red*, *delicious*, and *dirty* and were balanced to ensure both "yes" and "no" responses during the test session.

In each scenario, a quantity was removed, leaving some of the objects or mass item remaining. Following each vignette, the participant was asked about the difference of the subtraction operation (i.e., what remained after the subtraction was performed), as in (3).

(3) Do I still have…

a. 3-pound strawberries/4-inch ribbon? ('attributive' condition)

b. 3 pounds of strawberries/4 inches of ribbon? ('pseudopartitive' condition)

The correct response in the 'attributive' condition is 'yes', since some quantity with the original property remains. The correct response in the 'pseudopartitive' condition is 'no', since the total amount is decreased, and the MP is monotonic on the part-whole relation. Given previous findings that preschoolers are successful with similar subtraction problems involving cardinality (see Baroody, *et al.*, 2009; Hughes, 1981; Starkey & Gelman, 1982; Zur & Gelman, 2004), we predicted that the only variability would arise from participants' interpretation of measurement expressions, given the experimental scenario.

5.3. Results

Child and adult responses to the test items are presented in Table **2**. This time, the dependent measure is the percentage of acceptance. As in the previous experiment, we noted a contrast in responses between the 'count, mass' and 'mass, count' orders. Furthermore, within the 'mass, count' order, we noticed a categorical split in response patterns between two groups of the 10 children. (There were no such difference for adults.) For this reason, alongside the averaged results for all items, we present the individual results for the subgroups of items and children.

Table 2: results of Experiment 2: mean percentage of acceptance

	all items		'count' items		'mass' items	
	attrib.	pp	attrib.	pp	attrib.	pp
adults	95.8	6.3	100	8.6	91.7	3.6
children	55.0	22.5	45.5	20.1	65.0	25.0
'count, mass' order	65.0	0	50.0	0	80.0	0
'mass, count' order (a)	8.3	16.7	16.7	16.7	0	16.7
(b)	100	87.5	100	100	100	75.0

We turn first to the responses from the adults. In these results, we see a clear difference between the 'attributive' and 'pseudopartitive' conditions, with adults responding affirmatively to the former, but negatively to the latter ($t(22)=16.93$, $p<.0001$). Moreover, adults were more likely than chance to respond 'yes' in the 'attributive' condition ($t(11)=16.31$ $p<.0001$), and more likely than chance to respond 'no' in the 'pseudopartitive' condition ($t(11)=-9.74$, $p<.0001$). Such results not only provide us with a baseline, but also support theoretical claims about a difference between the two MPs concerning whether or not they are monotonic on the part-whole relation.

Children were also slightly more likely to respond affirmatively in the 'attributive' condition than in the 'pseudopartitive' condition ($t(18)=1.81$, $p=.09$). And like adults, children were also more likely than chance to respond 'no' in the 'pseudopartitive' condition ($t(9)=-2.40$, $p<.05$); however, they were no more likely than chance to respond 'yes' in the 'attributive' condition ($t(9)=.36$, $p=.73$). Because of the split we observed in the 'mass, count' order, we focused our attention on the 'count, mass' order for both conditions. Here, four of the five

children in the ‘attributive’ condition responded ‘yes’ to three (n=3) or four (n=1) of the four test items, while every single one of the five children in the ‘pseudopartitive’ condition for this order rejected all four test items.

Thus, the picture that emerges is that children make a clear distinction between the attributive and pseudopartitive MPs, varying their ‘yes’ and ‘no’ responses based on the MP in the target question. In this way, they are much like our adult participants. And like the adults, they are inclined to respond negatively for subtraction questions with a pseudopartitive MP. Where children diverge from the adults, however, was in their responses in the attributive condition, which hovered around chance unless they were in the ‘count, mass’ order and were evaluating ‘mass’ items. These findings are reminiscent of the findings from Experiment 1. In the next section, we turn to a discussion of the possible source of the response pattern in this experiment, and argue that an inclination to interpret the number word as referring to the cardinality of the set may be responsible for the depressed percentage of ‘yes’ answers observed in the ‘attributive’ condition, and may also have played a role in the consistently rock-bottom acceptance rate for the ‘count, mass’ children in the ‘pseudopartitive’ condition.

