

Quantification in Child Language

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"Who did you pass on the road?" the King went on, holding out his hand to the Messenger for some more hay.

"Nobody" said the Messenger.

"Quite right," said the King: "this young lady saw him too. So of course Nobody walks slower than you."

"I do my best," the Messenger said in a sullen tone. "I'm sure that nobody walks much faster than I do!"

"He can't do that," said the King, "or else he'd have been here first"

- Lewis Carroll, *Through the Looking-Glass and What Alice Found There*

Introduction

Quantificational expressions, like "every student", "no teachers", or "some of the books", provide us with the power to generalize, to express properties and relations that hold not just of individuals but of whole classes of individuals. As such, they can be contrasted with referring expressions. Indeed, the King's error in the passage above was to treat *nobody* as though it referred to an individual whereas the intended meaning was to generalize across all walkers. *Nobody walks faster than I do* expresses the idea that there is no individual whose speed exceeds mine. Said differently, if you measured everyone's walking pace, none of them would surpass mine. In this sense, the quantificational expression *nobody* allows us to generalize across all possible comparisons, not simply to compare two individuals.

Natural languages make use of numerous devices for expressing this kind of quantification. We have words whose meanings make reference to specific quantities (1, 2, 3,...), to approximate quantities (*a few, several*), to existence

(*some, any*), to universals (*every, all*), and to comparisons among quantities (*more, most*). In this chapter, we explore grammatical and psycholinguistic issues in children's acquisition and use of quantificational expressions.

In section 1, we begin with a discussion of the cognitive mechanisms that provide content to quantificational expressions in natural language. We focus on the capacity to represent number both approximately and precisely as well as the capacity to form set representations and use them for memory and cognition. We then discuss the role of syntax in identifying a novel word as quantificational. We end this section with a discussion of constraints on possible quantifier meanings.

In section 2, we examine the syntax and semantics of quantifiers in development. Critical to this investigation is the interaction between multiple quantifiers in a single sentence and between quantifiers and other potentially scope bearing elements. We explore the grammatical and psycholinguistic constraints at play in shaping children's acquisition and use of quantificational expressions, highlighting factors that can mask children's competence in this domain.

1. Learning Quantifiers

1.1 Cognitive Prerequisites: Approximation, Number and Sets

Humans have multiple ways of representing number (Gelman & Gallistel 1978, Carey 2009). First, we have the ability to approximate the number of items in a scene, through the Approximate Number System (ANS; Dehaene, 2009; Feigenson, Dehaene, & Spelke, 2004), a system of imprecise number representation shared by animals as diverse as rats (Meck & Church 1983),

guppies (Piffer, Agrillo, & Hyde, 2011), dolphins (Kilian, Yaman, Von Fersen, & Güntürkün, 2003), and gorillas (Beran & Rumbaugh, 2001).

The ANS provides us with a non-exact estimate of cardinality, and is the likely source of our gut-instincts about number, such as those we use when guessing how many marbles are in a jar. The critical signature of the ANS is that accuracy in discriminating two quantities (e.g., 10 cats versus 5 monkeys) is ratio-dependent: low ratios (e.g., 6:5, a ratio of 1.2) are very difficult to discriminate, while high ratios (e.g., 10:5, a ratio of 2.0) are very easy to discriminate. Discrimination is insensitive to the numerical distance between two numbers. For example, people show the same discrimination abilities for a 6:5 ratio as for 18:15 ratio, despite the fact that the difference in the latter is three times as big (Dehaene 1997, Barth, Kanwisher & Spelke 2003).

The ANS is also found in human newborns and infants (Izard et al 2009; Xu & Spelke 2000). For example, Xu and Spelke used a habituation paradigm to test 6-month-old infants' discrimination of the numerosities 8 vs. 16. Infants first saw repeated presentations of either 8 or 16 dots (non-numerical dimensions such as size and area were controlled so that infants could only respond based on numerosity). When tested with alternating arrays of 8 and 16 dots, infants looked longer at the numerically novel test arrays regardless of whether they had been habituated to 8 or 16, showing that they successfully responded to number. The same paradigm also shows that 6-month-olds can also distinguish 16 from 32 dots (maintaining the 2:1 ratio of the previous experiment), but not 8 vs 12 or 16 vs. 24 (i.e., a 2:3 ratio). The most difficult ratio that can be reliably discriminated,

known as the Weber fraction (or w), has been shown to improve over developmental time (Halberda & Feigenson, 2008; Halberda, Ly, Wilmer, Naiman, & Germine, 2012; Odic, Libertus, Feigenson, & Halberda, in press). By providing an estimate of the numerosity of a collection of individuals, the ANS may be a critical psychological mechanism for providing content to natural language quantifiers.

The second way in which people can represent number is through the natural numbers (e.g., *one*, *five*, *thirty-seven*). Unlike the ANS, natural number knowledge provides us with an exact, but effortful, sense of number, and discriminability is not ratio-dependent. Unlike the ANS, knowledge of the natural numbers is not evident in young children. Instead, they must learn the meaning of natural numbers through a slow and protracted period of development (Carey, 2009; Gelman & Gallistel 1978; Le Corre & Carey, 2007; Wynn, 1992). First, at around age 2, children begin counting; at this time, however, they do not understand the significance of this action, and use the count list much like a song (e.g., like their ABCs). Sometime around their 3rd birthday, however, children learn the meaning of *one*. At this stage, they can reliably give the experimenter one item when asked to do so, but a request for any other number will result in a random number of things (Wynn, 1992). After another few months, children then learn the meaning of *two*. During this stage, children exhibit knowledge of the meaning of *one* and *two* by a variety of measures while all other number words remain undifferentiated. A few months more and they learn *three*, and, by sometime around their 4th birthday, they appear to infer the meaning of all natural

numbers, and can now reliably provide the experimenter with as many items as they requested. At this point, children are considered “cardinality-principle knowers”, or CP-Knowers (Carey, 2009; Wynn, 1992). Interestingly, even when children become CP-Knowers, it still takes some time for them to map the number words onto ANS representations (LeCorre & Carey 2009).

