The Representation and Processing of Measure Phrases by Four-Year-Olds

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1. Introduction

In this paper we investigate young children's understanding of Measure Phrases. Measure Phrases (MPs), such as the underlined phrases in (1), are constructed from the combination of numeral (e.g., *two*) or a weak quantifier (e.g., *several*) and word expressing a unit of measurement (e.g., *feet*, *pounds*, or *cups*), and combine with nouns.

1. a. He needs <u>two feet</u> of rope.

   b. She gave birth to an <u>8-pound</u> baby.

While many investigations of number in linguistic and conceptual development have focused attention on how and when number words are acquired (Carey, 2004; Fuson, 1988; Gelman & Gallistel, 1978; Wynn, 1990, 1992; *inter alia*), and, to a lesser extent, what children have to learn about the interaction of number words with other elements in the syntax and semantics (cf. Musolino, 2004, 2009), the occurrence of number words in expressions of measurement has been largely ignored.

We have narrowed our focus to so-called *Attributive MPs* such as *4-foot rope* and *3-pound strawberries*, where the MP appears in attributive position, because by four years of age, children demonstrate a mastery of a number of key linguistic components for interpreting such MPs. First, they typically have solid counting skills and can map number words onto numerosities beyond the subitizing range. Second, they produce a wide range of NPs where a noun is modified by one or more adjectives. Finally, they both produce and comprehend noun-noun (NN) compounds (e.g., *mouse house*) phrases with similar surface structure.

* This work was funded by a RuCCS postdoctoral fellowship and NIH NRSA postdoctoral fellowship HD-057699. I am grateful to the children and staff at Pennington Presbyterian Nursery School, Douglass Psychology Child Study Center, Rutgers-Livingston Day Care Center, and Lakeview Child Center at Lawrenceville. The presentation of this work was greatly improved by discussions with Roger Schwarzschild, Viviane Déprez, Jane Grimshaw, Julien Musolino, and Rochel Gelman.

Expressions of measurement may pose a challenge for the young language learner for a number of reasons. First, they involve a use of number words that refers to something more abstract than the size of a set of discrete objects in the world. That is, measuring out *3 pounds of strawberries* may be more challenging than counting out *3 strawberries*. Second, children must learn how to talk about measurement, and to do this, they need to know which units correspond to which dimensions of measurement. For example, one needs to learn that we measure weight in pounds or kilograms, and not with inches or degrees. Finally, children need to know that MPs can combine with nouns in different ways (cf. 1a v. 1b), and that this difference in the syntax has implications for the semantics.

Anecdotally, we can observe that the path to full mastery of MPs is not a particularly easy one. Take, for example, this dialogue from the CHILDES database (MacWhinney, 2000) between Adam (Brown, 1973) and his mother. Adam (3;5) is pretending to be a grocer, as his mother requests "2 quarts of milk." In the course of the dialogue, he responds, "2 quarts of milk ... 2 milk butter…3 quarters of milk…2 quarters of milk…2 quarters of 2 milk …Two and one half milk." These errors are not at all surprising: direct instruction about measurement is not formally introduced until much later in school. However, it may be that even at three, children already know something about the *grammar* of measurement that follows directly from their syntactic and semantic representations. In the experiments discussed in this paper, we present preschoolers with situations in which they need not have prior knowledge about the units of measurement in order to more easily examine the syntactic and semantic representations they construct for expressions of measurement.

In Experiment 1, we contrast Attributive MPs with NN Compounds in order to determine whether children represent these MPs correctly in their grammar and have a basic understanding of the syntax-semantics mapping. In Experiment 2, we probe this mapping further by contrasting Attributive MPs with Pseudopartitive MPs, which are highly similar on the surface, but differ in how they measure out quantities. Experiment 2 also allows us to investigate the role of the numeral in children's incremental processing of these MPs. The combined set of results reveals that by four years of age children do represent Attributive MPs correctly, but must overcome the pressure to parse a numeral as though it consistently denotes the cardinality of a set.

