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RESPONSE

Number Word Acquisition: Cardinality, Bootstrapping, and Beyond: Reply to Commentaries

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It is of deep interest to both linguists and psychologists alike to account for how young children acquire an understanding of number words. In their commentaries, Barner and Butterworth both point out that an important question highlighted by our work, and one that remains highly controversial, is where number meanings originate. In doing so, both Barner and Butterworth present excellent examples of two different types of learning accounts.

ORIGINS OF NUMBER WORD MEANING

Barner favors a pragmatic bootstrapping account in which cues provided by language may signal to children that number words denote properties of sets. For Barner, our work provides "a clear model for how experiments can be used to test the syntactic bootstrapping of numeral meanings" (Barner, this issue). He expresses skepticism regarding a strong nativist position and is doubtful that exactness can be derived from preexisting, nonlinguistic representations (Carey, 2009a, 2009b; Spelke & Tsivkin, 2001). Instead, he and his collaborators argue that pragmatic inference may lead children to conclude that number words denote exact quantities.

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Butterworth favors an account that is situated within a number-specific domain. He suggests that a separate nonverbal natural number arithmetic domain guides verbal learning and is skeptical about the view that number word meanings can be bootstrapped from language. Unlike Barner, Butterworth explicitly argues that language is not responsible for children's understanding of the exact meaning of number words.

These commentaries have led us to view our account as a multidimensional one, appealing to aspects of both proposals. Children must learn the arithmetic-relevant meanings of numerical terms and symbols. Gelman and Williams (1998) have argued that children's nonverbal skeletal knowledge of the natural number arithmetic domain guides their identification of a verbal list that shares characteristics of the nonverbal system (i.e., a nonending repeatable list). The counting principles require a stably ordered list of different terms, each of which is applied once and only once to items in the set (the one to one principle). The last tag in this list represents the cardinality of the set (the cardinal principle). If the stable ordering principle were not honored, mathematically relevant operations would not be honored (see Gelman, 1972, 2006; Hartnett & Gelman, 1996). A prime candidate is the count list of the culture and not labels for concepts of objects. The difference has consequences for speed of learning. Label learning often proceeds rapidly or with what has been dubbed "fast mapping" (Carey & Bartlett, 1978; Heibeck & Markman, 1987) The serial learning of lists of successive terms that are unrelated is well-known to take a long time, even for adults. Still the availability of a nonverbal structure invites the possibility that children are intrinsically motivated to attend to the various contexts in which number words appear—a position that gains some support by the observation that young children practice, self-correct, and even develop idiosyncratic count lists (Gelman & Gallistel, 1978).

As Butterworth notes, many linguistic contexts also support learning of the count list and its use, including a variety of number-centered games (cf. Ramani & Siegler, 2011; Siegler & Ramani, 2008, 2009). These observations raise the question of the link between language, the referential context, and the nonverbal domain, and what the supportive role of language is in such contexts.

However, even allowing that nonverbal principles facilitate attention to verbal instantiations of the counting principles, this account does not suffice for all number word learning tasks. Children also have to acquire rules that are relevant to the status of number words as natural language expressions, which participate in a host of linguistic constructions and interact with other lexical items that have a similar syntactic and semantic status. The ability of number words to appear in the partitive construction or take scope as quantificational items are two instances of such uses.

This exchange also highlights the fact that research in this area could benefit significantly from further cross-cultural and cross-linguistic explorations, as well as further experimental investigations. For example, citing work by Gordon (2004) and Pica, Lemer, Izard, & Dehaene (2004), Barner wonders why we should posit that humans have innate, domain-specific knowledge of counting if counting is not universally observed across cultures. This observation raises the question of whether an innate numerical ability should be linked with something that is detectable on the surface (and encoded in a verbal count list). It is possible that this is, in fact, not the case. For example, some cultures appeal instead to body parts to make public a counting scheme (see Butterworth, 1999; Zaslavsky, 1973; Saxe, 1981). In addition, there are cultural restrictions against counting certain entities. For example, addressing the earlier claim that the Kikuyu in Kenya cannot count, Kenyatta (1953) points out that there is a taboo against counting cattle and other valuable possessions; nevertheless, tribesmen could provide the exact number of the set because they could count the cowry shells that they placed in one-to-one correspondence with the cattle. These studies may illustrate that even in the absence of a verbal count list, these groups still possess a notion of exactness.

BEYOND CARDINALITY

As the commentaries remind us, one of the key goals of developmental accounts of number word acquisition has been to try to explain how children learn that a phrase such as *two boys* picks out a set of boys with a cardinality of exactly two. While there is no doubt that cardinality is a fundamental aspect of number word meaning, a long line of work in linguistics and philosophy underscores the fact that full mastery of linguistic expressions involving number words extends far beyond their cardinality-denoting properties. In fact, number words have multiple senses, one being their function as arithmetic entities indicating exact cardinality of a group and another being a quantificational sense that allows for a wider range of interpretations (cf. Geurts, 2006; Koenig, 1991). Indeed, there are classic cases in language demonstrating that language learners should *not* rely upon the fact that a number word encountered on the surface will pick out a set with the corresponding cardinality in the world. To illustrate this point, we briefly review three such examples.