Representing precise cardinality, however, only scratches the surface of what people know about number words and other quantifiers, which also display complex interactions with other linguistic expressions, as we will review below. Nonetheless, it is important to determine whether knowledge of precise cardinality is a prerequisite for the acquisition of natural language quantifiers (Halberda, et al., 2008, Barner et al., 2009), an issue we return to below.

Representing the cardinality of a set requires not just knowledge of cardinality but also the capacity for representing sets. Set representations are necessary but not sufficient for building quantifier meanings, however. Quantifiers like *every*, *some*, or *most*, also require representing a relation between two sets. For example, when we say “every crayon is broken,” we are expressing a relation between the set of crayons and the set of broken things such that the former is a subset of the latter (Barwise & Cooper 1981). Set representations also appear to be in place in children well before they begin to use quantificational language. This can be seen by examining the interaction between object representations and working memory.

Many studies suggest a strict limit on the number of object representations that can be maintained in working memory at any given time (Sperling 1960, Luck &

Vogel 1997, Scholl 2001). For example, adults shown four or fewer objects will easily detect a change to any one of the object's features, but are much less likely to notice a change when shown more than four objects (Luck & Vogel 1997). The same limit constrains working memory early in development. Infants can remember one, two, or three individual objects at a time but not more than this (Feigenson & Carey 2003). For example, Feigenson & Carey (2003) showed infants a particular number of identical objects being hidden inside a box, and then retrieved just a subset of them. Infants' patterns of searching in the box indicated whether they remembered the total number of objects originally hidden. Infants from 12 to 20 months searched correctly when three or fewer objects were hidden, but failed when more than four objects were hidden.

Correct searching in the hidden objects task does not require a representation of number or sets, however, only a pointer to individual objects and a limit on how many objects can be held in memory. Strikingly, however, the number of objects that infants can remember increases if the objects can be chunked into sets. Using the same hidden object task, Feigenson and Halberda (2004) show that 14-month-old infants can remember four hidden objects if they are presented as two spatially separated sets of two, but not if they are presented as a single spatially unified set of four. Similarly, infants also can use semantic knowledge to group individual objects into sets. By 14 months infants can simultaneously remember two sets of two cats and two sets of two cars, but not a single set of four different cats or four different cars (Feigenson & Halberda 2008). Thus, the capacity for set representation appears to be in place early in

development and can thus support the acquisition of quantificational language.

In sum, quantificational meanings in natural language would seem to depend on three independent cognitive faculties that build representations of approximate number, precise number and sets. While approximate number and set representations appear very early in development, precise number appears in a more protracted fashion during development. Thus, an important research question concerns the degree to which these representational systems are engaged in the acquisition of natural language quantifiers.

1.2 Learning quantifiers: semantic resources

1.2.1 Number knowledge as a prerequisite?

Given the protracted development of precise number representations in children, we can ask whether number representations are a prerequisite for learning other quantifiers. For example, the meaning of a proportional quantifier like *most* is typically expressed in terms of cardinality representations, as in (1a).

- (1) a. $\text{most}(X,Y) = \text{True iff } |X \ \& \ Y| > |X - Y|$
 b. Most of the crayons are broken.

Thus, (1b) is true just in case the number of broken crayons is greater than the number of unbroken crayons. Do children have to have acquired number words, in order to represent the meanings of quantifiers that seem to have numerical content?

Initial evidence may be consistent with this possibility. Children's acquisition of *most* has been shown to be protracted. Papafragou and Schwarz (2005) found that in contexts where children need to verify whether a dwarf "lit most of the candles", children do not appropriately select situations in which

more than half of the candles are lit until well after their 5th birthday, an age at which they are already prodigious counters. Barner and colleagues (Barner, Libenson, et al., 2009) have likewise shown that both English- and Japanese-speaking 4-year-olds often interpret *most* in a non-adult way, often to mean what *some* means, and do not yet appreciate that *most* is only true in more-than-half situations.

On the other hand, studies that provide children with clear alternatives in the question (e.g., “Are most of the crayons blue, or yellow?”) seem to find better performance even in 4-year-olds (Halberda et al., 2008), suggesting that children have at least some meaning for *most* by this age, though it perhaps undergoes further development.

Indeed, Halberda, Taing & Lidz (2008) asked about the dependence of *most* on number knowledge by examining correlations in between performance on a *most* task (*are most of the crayons blue, or yellow?*) and their performance on standard number knowledge tasks (Gelman & Gallistel 1978, Wynn 1992). These authors found a significant number of children who acquired *most* prior to learning the cardinality principle. Moreover, these children, despite not knowing natural numbers, showed clear ratio-dependent performance - the critical signature of the ANS. Thus, prior to acquiring natural numbers, the ANS may provide the content over which children’s understanding of *most* develops.

Moreover, Odic et al (2014) showed that even when children acquire the cardinality principle, it still takes several months before they begin to use their number knowledge in verifying sentences containing *most*. They found that

young CP-knowers use the ANS to verify *most* sentences, even directly after counting the items in the array and hearing the experimenter repeat the numbers (e.g., *There are 9 goats and 5 rabbits. Are most of the animals goats, or rabbits?*). These findings suggest that the initial meanings for quantifiers do not depend on knowledge of cardinality and that the ultimate representation of quantity in semantic representations must be broad enough to be verified by both precise cardinalities and by ANS representations (see also Odic et al 2013 for evidence about the count-mass distinction in early comparative quantifiers).

1.2.2 Possible quantifier meanings: the case of conservativity

In the framework of generalized quantifier theory (Mostowski 1957), sentences with the form in (2) express a relation between two sets: the set of dogs, and the set of brown things.

- (2) a. every dog is brown
b. some dogs are brown
c. most dogs are brown

If we represent these sets by DOG and BROWN, respectively, the truth conditions of the three sentences in (2) can be expressed as in (3).

- (3) a. 'every dog is brown' is true iff $DOG \subseteq BROWN$
b. 'some dog is brown' is true iff $DOG \cap BROWN$
c. 'most dogs are brown' is true iff $|DOG \cap BROWN| > |DOG - BROWN|$

When we examine the set of determiners that occur in natural language, a striking generalization emerges about the relations they pick out: all natural language determiners are conservative (Keenan & Stavi 1986, Barwise & Cooper

1981, Higginbotham & May 1981). A determiner is conservative if the following biconditional holds:

$$(4) \quad R(X,Y) \Leftrightarrow R(X, X \cap Y)$$

For example, “every” expresses a conservative relation because (5a) and (5b) are mutually entailing:

- (5) a. every dog is brown
 b. every dog is a brown dog

Perhaps more intuitively, conservative relations “live on” their internal argument. In determining whether (5a) is true, one need only consider the dogs; other things that are brown (e.g., cats, beavers, grizzly bears, etc) are irrelevant.