2. Experiment 1

The purpose of this experiment was to determine whether four-year-olds represent the syntax of Attributive MPs correctly and recognize the syntax-semantics mapping. In this study, we contrast Attributive MPs such as *2-cup cards* with phrases that bear a resemblance to them on the surface level, but which have a different underlying syntactic structure: NN compounds with a numeral (e.g., *2 cup-cards*). While there are certain prosodic differences between the two types of phrases (i.e., whether the primary pitch accenting is on

the first or second N, and whether the phrase-internal pause is between the numeral and the first N or between the two Ns), these phrases are similar enough that a comparison between the two allows us to tap into children's knowledge of Attributive MPs.

Now while these two types of phrases are highly similar on the surface, their underlying syntactic structures are distinct. (See Figure 1.) In Attributive MPs, the numeral and first noun together modify the second noun (e.g., *cards*). In NN compounds, the first noun modifies the second one, and the numeral picks out the number of such items.

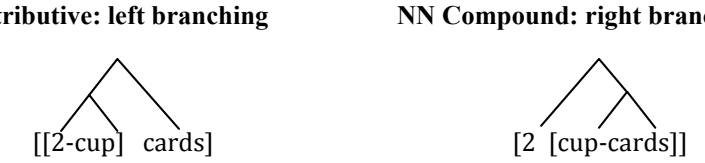


Figure 1: Difference between Attributive syntax and NN compound syntax

Previous research has demonstrated that by four years of age, children produce and comprehend a variety of NN compounds (Berman & Clark, 1989; Clark & Berman, 1984; Clark et al., 1985; Gordon, 1985; Gottfried, 1997; Krott et al., 2009; Nicoladis, 1999, 2003), including those where the two nouns share a relation such as the one in *cup card* (cf. Clark et al., 1985). Furthermore, four-year-olds can distinguish Adjective Noun-Noun phrases from Adjective-Noun Noun phrases using plural marking on the first noun (e.g., *red rat-eater* v. *red-rats eater*, Alegre & Gordon, 1996). Thus it is possible that if children do not properly represent Attributive MPs, they might default to another representation that is already in their grammar.

2.1. Method

20 three-year-olds (11 girls; mean age = 3;7, range = 3;1 to 3;11) and 20 four-year-olds (10 girls; mean age = 4;6, range = 4;1 to 4;11) participated. Data from one additional child was not included in the analysis due to inability to pay attention during the task. Children in both experiments were recruited from preschools or daycares in Central NJ. Only those children whose parents consented participated. Children were tested individually in a quiet room on the premises or in a quiet area of the classroom. Schools were given giftcards as a token of our appreciation. Most parents indicated that their children were White/Caucasian were native English speakers. All children were fluent speakers of American English.

Experiment 1 employed a forced-choice paradigm with two between-subject experimental conditions: Attributive MP+N (Attributive) and NN compound. There were 10 children in each age group in each condition. Gender and age were balanced within and across conditions. Stimuli were jpeg images

of objects edited on computer, printed out, and presented to children on laminated 8.5 x 11" sheets of paper, with a line separating the images on either side. There were 13 items, of which there were eight test items and five fillers. These items were pseudorandomized and presented to children in one of two orders. There was no effect of order of presentation. The test items involved a contrast between an image fitting an Attributive MP+N description and an image fitting a NN compound description (cf. Figure 2), thereby allowing us to determine whether children at the ages tested differentiate between the two.[1]

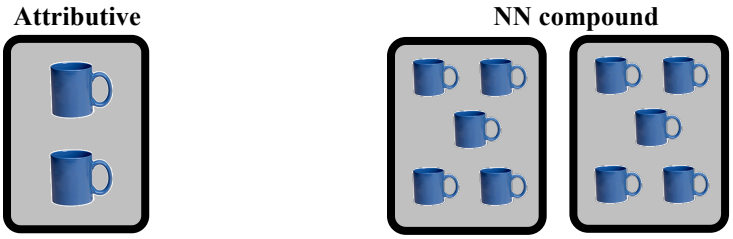


Figure 2: Representative contrast in Experiment 1

For each item, the experimenter instructed the participants to select the target for their condition using wording that did not provide a number cue in the verb (e.g., *Point to / Can you find / Where do you see the …*). The filler items involved object color (e.g., *green boots* v. *green apple*) and were the same for children in both conditions. The request only varied depending on the side of the previous test item so that the side of the correct choice varied throughout the session.