First, consider the interaction of numerals with each other or other quantified expressions. It has been observed that a simple transitive sentence containing two numerically quantified expressions such as *Three men painted two squares* has a range of interpretations, taking into account factors such as the scopal interaction of the two numerical expressions and the number of events, among other factors (Gil, 1982; Hintikka, 1974; Link, 1983, 1987, 1991; May, 1985; Scha, 1981, 1991; Schwertel, 2005). This fact has been verified experimentally in both children and adults (Musolino, 2009, 2010). Relevant here is the observation that not all of these readings involve exactly three men and exactly two squares; for example, the sentence would be true in a situation in which each man has the property of painting two squares, in which case six, and not two, squares would have been painted. While studies by Lidz and Musolino (2002), Musolino and Gualmini (2004), and Musolino (2009, 2010) have revealed that children and adults may have different preferences for interpreting such sentences (see also Syrett & Musolino, 2010a; 2010b; submitted), for related findings), preschoolers are still able to access the full range of interpretations available to adults. Moreover, they do not generate interpretations indiscriminately, suggesting that, like adults, they are constrained by a rich array of grammatical principles that determine the set of logically possible combinations. These findings raise questions about the source of this linguistic knowledge and how it interacts with the conceptual representation of number words.

The second two cases illustrate that reliance on exact cardinality of a set is misleading for the correct interpretation of some sentences and that children must overcome any preference to interpret number words in this way. For example, language learners relying upon number words to denote the cardinality of a set of discrete objects would be derailed in their interpretation of measure phrases such as *two pounds of x* or *two-pound x*, which do not refer to set size, but differences in quantity. In such expressions, the number word indicates the number of units of measurements along a relevant (and in most cases continuous) dimension, such as length or weight. Recent experimental results by Syrett and Schwarzschild (2009) and Syrett (2010, submitted), suggest that four-year-olds are on their way to an adult-like interpretation of measure phrases (MPs), but may be drawn towards an exact cardinality interpretation. For example, they distinguish between MP expressions that pick out an entire quantity (i.e., pseudopartitives such as *two pounds of Y*) and those that pick out a quantity per unit (i.e., attributives such as *two-pound Y*), and between the latter and expressions with a similar surface-level syntax (i.e., compound noun phrases such as *two butterfly-cards*), thereby indicating a developing knowledge of the appropriate syntax-semantics mapping. However, their responses indicate that they still appear to be drawn toward treating the number as referring to the size of the set.

Third, it has been known at least since Horn (1972) that number words do not always give rise to "exact" readings (cf. Breheny, 2008; Carston, 1985, 1998; Geurts, 2006; Horn, 1972, 1989, 1992; Koenig, 1991; Levinson, 1983, 2000; Sadock, 1984). Indeed, their interpretation depends on the context of the utterance and the linguistic environment in which these lexical items appear. For example, while *two* in *John has two children* is typically interpreted as "exactly two," the same phrase is interpreted as "at least two" (i.e., two or more) in a sentence such as *You need to have two children to be eligible for government assistance*. Moreover, in a statement such as *You can miss two questions and still get an A on your exam*, the number appear to have an "at most" reading: Students can miss up to two items but no more to get an A. Thus, concluding that number words are always interpreted as expressing exact cardinality would turn out to be a problematic assumption for language learners to make. These examples also highlight that it is the interaction of number words with other aspects of the utterance (such as modality and real-world knowledge), which contribute to the interpretation that is generated or preferred. Recent experimental evidence indicates that while young children are strongly inclined to assign number words an exact reading (cf. Huang, Snedeker, & Spelke, submitted; Hurewitz et al., 2006; Musolino, 2004; Papafragou & Musolino, 2003), they are still capable of accessing "at least" and "at most" readings as well (Barner & Bachrach, 2010; Musolino, 2004).

Children do need to learn about the cardinality-denoting properties of number words as these commentaries and a long line of developmental literature on number word meaning remind us. But this discussion also highlights the fact that knowledge of exact cardinality only scratches the surface of the many meaningful uses of number words. Beneath the surface lies a system that must be *flexible* enough to take language users beyond exact cardinality, but also *constrained* enough to generate only those logically possible options that are allowed by the grammar. A new challenge for researchers investigating number word acquisition will be to try to understand how knowledge of cardinality and the conceptual representations of number word meaning interact with abstract linguistic representations to allow children to arrive at the correct interpretations of sentences containing numerically quantified expressions. Although we have already begun to address these questions in our own work, it is clear that much remains to be done both in English and cross-linguistically.

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