Assuming that innate properties of the language faculty are to be expressed in typological generalizations, a reasonable hypothesis to consider is that the lack of non-conservative determiners in the world’s languages derives from the (in)ability of the human language faculty to associate sentences like those in (2) with the claim that a non-conservative relation holds between the set of dogs and the set of brown things (cf. Pietroski 2005, Bhatt & Pancheva 2007, Fox 2002 for analyses). Of course, it could also be the case that typological generalizations like the restriction to conservative determiners fall out not from constraints on possible meanings, but from the interaction between a less restrictive language faculty and other properties of experience.

Indeed, Inhelder & Piaget (1964) observed that some children will answer ‘no’ to a question like (6) if there are blue non-circles present. When prompted, these children will explain this answer by pointing to, for example, some blue

squares.

(6) Are all the circles blue?

Taken at face value it appears that these children are understanding (6) to mean that (all) the circles are (all) the blue things. Since answering (6) on this interpretation requires paying attention to non-circles that are blue, this would mean that children had acquired a nonconservative meaning for *all*.

Similar 'symmetric responses' have been observed with questions like (7) involving transitive predicates. Some children will answer 'no' to (7) if there are elephants not being ridden by a girl (Philip 1995); see Geurts (2003); Drozd (2000) for review.

(7) Is every girl riding an elephant?

Consider the interpretation of *every* that these children appear to be using. If *every* is analysed as a determiner with a conservative meaning, then answering (7) should require only paying attention to the set of girls (and which of the girls are riding an elephant), since this is the denotation of the internal argument *girl*. Clearly *every* is not being analysed in this way by the children for whom the presence of unriden elephants is relevant. However, these children are also not analysing *every* as a non-conservative determiner. Such a determiner would permit meanings that required looking beyond the set of girls denoted by the internal argument and take into consideration the entire set denoted by the external argument; but crucially, the external argument is [*is riding an elephant*] and denotes the set of elephant-riders, not the set of elephants. So allowing a non-conservative relation into the child's hypothesis space would leave room for

an interpretation of (7) on which the presence of non-girl elephant-riders triggers a 'no' response, but would do nothing to explain the relevance of unriden elephants. On the assumption, then, that the symmetric responses to (6) and (7) are to be taken as two distinct instances of a single phenomenon, this phenomenon is more general than (and independent of) any specific details of determiners and conservativity.

Looking more directly into the source of children's symmetry errors, Crain et al. (1996) have argued that these errors have more to do with the felicity of the question than with children associating an incorrect meaning with the quantifier. In contexts where it is clear which elements of the scene are relevant to answering the question, children do not make symmetry errors. Thus, children's symmetry errors do not speak directly to the question of the origins of the constraint on conservativity. Similarly, Sugisaki & Isobe (2001) show that children make fewer symmetry errors when there are a greater number of extra elements (e.g., 3 unriden elephants instead of 1) in the display, suggesting a nonlinguistic source for symmetry errors.

Keenan and Stavi (1986) suggest that learnability considerations may play a role in explaining the origins of conservativity. They argue that the size of the hypothesis space for possible meanings would be too large if it allowed both conservative and nonconservative relations. In a domain with n elements, there are 2^{4^n} possible determiner meanings, with 2^{3^n} of these being conservative. However, Piantadosi et al (2014) argue, based on a computational model of quantifier learning, that even with a hypothesis space containing nonconservative

determiners, it is possible to learn the English quantifiers. Nonetheless, this result leaves unexplained the typological generalization about extant determiner meanings, and does not address the question of whether children consider nonconservative relations when learning natural language quantifiers.

To assess this question more directly, Hunter & Lidz (2013) taught children two novel determiners, one which was conservative and one which was nonconservative. The determiners in Hunter & Lidz (2013), both pronounced *gleeb*, had a meaning like “not all”. The conservative variant of this determiner is given in (8a) and its nonconservative counterpart in (8b):

(8) a. $\text{gleeb}(X,Y)$ is true iff $X \not\subseteq Y$.

b. $\text{gleeb}'(X,Y)$ is true iff $Y \not\subseteq X$.

(9) *gleeb* girls are on the beach

So, on the conservative use of *gleeb*, (9) is true just in case the girls are not a subset of the beach-goers. Or, said differently, it is true if not all of the girls are on the beach. This relation is conservative because it requires only attention to the girls. Similarly, the biconditional in (10) is true.

(10) *gleeb* girls are on the beach \Leftrightarrow *gleeb* girls are girls on the beach

On its nonconservative use, (9) is true just in case the beachgoers are not a subset of the girls. It is true if not all of the beach-goers are girls. This relation is nonconservative because evaluating it requires knowing about beach-goers who are not girls. The biconditional (10) comes out false for this meaning because the sentence on the right can never be true whereas the one on the left can be. That

is, *gleeb girls are girls on the beach* would mean “not all of the girls on the beach are girls”, which can never be true.

Hunter & Lidz found that 5-year-old children were able to successfully learn the conservative quantifier, but not the nonconservative one. Note that the conditions expressed by these two determiners are just the mirror image of each other, with the subset–superset relationship reversed. By any non-linguistic measure of learnability or complexity, the two determiners are equivalent, since each expresses the negation of an inclusion relation. Thus, the observed difference should follow not from extralinguistic considerations, but rather from constraints on the semantic significance of being the internal or external argument of a determiner.

An additional way of seeing the asymmetries between the internal and external arguments of a quantifier comes from the monotonicity profiles of real quantifiers. Consider, for example, the pattern of entailments among the sentences in (11).