Given previous research on NN compounds, we predicted that at least the four-year-olds in that condition would choose correctly. However, it was also possible that the combination of a numeral with an NN compound could result in some confusion. If children do not represent Attributives correctly, they could either default to familiar NN compound syntax and choose the two cup-cards more often, or perform at chance-level, not knowing what to choose.

2.2. Results

The results from Experiment 1 are presented in Figure 3. At first glance, it appears that while three-year-olds have difficulty with the task, patterning no differently from chance, four-year-olds succeeded in both conditions. In the

[1] It was necessary that the Attributive MP+N be singular, since a contrast between *2-cup cards* and *2 cup-cards* would mean that at least two cards with cups on them were on each side of the sheet. On a related note, no child mentioned the plural ending on *card* when justifying their choice.

Attributive condition, they consistently chose the card with 2 cups (or a similar item), while in the NN compound condition, they chose 2 cards with cups on them (or a similar item). Two-tailed t-tests revealed no significant difference from chance for the three-year-olds in either condition, but a significant difference from chance for four-year-olds in both conditions (Attributive: $t(9) = 1.90$, $p < 0.05$; NN compound: $t(9) = 2.93$, $p < 0.01$). While there was no difference between the two age groups in the Attributive condition ($t(18) = -0.58$, $p = 0.29$), there was a marginally significant difference in the NN compound condition ($t(18) = -1.52$, $p = 0.07$).

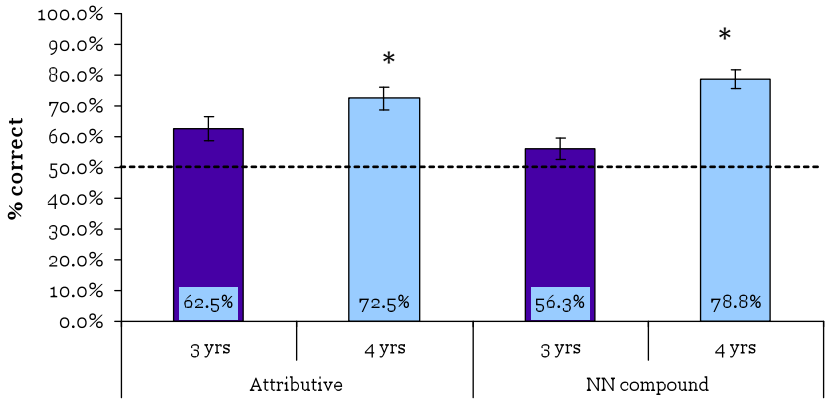


Figure 3: Percentage of correct responses in Experiment 1

Closer examination of the data, however, revealed that within each age group in each condition, there was a split between a group that consistently chose correctly and a smaller group of children who consistently did not (Attributive: 3-year-olds: 89.6% (6) v. 21.9% (4), 4-year-olds: 94.6% (7) v. 20.8% (3); NN Compound: 3-year-olds: 81.3% (6) v. 18.8% (4), 4-year-olds: 92.2% (8) v. 25.0% (2)). Children's justifications in the Attributive condition provide additional support: they typically identified the *2-cup card* by pointing to the two cups on it, contrasting it with the other cards, with five cups on them.

2.3. Discussion

The results of Experiment 1 show that children as young as three correctly distinguish Attributive MP+Ns from NN compounds with numerals, phrases that bear a strong resemblance to them on the surface. When they responded to questions about Attributives, children referenced the number of items on the objects, whereas for NN compounds with numerals, they referenced the number of objects in a set. These results are a first step in demonstrating that preschoolers not only represent the syntax of Attributive MPs correctly, but also have knowledge of the syntax-semantics mapping. In Experiment 2, we contrast

Attributive MPs with MPs that are also similar on the surface to probe their understanding further.

3. Experiment 2

In Experiment 2 we employed imageable, non-standard units of measurement and contrasted Attributive MPs with Pseudopartitive MPs to further investigate their understanding of these expressions of measurement and shed light on the role of numerals in how children construct the syntactic representations of these MPs in real time.