5.4. Discussion

In this experiment, adults correctly distinguished between attributive MPs, which measure out a property of individuals (e.g., weight per unit), and pseudopartitive MPs, which measure out a property of an entire quantity (e.g., overall weight). Children, too, were sensitive to this distinction. However, their performance was subject to the actual items and the order in which they saw these items. We are thus left needing to account for the variability among responses, especially in light of the results of Experiment 1 and the results of the previous research reviewed above. Upon further examination of children’s justifications paired with their response

patterns, it appears that the explanation lies in children's tendency to treat the number word in the MP as an indicator of cardinality.

While some children responded to the subtraction question *Do I still have 3-pound strawberries?* correctly, as in (4), others responded as though it were simply a question about the number of strawberries present, as in (5).

(4) a. [child nodded head yes] Because they're the kind … Because they're 3-pound strawberries. (age 4;8)

b. [child nodded head yes] There's two more left. (Experimenter asks, "How much do you think each weighs?") Three pounds. (age 4;10)

(5) a. No. Those are just two. (age 4;1)

b. No, just two. [child held up two fingers.] … Two strawberries (age 4;5)

It is by now well attested that preschoolers are aware that when a subset of items is removed from a larger set, a number word that was applied to the original set no longer applies (cf. Condry & Spelke, 2008; Lipton & Spelke, 2006; Sarnecka & Gelman, 2004). These results have been used to argue that children in these tasks are aware that such numbers refer to an exact numerosity – or cardinality. It is therefore possible that children in the current experiment recruited what they know about the 'exact cardinality' meaning of number words and their application to a set of objects, and were drawn to focus on set size when rendering their response. Note, however, that while this line of reasoning explains the chance-level of responses in the 'attributive' condition and perhaps the suppressed 'no' responses in the 'pseudopartitive' condition, it cannot explain the difference between the 'attributive' and 'pseudopartitive' conditions, which approached overall significance and was significant for the count items. The difference between the conditions must be due to children's recognition that the two MPs

measure out quantities differently—a difference encoded in the syntax-semantics mapping. An intriguing line of follow up research would be to suppress the perceptual salience of numerosity (perhaps occluding the objects all together or simply presenting the linguistic stimuli alone) to see if children's responses to the attributive MPs improve in the absence of visual objects to quantify.

One lingering question is why we observed a level of variability in the 'mass, count' order that was not there for the 'count, mass' order. Although we cannot be entirely sure what the reason was, we speculate that it was precisely because the 'count' items involved a set of discrete objects. In the 'attributive' condition, the experimenter was emphasized that *each* individual member of the set had the property in question (e.g., was a 3-pound strawberry). In the 'pseudopartitive' condition, the experimenter emphasized that *all together* the objects weighed three pounds. This highlighting of linguistic and conceptual properties is not possible with the 'mass' items, which do not involve set membership. Thus, encountering items that permitted this emphasis in the initial trials may have opened doors for children in the latter 'mass' trials.

6. Conclusions

The goal of this brief article was twofold. First, we aimed to investigate young children's interpretation of measurement expressions – specifically their interpretation of attributive MPs. Second, we sought to follow up on previous research suggesting that four-year-olds may be unduly influenced by the cardinality component of number word meaning when interpreting these expressions. In the first experiment, we showed that children trend toward an adult-like interpretation of expressions such as *3-pound strawberries*, recognizing that they refer to a property of individuals, and not an entire collection. In the second experiment, children also

demonstrated knowledge that attributive and pseudopartitive MPs measure out quantities differently, but also appeared to be drawn towards interpreting the number word in the MP as an indicator of cardinality when possible. It thus appears that four-year-olds are on the cusp of fully interpreting these expressions correctly, but are torn between the different senses of number word meaning that are called upon in different linguistic environments, given the context. What the current results also illustrate is that there is ample room for future experimentation to explore a range of factors that may have an effect on children's interpretation of measurement expressions in a real world context, including but not limited to the specific dimension being tested, the role of the dimension in the object function, and the salience or suppression of set numerosity.

Of course, given the extent to which number words appear in count routines, arithmetic operations, and labels for set size, the finding that children are inclined to rely on the cardinality aspect of number word meaning in the interpretation of phrases containing them may not be entirely surprising. But another way to interpret these results is to say that in light of the fact that the scales are tipped heavily in cardinality's favor, it is impressive to discover that at four years of age, many children recognize that a measure phrase can be used to pick out the kind of object based on an individual property of that object such as how much the object weighs or how wide it is. The challenge for future research is to determine the conditions under which children's performance with measurement expressions can be improved, and what children at this age know about the semantic aspects of number word meaning above and beyond cardinality.

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