- (11) a. every dog bit a cat
b. every chihuahua bit a cat
c. every dog bit a siamese cat

The sentence in (11a) entails the sentence in (11b), but not the sentence in (11c). The sentence in (11c) entails the sentence in (11a), but the sentence in (11b) does not. These patterns reflect the fact that *every* is downward-entailing in its first argument, but not its second. Because chihuahuas are a subset of dogs, anything that is true of every dog will also be true of every chihuahua. Similarly

events of siamese cat-biting are a subset of the events of cat-biting in general. However, *every* is not downward entailing in its second argument, and so this subset-superset relation is unrelated to the meaning of *every*. Consequently, (11a) does not entail (11c). Note that different quantifiers show different properties with respect to these entailments. For example, *some* is not downward-entailing in its first argument. (12a) does not entail (12b).

- (12) a. Some dogs are running
b. Some chihuahuas are running

Gualmini, Meroni & Crain (2005) used these entailment patterns to show that children's early understanding of *every* is appropriately asymmetric. They showed that 5-year-olds correctly interpreted disjunction conjunctively when it occurred in the first argument of *every*, but not when it occurred in the second argument. That is, (13a) implies that both every boy who ate cheese pizza *and* every boy who ate pepperoni pizza got a snack. But, (13b) does not entail that every ghostbuster will choose both a cat *and* a pig. (see Goro, this volume, for further discussion of the interpretation of disjunction):

- (13) a. every boy who ate cheese pizza or pepperoni pizza got sick
b. every ghostbuster will choose a cat or a pig

In sum, children's knowledge of the asymmetries between the internal and external arguments of quantifiers appear to be in place by preschool. Moreover, these asymmetries, as illustrated through a constraint on possible determiner meanings, contributes to children's acquisition of novel quantifiers.

1.3 Learning quantifiers: syntactic contributions

Having identified some semantic conditions on early quantifier meanings, we now turn to the question of how children identify which words are quantificational to begin with. Wynn (1992; see also Condry & Spelke 2008) found that children at the age of 2 years 6 months, who do not yet understand the relationship between the words in the count list and exact cardinalities, nevertheless understand that the number words describe numerosity. This result is striking in light of the observation that it takes children another full year to gain the knowledge of which exact quantities are associated with any particular number word (Wynn 1992, Carey 2009).

Examining the distribution of numerals in the CHILDES database of child-directed speech, Bloom and Wynn (1997) proposed that the appearance of an item in the partitive frame (e.g., as *X* in [*X of the cows*]) was a strong cue to number word meaning.

Considering a sentence like (13) with the novel word *gleeb*, it is plain to the adult speaker of English that this word cannot describe anything but a numerical property of the set of cows (13a-e).

- (13) Gleeb of the cows are by the barn.
- | | |
|--|--------------------|
| a. * Red of the cows are by the barn. | *color |
| b. * Soft of the cows are by the barn. | *texture |
| c. * Big of the cows are by the barn. | *size |
| d. Many of the cows are by the barn. | approximate number |
| e. Seven of the cows are by the barn. | precise number |

In other grammatical frames, such strong intuitions are not observed: adult English speakers allow for the novel word in (14) to describe any number of properties that might be instantiated by a group of cows, (14a-e).

(14) The gleeb cows are by the barn.

- a. The red cows are by the barn.
- b. The soft cows are by the barn.
- c. The big cows are by the barn.
- d. The many cows are by the barn.
- e. The seven cows are by the barn.

Adults, of course, have had a lifetime of language experience, and so their intuitions do not yet inform our understanding of what would compel a child to decide what meaning the speaker of the sentences in (13) or (14) had in mind.

Syrett, Musolino and Gelman (2012) tested the hypothesis that the partitive frame (i.e., [*X of the cows*]) is a strong cue to quantity-based meanings (cf. Jackendoff 1977). If it were, then embedding a novel word in this frame should lead children to pick a quantity-based interpretation in cases when both this and an alternative, quality-based interpretation were available.

In Syrett et al's word learning task, they restricted the potential referents for the novel word *pim* to the quantity TWO and the quality RED. They found that the partitive predicted quantity-based judgments only in restricted cases, casting doubt on the robustness of a syntactic bootstrapping account based on the partitive as a strong cue.

These authors went on to observe that in child directed speech, a great variety of non-quantity-referring expressions occur immediately preceding *of*. For example, nouns referring to a geometrical feature of an object naturally occur in that position:

(15) the *back/front/side/top* of the refrigerator

Similarly, measure expressions also occur immediately before *of*:

(16) a. an *hour/mile* of the race

- b. three *pounds/buckets* of fruit

They suggest, therefore, that occurring immediately before *of* may not be as strong a cue to quantity-based meanings as suggested by Bloom & Wynn (1997).

Wellwood, Gagliardi & Lidz (2014) extend this work, arguing that the relevant cue is more abstract: being a determiner. A partitive construction in English of the form [___ of the NP], where nothing occurs to the left of the open slot in the frame, is a strong cue to being a determiner, which in turn restricts the interpretation of a word in that slot to quantity-based meanings. Note, that the geometrical or measure expressions in (14-15) do not occur naturally in this context; when they occur before *of*, they require a determiner to their left.

Wellwood et al suggest that this is a powerful cue to quantity-based meanings, but that children in Syrett et al's experiment failed to use the cue because the potential quantity meaning was a particular number, which we independently know are difficult for children at the relevant age to acquire (Gelman & Gallistel 1978, Carey 2009). Thus, Wellwood et al examine whether children can use determiner syntax as a cue for quantity-based meanings that are not restricted to a specific number (cf. Barner, Chow & Yang 2009).

These authors exposed children to positive examples of a novel word, *gleebest*, in three syntactic contexts:

- (16) a. Gleebest of the cows are by the barn
- b. The gleebest cows are by the barn
- c. The gleebest of the cows are by the barn

Each use of *gleebest* was also paired with a scene that confounded two properties: the cows by the barn being most numerous (relative to a set of cows

not by the barn) and the cows by the barn being the most spotted (again relative to cows not by the barn). These properties were later deconfounded such that the most numerous cows were not the spottiest and children were asked to identify which set of cows was *gleebest*. They found that children systematically interpreted *gleebest* as referring to quantity when it occurred as a determiner and that they interpreted it as referring to spottiness when it occurred in the other syntactic frames. Thus, they concluded that children are able to use the syntactic position of a novel word to determine whether it is a quantifier. In particular, identifying a novel word as being a determiner leads to the conclusion that it has a quantity-based interpretation.