3.1. Method

39 children (18 girls, 21 boys; mean age = 4;2, range = 3;8 to 5;0) participated. This experiment employed a modified *visual world paradigm* (Allopenna, Magnuson, & Tanenhaus, 1998; Altmann & Kamide, 1999; Huettig & Altmann, 2005; Snedeker & Trueswell, 2004; Tanenhaus *et al*., 1995; Trueswell *et al*., 1999; Yee & Sedivy, 2006; *inter alia*).[2] Children were seated in front of a laptop computer screen and were videotaped while participating.

The test session was composed of 16 items, divided into four blocks of four items each. In each block there were three filler items, followed by a test item (see Table 1). Each block was preceded by a screen with the block number in the center, followed by a dark screen, displayed for 1 second. Objects were arranged in four quadrants, including a target, a competitor, and two distractors.

Table 1: Structure of the blocks in Experiment 2 with examples of the target item and its competitor (in parentheses)

	Condition	
	Attributive	Pseudopartitive
filler 1 (phonological, lexical)	one word *horse* (*horn*)	one word *horse* (*horn*)
filler 2 (phonological, phrasal)	NN compound *milk bottle* (*mitten*)	N + complement *bottle of milk* (*ball*)
filler 3 (semantic, phrasal)	Attributive *2-frog hat* (*2 frogs*)	N + PP modifier *hat with 2 frogs* (*hat*)
test	Attributive *2-cup card(s)* (*2 cups of cards*)	Pseudopartitive *2 cups of cards* (*2-cup card*)

[2] Here we present only an analysis of participants' choices in response to the experimenter's instructions and not eye tracking data, for reasons of space.

The filler items served a number of purposes: to provide children with practice scenarios in which a target was accompanied by a competitor and distractors (all fillers), to vary cardinality within the quadrants (fillers 1 and 3), to present children with syntactic constructions that were identical to or as complex as the target phrases in the test item (fillers 2 and 3), and to encourage children to listen through to the end of a phrase in the same scenario (filler 3). The test items involved a contrast between an Attributive MP+N interpretation and a Pseudopartitive MP+N interpretation, as illustrated by the test items presented in Table 2.

Table 2: Experiment 2 targets for the test items in the two conditions

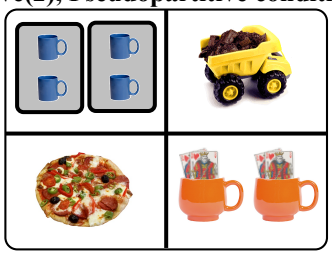
Attributive condition (1, 2)		Pseudopartitive condition	
Target phrase	Target item	Target phrase	Target item
2-cup card(s)	card(s) with 2 cups on it/them	*2 cups of cards*	2 cups with 2 cards in each
2-wagon watch(es)	watch(es) with 2 wagons on the face(s)	*2 wagons of watches*	2 wagons with 2 watches in each
2-box book(s)	book(s) with 2 boxes on the cover(s)	*2 boxes of books*	2 boxes with 2 books in each
2-cart can(s)	can(s) with 2 carts on the outside(s)	*2 carts of cans*	2 carts with 2 cans in each

Children were randomly assigned to one of three between-subject conditions—Attributive (1), Attributive (2), or Pseudopartitive, which differed with respect to which MP they heard and the experimental display. See Figure 4.

Attributive (1) condition

Point to the 2-cup card.

Attributive(2), Pseudopartitive conditions



Point to the 2-cup cards/2 cups of cards.

Figure 4: Representative test displays in Experiment 2

The two Attributive conditions differed only in the number of items in the target quadrant and the plural marking on the second N. The position of the target objects was pseudorandomized across items. Each target or competitor object had two of the other target objects *on* or *in* it (i.e., each card had two cups on it, and each cup had two cards in it). The two distractors also instantiated the concepts ON and IN so as not to make the target objects any more conceptually

or perceptually complex.

Prior to each item within a block, children participated in a naming task. In this portion of the task, children were shown individual same-type, different-token pictures of each of the objects seen in that item's quadrants and were asked to name the object. For each object, the experimenter prompted, "What's this/that," unless such prompting was not necessary. If a child did not know the name of an object, did not recognize the object, or offered an alternative name (e.g., *carriage* for *stroller*) the experimenter provided the intended name of the object and encouraged the child to say it. The naming task ensured that none of the objects was novel and that the names of all objects had been mentioned prior to their presentation in the quadrant. The order of the objects within the naming task was pseudorandomized so that phonological competitor objects never appeared consecutively. Following the naming task, a black screen with a yellow cross in the center appeared for two seconds. The child was asked to look at the cross. The experimenter noted the arrival of the test item by telling the child to "Get ready." The test screen then appeared, and the child was asked to point to one of the quadrants.