Summarizing this section, we have seen that children have the cognitive resources to support quantificational meanings early in development. Approximate number representations and set representations are available to be recruited for possible quantifier meanings prior to the acquisition of precise number representations. Moreover, children are restricted in the space of possible relations between sets that they consider as potential quantifier meanings. Finally, children are able to use the syntax of a novel word in order to identify that it is a quantifier and to restrict its interpretation appropriately.

2. The Syntax and Semantics of Children's Quantifiers

Having established the cognitive and linguistic constraints on early quantifier acquisition, we now turn to the behavior of quantifiers in syntactic contexts to see the degree to which children's quantificational syntax and semantics aligns with adults'.

2.1 Beyond exactness in the acquisition of number

Many sentences containing number words assert either lower bounded or upper bounded interpretations of the number (Horn 1972). For example, in (17a) the students who can go home early must have read at least two books. Students who read three or more can also go, and so the sentence illustrates a lower bounded interpretation of *two*.

- (17) a. Every student who read two articles can go home early
b. Prisoners are allowed to make three phone calls.

In (17b), the rule gives prisoners permission to make up to three phone calls and no more (Carston 1998). Hence, this illustrates an upper bounded interpretation of *three*.

The sentential meanings in (17) involve an interaction between the lexical semantics of the number words, the lexical semantics of the other quantifiers or modals in the sentence, and the procedures for deriving pragmatic meaning from sentence meaning (Horn 1972, Carston 1998, Breheny 2008, Kennedy 2013).

There is considerable debate about the lexical contribution of number words (Horn 1972, Barwise & Cooper 1981, Sadock 1984, Horn 1992, Krifka 1998, Breheny 2008, Kennedy 2013) but what is clear is that sentences containing number words do not always convey exact (i.e., simultaneously upper and lower bounded) interpretations.

Papafragou & Musolino (2003) examined the meaning of number words in comparison to other scalar terms. They created contexts in which the use of a weaker term (*some, two*) was true but also compatible with a stronger term (*all,*

three). For example, they showed contexts in which three horses attempted and succeeded at jumping over a fence and then asked participants to judge a puppet's utterance of "*some/two horses jumped over the fence*". Adults rejected both utterances, presumably because pragmatics dictates that the puppet should have used the stronger term. Interestingly, though, four- and five-year-old children rejected the numeral but not *some*. That is, children required an exact use of the number word in this context, just like adults, even though they failed to enrich the meaning of *some* to *some but not all* in this context, unlike adults. Moreover, this result suggests that the pragmatic mechanisms that restrict a quantifier's interpretation in context are different for numbers than they are for *some* (see Papafragou & Skordos, this volume).

Musolino (2004) went on to show that children are not restricted to exact interpretations of number words, however. He showed that children do allow for lower bounded and upper bounded interpretations when those interpretations are licensed by an interaction between the number word and a modal. For example, children observed a game in which a troll tried to put hoops on a pole and a judge (Goofy) set the rules of the game. The troll successfully put 4 out of 5 hoops on the pole. In the *at least* condition, the experimenter said, "Goofy said that the troll had to put two hoops on the pole to win. Did the troll win?"

In this case, adults interpret the condition for winning as putting *at least two* hoops on the pole and so responded that the troll does win in this case. Four- and five- year old children showed the same pattern, indicating that nonexact

readings are licensed for children. In this case, even though he put 4 and not (exactly) 2 hoops on the pole, the troll won the prize.

In the *at most* condition, the experimenter said, “Goofy said that the troll could miss two hoops and still win. Did the troll win?” Here, adults interpreted the condition for winning to be missing *no more than two* hoops, and so answered ‘yes.’ And again, 4- and 5-year-old children showed the same pattern, accepting an outcome of missing one ring as compatible with the use of *two*. Thus, children are able to take into account interactions between number words and modals in determining whether a sentence expresses an *at least* or an *at most* reading of the number word.

In still other cases, number words occur in sentences where reference to an exact number is not required, because of scope interactions (Barwise 1979). For example, in a sentence like (18), we have several possible readings.

(18) Three boys held two balloons

This sentence is compatible with four readings. First, consider two (scope-independent) readings in which the total number of boys and balloons match those in the expression. On the “each-all reading”, there are three boys who, together, hold two balloons. That is, each of the two boys is holding all of the balloons and all of the balloons are held by each boy. This contrasts with the “cumulative reading,” where a total of two balloons are held by a total of three boys, though no one balloon is held by more than one boy. This reading is exemplified by a situation with one boy holding one balloon and another boy holding two.

But there are two more readings in which, because of scopal interactions between the number words, the number of boys and balloons picked out may be different from the numbers in the sentence. On the wide-scope subject interpretation, illustrated by a situation in which three boys hold two balloons each, the sentence identifies three boys but six balloons. Finally, on the object wide-scope interpretation, exemplified by a situation with two sets of three boys each holding one balloon, the sentence identifies two balloons but six boys. In these kinds of cases, the meanings of the number words interact in such a way as to hide their precise meanings in the final interpretation. That is, although a number word like *three* might lexically pick out sets of three things, when these words occur in complex linguistic contexts, the situations they define may not always have a single set of three things in them.

Musolino (2009) examined whether children allowed these kinds of interactions between quantifiers, or whether they were restricted to interpreting them in such a way that, for example, every use of “three” picked out precisely things. To the extent that they did, this would show that children’s knowledge of number words included whatever syntactic or semantic properties allowed for these kinds of interactions, beyond the lexical semantic contribution of the number word.

Musolino found that children were able to access the wide-scope subject interpretation and the each-all interpretation at adult-like levels, but that they showed more difficulty with the wide-scope object and cumulative interpretations. Children’s acceptance of the wide-scope subject interpretation illustrates that

children are aware of the effects of scope in number word interpretation. In such contexts, even though the sentence mentions only two balloons, it ultimately refers to six. The fact that children are able to access this interpretation reveals the complexity of their knowledge of the syntax-semantics interface for number words.

Interestingly, children's difficulties with the cumulative and wide-scope object interpretations appeared to be an exaggeration of adult preferences. Adults also showed preferences for the each-all and wide-scope subject interpretations, though they were able to access all four readings. These preferences may be related to children's independently observed difficulties with inverse scope interpretations, an issue we turn to now.

2.2. *Isomorphism and the scope of negation*

Consider the ambiguous sentences below along with their potential paraphrases.

- (19) Every horse didn't jump over the fence
- a. Every horse failed to jump over the fence.
 - b. Not every horse jumped over the fence
- (20) The Smurf didn't catch two birds
- a. It is not the case that the Smurf caught two birds
 - b. There are two birds that the Smurf didn't catch

In each case, two scope readings are possible, indicated by the paraphrases. In (19), when the quantified subject is interpreted outside the scope of negation, the sentence can be paraphrased as (19a), equivalent to none of the horses jumped over the fence. This reading is called an *isomorphic* interpretation since the

scope relation between the quantified subject and negation can be directly read off of their surface syntactic position. (19) can also be paraphrased as in (19b), in which the quantified subject is interpreted within the scope of negation. This is called a *non-isomorphic* interpretation since in this case surface syntactic scope and semantic scope do not coincide. Similarly, (20) also exhibits an isomorphic interpretation (20a) as well as a nonisomorphic interpretation (20b).

Several studies on the acquisition of quantification have shown that when given a Truth Value Judgment Task (TVJT), preschoolers, unlike adults, display a strong preference for the isomorphic interpretation of sentences like (19-20) (Musolino (1998), Musolino et al. (2000), Lidz and Musolino (2002), Musolino and Gualmini (2004), Noveck et al. (2007), among others). This is what Musolino (1998) called “the observation of isomorphism”.

Isomorphism effects have been found in several languages (Lidz & Musolino 2002, Lidz & Musolino 2006, Noveck et al. 2007, Han, Lidz & Musolino 2007)¹. Lidz and Musolino (2002) examined sentences containing a quantifier and negation in Kannada in order to determine whether isomorphism should be described in structural or linear terms. Kannada provided a good testing ground because, unlike English, linear order and syntactic height can be easily deconfounded. For example, in (21) the quantifier in object position precedes negation, but negation c-commands the quantifier.

(21) vidyaarathi eraDu pustaka ooD-al-illa (Kannada)
student two book read-INF-NEG
'The student didn't read two books.'

¹ One exception to this concerns indefinite object NPs in Dutch, which seem to be restricted to narrow scope for children, possibly because these indefinites are interpreted as property-denoting (Kramer 2000).

Hence, if isomorphism were structurally driven, we would expect wide scope for negation. If it were based in linear order, we would expect wide scope for the object. Lidz and Musolino found that children assigned wide scope to negation, suggesting that the isomorphism effect should be described in structural, not linear, terms.

Explaining isomorphism

In order to account for the observation of isomorphism - as it pertains to universally quantified NPs and negation - Musolino et al. (2000) observe that in Chinese, the equivalent of a sentence like (19) allows only an isomorphic, i.e. 'none' interpretation. They argue that learners should universally consider a Chinese-type grammar first, so as to avoid the potential problem of having to retract from a more permissive grammar (Berwick, 1985; Pinker, 1989; Crain, 1991; Crain and Thornton, 1998; Wexler and Manzini, 1987; Goro 2007). For Chinese learners, this would be the correct grammar, but English learners at this stage must ultimately move to a more general grammar on the basis of experience.

However, this analysis of children's isomorphism depends on the effect being due to the grammar and not to other factors having to do with the mechanics of ambiguity resolution. Indeed, Musolino & Lidz (2006) showed that English-learning 5-year-olds do not have a hard-and-fast ban against nonisomorphic interpretations. When such sentences occur in contrastive contexts like (22), the isomorphism effect is weakened.

(22) Every horse jumped over the log but every horse didn't jump over the fence.

Viau, Lidz & Musolino (2010), building on Gualmini 2008 & Gualmini et al (2008), argued that this weakening of isomorphism arose not from the form of (22), but rather to the pragmatics of negation. In particular, they argued that negative sentences are used to negate expectations that are established in the discourse context. The successful jumping events associated with the first conjunct in (22) are sufficient to create the expectation that every horse would also jump over the fence, the negation of which is the non-isomorphic interpretation of the second conjunct. Indeed, they found that such contexts, even without an explicit contrast, reduced the amount of isomorphism exhibited by preschoolers. Together, these studies argue that observations of isomorphism do not reflect grammatical knowledge *tout court*. Rather, they arise in children whose grammars generate both interpretations of such ambiguous sentences and reflect aspects of an immature ambiguity resolution process.

However, to say that the discourse context surrounding the use of sentences containing quantifiers and negation can impact ambiguity resolution, does not yet tell us how discourse contributes to ambiguity resolution and whether it is the only factor that does so. Viau, Lidz & Musolino (2010) addressed the second point by demonstrating that other factors beyond discourse can impact children's interpretations. Specifically, they showed that experience with nonisomorphic interpretations can lead children to access those interpretations even in suboptimal discourse contexts. Using a priming manipulations, they showed that children who heard scopally ambiguous sentences in contexts that were highly supportive of the nonisomorphic interpretation both accessed those

interpretations more and also were able to carry that experience over to less supportive discourse contexts. Similarly, they showed that experience with unambiguous sentences like (23a), that are synonymous with the nonisomorphic interpretation of (23b), also carried over to the ambiguous cases, leading to higher rates of nonisomorphic interpretations.

- (23) a. Not every horse jumped over the fence
 b. Every horse didn't jump over the fence

Lidz & Musolino (2003) and Musolino & Lidz (2003, 2006) argued that the isomorphic interpretation is the first interpretation that children access, and that revising initial interpretations is difficult for children (Trueswell 1999, Leddon & Lidz 2006, Conroy 2008, Omaki et al 2014). Moreover, discourse factors can help the revision process.

Support for this view comes from several adult studies demonstrating that children's only interpretation corresponds to adults' preferred or initial interpretation (Musolino & Lidz 2003, Conroy, Fults, Musolino, & Lidz, 2008). For example, Musolino & Lidz (2003) presented sentences like (24) in contexts that were equally compatible with both interpretations, for example if there were a total of three birds, only one of which was caught. Adults in such contexts explained that the sentence was true because the smurf only caught one bird, illustrating that they had accessed the isomorphic interpretation. They did not say that the sentence was true because of the two uncaught birds, which verify the nonisomorphic interpretation.