A brief training session preceded the test session. The purpose of this session was to introduce children to the format of the task given a simplified scenario in which there were no competitor objects and children were not under any time pressure. No child had difficulty with these items.

Children's responses were predicted to follow different patterns, based on their knowledge of the MP syntax and their incremental processing of the experimenter's utterance. If children first locked on to the numeral *two*, they should first narrow down the quadrants in the display based on this information, then make their selection using another strategy or choose at random. If children simply chose based on the content of the first noun, also most likely a result of incremental processing of the utterance, the choice of the Pseudopartitive target (e.g., *2 cups of cards*) should most likely be above chance in every condition, because the first noun in both MPs (e.g., *cup(s)*) refers to the two discrete objects in this quadrant. Finally, if children represent the MPs correctly and are not mislead by their incremental processing of the instructions, their choice of the target should be above chance in every condition: Attributive conditions: *2-cup card(s)*, Pseudopartitive condition: *2 cups of cards*.

3.2. Results

As children were at or near ceiling for the three sets of filler items (Filler 1: Att (1): 98%, Att (2): 98%, PP: 96%; Filler 2: Att (1): 100%, Att (2): 100%, PP: 98%; Filler 3: Att (1): 96%, Att (2): 100%, PP: 100%), we therefore concentrate on their responses to the four test items in the three conditions. These results are presented in Figure 5. Note that children never pointed to the distractors; their choices were always between the target and the competitor. We therefore treat chance as 50%, rather than 25%. In one-tailed t-tests, only children in the Pseudopartitive condition chose the target more often than predicted by chance

($t(12) = 10.15$, $p < 0.0001$). Children in the Attributive (2) condition were at chance between the two MPs, while children in the Attributive (1) condition were surprisingly more likely to select the competitor ($t(12) = -2.20$, $p < 0.03$).

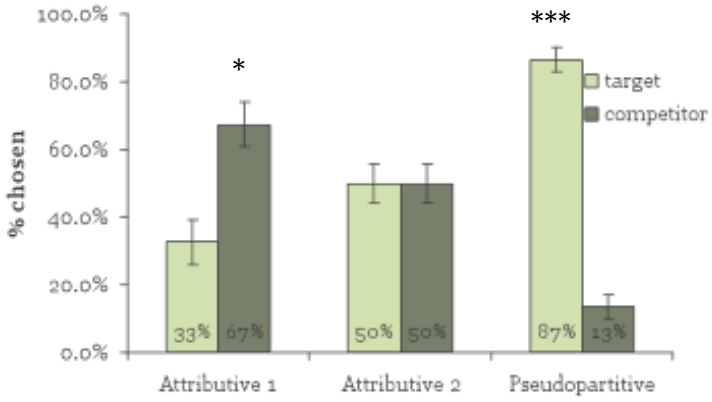


Figure 5: Percentage of choice of target and competitor in Experiment 2

While one might be led to conclude from these results that children can correctly parse Pseudopartitive MPs, but their ability to parse Attributive MPs is still developing, this conclusion is not supported by the results of Experiment 1. Children did not consistently choose based on the first noun, as the same pattern of responses is not observed across conditions. Because children did not consistently choose the correct target in each condition, we are forced to look at other factors that could be responsible for this pattern of responses. While we cannot say with certainty what the time course is for children's processing of these phrases based on these data alone, it seems that children recruited some combination of surface-level cues when choosing a quadrant. The pattern of results appears to support a strategy in which children first parse the numeral, and then use prosodic cues, the presence of plural marking on the first noun, and/or the *of* following the first noun to further narrow their selection. In the next section we sketch out some details of what such an account might involve.