- (24) The smurf didn't catch two birds

Similarly, Conroy et al. (2008) asked adults to complete sentence fragments like (25), after hearing a story in which no boys painted the barn and only some of the boys painted the house.

(25) Every boy didn't paint the ____

When participants were asked to complete the sentence under time pressure, they gave 80% surface scope responses (completing the sentence with *barn*). But, without time pressure they were equally likely to say either *barn* (surface scope) or *house* (inverse scope).

Together, these findings suggest that adults' initial interpretation of such sentences corresponds to the only interpretation that children arrive at, pointing to revision difficulty as a major contributor to their bias (Trueswell et al 1999, Conroy 2008, Omaki & Lidz 2014).

The priming results of Viau, Lidz & Musolino (2010), discussed above, further support the view that isomorphic interpretations come first and need additional support to be overridden. By increasing the baseline likelihood of the nonisomorphic interpretation, revision away from the isomorphic interpretation becomes easier.

Lidz, Conroy, Musolino & Syrett (2008) also showed that the isomorphism effect can be modulated by structure inside the quantified nominal, comparing sentences like (26a) and (26b). They found that in discourse contexts that made the isomorphic reading true and the nonisomorphic reading false, children accessed the isomorphic reading for both. However, in contexts that made the isomorphic reading false and the nonisomorphic reading true, only children who

heard (26b) accessed the nonisomorphic interpretation.

- (26) a Piglet didn't feed two Koalas.
b. Piglet didn't feed two Koalas that Tommy fed.

The content of the relative clause here seems to focus children's attention on the contrast between the Koalas that Tommy fed and those that Piglet fed, leading to a higher availability of the nonisomorphic interpretation. This result also fits with the view that isomorphic interpretations reflect children's initial interpretations. Difficulty revising can be overridden by making the cues to revision salient, as the relative clause in (26b) does.

Lidz & Conroy (2007) found a similar effect in the 'split partitive' construction in Kannada, illustrated in (27)

- (27) *avanu ii seebu-gaL-alli eradu orey-al-illa*
he these apple-PL-LOC two peel-INF-NEG
'He didn't peel two apples.'

Here, the noun phrase that the number word quantifies over occurs with locative case outside of the VP and does not form a constituent with the number word. Nonetheless, such sentences are scopally ambiguous, though adults report a preference for the number to scope over negation.

Lidz & Conroy (2007) compared the split-partitive (27) against canonical quantified sentences (21) and found that (holding discourse context constant) children accessed only the nonisomorphic interpretation in the split-partitive sentence, and that they accessed only the isomorphic interpretation in the canonical sentence. This suggests, first, that isomorphism effects are not merely effects of discourse context, and second, that drawing attention to a contrast set

linguistically, helps to override isomorphism effects. Moreover, in a priming design, these authors found that experience with the split-partitive helped children access the non-isomorphic interpretation of canonical sentences, but that the reverse did not hold. Children who were primed with canonical sentences with an isomorphic interpretation did not show an increase in isomorphic interpretations of the split-partitive.

2.2 *Scope ambiguities without negation*

Goro (2007), building on Sano 2003 and Marsden 2004, examined children's interpretations of multiply quantified sentences in English and Japanese.

Whereas such sentences are ambiguous in English, they are unambiguous in Japanese:

- (28) a. Someone ate every food
- b. Dareka-ga dono tabemono mo tabeta
someone-NOM every food ate
"Someone ate every food"

The surface scope interpretation in which a single person eats all of the food is acceptable in both languages. However, the inverse scope interpretation in which each food is eaten by a different person is possible in English but not Japanese.

Goro (2007) tested children and adults' interpretations of these sentences in contexts that made the inverse scope reading true and the surface scope reading false, and which also made the surface scope reading relevant to the context. He found that both English speaking adults and 5-year-olds accessed the inverse scope at a rate of about 40%. This finding suggests that there is a

bias for surface scope interpretations in both adults and children, as discussed above (see also Kurtzman & McDonald 1993, Marsden 2004 *inter alia*).

Japanese speaking adults and children differed, however. The adults, as expected, never accessed the inverse scope interpretation. Children, however, showed acceptance rates similar to those of English speaking children and adults, suggesting that Japanese learners early acquisition of scope is more permissive than their exposure language.

The fact that children allow an overly general set of interpretations to multiply quantified sentences in Japanese could potentially introduce a subset-problem, since evidence for the impossibility of the inverse scope interpretation is unlikely to occur. Goro (2007) argues that the subset problem is averted if the grammatical rules responsible for the lack of inverse scope are not explicitly represented as such. Instead, Goro argues that scope is restricted because of properties of the nominative case-marker, which when attached to certain indefinites enforces a specific interpretation. Other indefinites that resist specific interpretations do not block inverse scope:

- (29) Hutari ijyou-no gakusei-ga dono kyoujyu-mo hihan-sita
two greater-than-GEN student-NOM every professor criticize-did
“More than two students criticized every professor”

Thus, the Japanese child who allows inverse scope with an indefinite subject does not have to learn to remove a covert scope shifting operation from the grammar, but rather only needs to learn the additional interpretive properties of nominative case marking, from which the restriction against inverse scope follows (see Goro 2007 for details).

2.3 Quantifier Raising and Antecedent Contained Deletion

The potential for quantifiers to shift their scope can also be seen in the interaction between quantifiers and ellipsis. The relevant case concerns Antecedent Contained Deletion (ACD), first discussed by Bouton (1970). ACD is a special case of verb phrase ellipsis (VPE) and provides one of the strongest pieces of evidence for the covert displacement operation of QR (Fiengo and May 1994, Kennedy 1997). Elided VPs are generally interpreted as identical in reference to another VP in the discourse context (Hankamer and Sag (1976)). For example, in (30), the elided VP (signaled by *did*) is interpreted as identical to the underlined VP (tense aside).

(30) Lola jumped over every frog and Dora did too.

= Lola jumped over every frog and Dora did jump over every frog too.

What makes ACD unique, though, is that the elided VP is contained in its antecedent. As is illustrated in (31), the elided VP is part of the underlined VP.

(31) Lola jumped over every frog that Dora did.

Thus, if we were to replace the elided VP with the matrix VP, the ellipsis site would remain in the replacement VP:

(32) Lola jumped over every frog that Dora did [jump over every frog that Dora did ...]

Any attempt to resolve the ellipsis with this antecedent VP results in another elided VP ad infinitum. And as long as the elided VP is contained in its antecedent, the two VPs cannot possibly be identical and so the ellipsis cannot be properly resolved. The sentence therefore remains uninterpretable as long as

the quantified noun phrase remains *in situ*. An operation of covert displacement, however, averts the infinite regress (May 1977). After movement of the QNP, the elided VP can now find a suitable antecedent, as illustrated in (33).

- (33) a. Lola jumped over [every frog that Dora did] next step: QR
b. [every frog that Dora did] Lola jumped over t next step: VPE resolution
c. [every frog that Dora did [jump over t]] Lola [jumped over t]

These examples illustrate that quantifier raising must apply in ACD environments, because if it did not, there would be no way to assign a meaning to the elided VP.

Syrett & Lidz (2009) demonstrate that 4-year-olds successfully interpret simple sentences containing ACD and that they distinguish them from coordinate structures with deletion:

- (34) a. Miss Red jumped over every frog that Miss Black did
b. Miss Red jumped over every frog and Miss Black did too

Four-year-olds interpreted (34a) as requiring that the two characters jump over the same frogs, whereas in (34b) they allowed an interpretation where each character jumps over all of the frogs that she was assigned to jump over, even if they jumped over disjoint sets of frogs.

Kiguchi and Thornton (2004), adapting Fox (1999) used the interaction between ACD and the binding principles (Chomsky 1981) to determine whether children correctly apply QR and also whether they target the appropriate landing site for this operation. The authors showed that four-year-olds, like adults, consistently reject coreference in sentences such as (5).

- (35) a. *Darth Vader found her_i the same kind of treasure that the Mermaid_i did.
 b. *[the same kind of treasure that the Mermaid_i did find her_i t] Darth Vader found her_i t

To identify whether the source of this response pattern was due to a Principle C violation at S-structure (because the name is c-commanded by the pronoun) or to a Principle B violation at LF (because the pronoun is c-commanded by the name), the authors showed that four-year-olds, who typically obey Principle C (Crain & McKee 1985, see also Baauw, this volume for review), allow coreference between a VP-internal pronoun and a name that it c-commands on the surface, as in (36).

- (36) Dora gave him_i the same color paint the Smurf_i's father did

Here, the only way to avert the violation of Principle C that would obtain at S-Structure is to QR the QNP the same color paint the Smurf's father did so that at LF (after QR), the NP the Smurf is no longer in the c-command domain of the pronoun him. Unlike in (35), the name (here, in the possessor position) does not c-command the pronoun at LF. This derivation is illustrated in (37):

- (37) a. Dora gave him_i [the same color paint the Smurf_i's father did]
 b. [the same color paint the Smurf_i's father did] Dora gave him_i t
 c. [the same color paint the Smurf_i's father did [give him_i t]] Dora [gave him_i t]

The authors argued that the lack of Principle C effects in such cases provides support for children's ability to apply QR. Children's responses to sentences like (35) must therefore derive from an LF Principle B violation and not

from an S-structure Principle C violation. This conclusion, then, entails that children are able to apply QR in order to resolve ACD (cf. Fox 1999).

Kiguchi & Thornton further argued that while children's grammars allow QR to target a VP-external landing site, this movement is restricted to a position that is lower than the subject. Support for this claim comes from the fact that children allow coreference in (38a) but reject it in (38b), where there is a Principle C violation at LF.

- (38) a. *He_i jumped over every fence that Kermit_i tried to.
b. *He_i [every fence that Kermit_i tried to jump over] [jumped over t]

Syrett & Lidz (2011) probed the question of the landing site for quantifier raising further. These authors asked whether in mult clause sentences containing ACD, each of the VPs in the sentence was available as an antecedent of the elided VP. They examined both infinitival and finite complements, as in (39-40).

- (39) Kermit wanted to drive every car that Miss Piggy did
= that Miss Piggy drove (embedded)
= that Miss Piggy wanted to drive (matrix)

- (40) Goofy said that Scooby read every book that Clifford did
= that Scooby read (embedded)
= that Clifford said that Scooby read (matrix)

In the case of nonfinite complements (39), they found that children could access both potential interpretations, suggesting that both the matrix and embedded VPs are available as landing sites for QR.

In the case of finite complements, these authors found that four-year-olds are more permissive than adults in allowing a quantificational NP to scope outside of a tensed clause. Four-year-olds systematically accessed both interpretations of (40), unlike adults, who only accessed the embedded VP interpretation.

Syrett & Lidz (2011) argue that children's permissive interpretations result not from them having acquired the wrong grammar, but rather reflect differences in the memory processes that control antecedent retrieval in on-line understanding (cf. Martin & McElree 2008).

In sum, studies on the syntax of quantification and scope suggest that preschoolers have access to the same grammatical resources as adults, having placed their newly acquired quantifiers in a rich syntactic and semantic system giving rise to complex interactions between those quantifiers. The cases where children appear to be less permissive than adults appear to derive from difficulties revising initial interpretations. Cases where children appear to be more permissive than adults also seem to involve the interaction of independent grammatical or processing factors.

3. Conclusions

The study of quantification in child language has revealed several important insights. First, children's initial hypotheses about quantifier meanings are informed by syntactic principles governing the link between word meanings and linguistic categories. Second, early acquisition of quantifiers is informed by constraints on possible quantifier meanings and the cognitive mechanisms

through which these meanings can be evaluated. Second, children's knowledge of quantifiers includes the ability for meaning interactions implemented via syntactic movement. Cases where children differ from adults are explained by two aspects of development: (a) the on-line information processing mechanisms through which sentence interpretation is reached and (b) interaction with pragmatic reasoning. Immature processing mechanisms can impact the capacity to revise initial interpretations or the memory retrieval processes through which interpretations arise in real time. In addition, children's immature pragmatic abilities can lead them to fail to use information in the context or in the linguistic signal to either revise or restrict their initial interpretations.

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