3.3. Discussion

In Experiment 2, we observed that when asked to point to the *2 cups of cards*, children overwhelmingly chose correctly. By contrast, when asked to point to the *2-cup cards*, they were at chance. Even more surprising, perhaps, was that when children were asked to point to the *2-cup card*, they were more likely to choose the competitor, the two cups with cards in them. Above, we suggested that the parsing of the phrase-initial numeral could play a role in this pattern of responses. Here we elaborate on this hypothesis.

Upon hearing the numeral *two*, children begin by narrowing down their selection to all quadrants with two discrete objects in them. In the Attributive (1) condition, there is only one such quadrant, the one with two cups in it (cf. the lower right quadrant of the first display in Figure 4). Upon directing their attention to this quadrant, children have difficulty going back to revise their parse, and so are likely to incorrectly select this quadrant when asked to point to the *2-cup card*. In the Attributive (2) and Pseudopartitive conditions, there are two competing quadrants – the one with the two cards and the one with the two cups (cf. the upper left and lower right quadrants of second display in Figure 4). In these conditions, children must continue to listen to the instructions to make their selection. The fact that these two conditions do not display similar patterns appears to indicate that children are parsing the MPs differently; otherwise, we would expect to see the same pattern in both conditions – either chance-level performance or selection of the quadrant containing the two cups. It may be that the presence of the plural marking on *cups* in the Pseudopartitive condition, along with the prosodic cues, helps children choose correctly in this condition, while in the Attributive condition, the lack of plural marking on the head of the MP confuses them, leading them to choose randomly.

Such errors in parsing caused by extragrammatical factors have been attested in a wide range of linguistic phenomena. For example, when presented with a NN compound in a forced-choice paradigm such as *mouse-hat* (Clark *et al*., 1985) or *stick-bug* (Gottfried, 1997), children may choose the object referred to by the first noun (e.g., the mouse or the stick) instead of a picture described by the entire phrase. Likewise, when given a choice between multiple objects of the same kind that are different colors and asked to select a target object, children who are learning languages in which adjectival modifiers follow nouns (e.g., Hebrew (Ninio, 2004), Spanish (Weisleder & Fernald, 2008)) may choose the object before attending to the following modifier and therefore select the wrong object. And finally, when given instructions such as *Put the frog on the napkin in the box* (Trueswell *et al*., 1999), children may attach the first PP to the VP as a locative instead of inside the NP as a restrictive modifier, therefore incorrectly assigning it a 'destination interpretation'.

Perhaps most relevant to this study, however, is previous research on how children process ordinals (e.g., *second*). Roeper (1972) and Matthei (1982) reported that when given instructions such as *Point to the second green ball* in a scenario such as the one captured in Figure 6, children age four to six have been known to pick the second ball, instead of the third ball (the correct choice).

red ball green ball green ball red ball red ball green ball

Figure 6: Scenario for *Point to the second green ball*

The fact that Matthei (1982) also reported a similar trend when children are asked to point to *the second ball* in a series of boxes and balls points to the role of the incremental processing of the ordinal. In fact, Hamburger and Crain

(1984) showed that when four- to six-year-olds are allowed to handle the objects first, and are given the instructions before being shown the objects, their performance improves significantly. In the current study we appear to have observed a similar situation with numerals.

Indeed, there is independent evidence that although children in the Attributive (1) condition were more likely to choose incorrectly, they still may have encoded the syntax correctly, and that this had an impact on the semantics. Children who first participated in the Attributive 1 condition of Experiment 2 were more likely to answer questions about the measurement of part-whole relations in a follow-up subtraction-oriented task than those children who had no such prior exposure. So while they were ostensibly misled by the presence of the numeral, they may as yet have represented the Attributive MP correctly.

4. Conclusions

Two experiments designed to assess preschoolers' knowledge of Attributive MPs such as *2-cup cards* lead us to conclude the following. First, children are able to distinguish these MPs from other phrases with similar surface-level features, NN Compounds preceded by a numeral and Pseudopartitive MPs. Second, by four years of age, children know that the numeral and first N combine to pick out an attribute of the second N. However, the presence of the numeral can also be misleading, as children as drawn to treat it as a cardinality indicator and interpret it as picking out discrete entities in the discourse. As with other linguistic expressions, the pressure to do so in real time can result in performance that masks children's underlying knowledge of these MPs.

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