Language and Cognition in Development

Stella Christie

Northwestern University

Dedre Gentner

Northwestern University

1 Introduction

The hypothesis that language can influence thought – generally known as the Whorfian hypothesis – has inspired strong opinions in both directions. Early enthusiasm in the 50's and 60's was followed by decades of disregard or worse. Now the wheel has turned again, and the question of whether and how language might influence cognition is openly tested and debated. (See Gentner & Goldin-Meadow, 2003, and Gumperz & Levinson, 1996, for discussions of the forces behind this evolution.) However, work on language and thought remains extremely contentious, and many of the claims reviewed here are under challenge.

In some important ways, the field of cognitive development has been relatively open to the idea that language influences thought. Within adult cognitive psychology, the language-and-thought hypothesis is associated primarily with Benjamin Lee Whorf and his mentor, Edward Sapir (e.g., Whorf, 1956), who proposed that specific properties of a language's grammar and lexicon could influence cognition in speakers of that language: "We dissect nature along lines laid down by our native language," (Whorf, 1956: 213).

But in developmental theory, the figure most associated with the view that language influences thought is the Russian psychologist Lev Vygotsky (1962). Unlike Piaget, for whom conceptual development proceeds via interactions with experience, with language serving only as a means of communication, Vygotsky saw language and culture as critical to the development of thought. One could say that Piaget viewed the child as tiny scientist, whereas Vygotsky viewed the child as cultural apprentice.

Vygotsky's view on the effects of language differed from that of Whorf and Sapir. Rather than focusing on the effects of speaking one language versus another, Vygotsky theorized about the effects of language as such. He proposed that the internalization of language provides children with the means to direct their own thought: to achieve focused attention and will, and a means of introspecting about one's own cognition. Vygotsky offered a view of language as providing scaffolding for new concepts; he suggested that hearing a new term or a new assertion, even when the child has poor initial understanding, might both invite and guide the child to future learning.

Advances in cognitive psychology, linguistics, and linguistic anthropology have led to progress on some classic questions. For example, a perennial question in the development of language and thought is which comes first—the concept or the linguistic term. Scholars like Bowerman (1981, 1989) have long raised challenges to the standing Zeitgeist that concepts come first, with language merely naming them. But until recently there was no way to address this directly. With the recent explosion of techniques for studying infant cognition, it is becoming possible to address the question of whether and how prelinguistic cognition differs from post-linguistic cognition. As another example, comparative studies of apes and young humans are another new source of insight. But this recent progress has also made it clear that the question of whether language influences thought needs to be decomposed into more specific questions.

A set of fine-grained questions has emerged concerning when and how language effects might occur (Gentner & Goldin-Meadow, 2003; Gumperz & Levinson, 1996, Wolff & Holmes, in press). Taking linguistic determinism—the hypothesis that the language we speak determines how we perceive the world—as the starting point, one way to delimit the hypothesis is to specify *when* we should expect to see effects of language on cognition. This was the move that Slobin (1996, 2003) made in his influential *thinking-for-speaking* hypothesis, which holds that language influences thought only when language is actively used. The initial statement was couched in terms of 'when actually speaking', but later research has broadened the scope to include comprehending language and perhaps even using language internally (though this move makes the thinking-for-speaking view harder to distinguish from linguistic determinism). Another way to delimit the effects of language is to assume that language augments, but does not replace, other ways of construing the world. This is the route taken by the *language as tool kit* view—that acquiring a language provides new representational resources—including new relational schemas as well as new categories—that augment our capacity for encoding and reasoning (Gentner, 2003, 2010; Gentner & Christie, 2010; Loewenstein & Gentner, 2005; see Frank, Fedorenko, Everett, & Gibson, 2008, for a similar view). These linguistically-inspired representations may become habitual, so that they are readily accessible even without the internal use of language (Hunt & Agnoli, 1991; Levinson, Kita, Haun, & Rasch, 2002; Lucy, 1994). On this view, language provides tools that facilitate forming and using particular representations—

representations that may be intellectually potent—but does not replace all other encoding formats. Another distinction that needs to be made is that between effects of language on thought, and effects of language on language (Gleitman & Papafragou, 2005). For example, the difference between the naming patterns of English vs. Japanese children for substances and objects (as in Imai and Gentner's (1997) work) does not entitle the conclusion that Japanese and English speakers think about objects and substances differently, though it does set the stage for further investigation (e.g., Imai & Mazuka, 2003).

The distinctions among these views make it clear that the language and thought issue is far subtler than the extreme version of the Whorfian hypothesis: that language acts to determine our perception of the world—as a kind of permanent lens on the mind's eye.

From this perspective, the developmental course of language effects is of central interest. In this paper we review evidence that language acts during cognitive development to promote certain kinds of conceptual structures. In terms of the toolkit hypothesis, the question we ask is when and how language facilitates the acquisition of cognitive tools. Our discussion is organized around three domains of active research: space, number, and theory of mind. There are other arenas that could be discussed, including temporal relations (e.g., Boroditsky, 2001), noun learning and object individuation (e.g., Lupyan et al., 2007; Xu, 2002), and object categorization (e.g. Markman, 1989; Waxman, 2002; Waxman & Markow, 1995), but given the limitations of space we prefer to go deeply into a few areas.

2 Space

The domain of space is an obvious place to investigate the question of whether language affects cognition, for several reasons. First, spatial information is universally available to human regardless of where they live. Indeed, we are all constrained by the same universal laws of physics: an apple placed in a bowl always rests on the bottom of the bowl, rather than floating in mid air within the bowl. Second, it is comparatively easy to construct nonlinguistic situations and events to which people can react regardless of their language (Here spatial concepts contrast with, say, counterfactual reasoning or concepts of justice.) Third, spatial knowledge is of fundamental importance in human reasoning, both directly in activities like navigation and manipulation, and through spatial analogies and metaphors, which occur commonly in human language and thought. Finally, a prerequisite for finding language-driven variability in concepts is variability in the language, and here space is an ideal domain. Recent research has revealed an astonishing variety of ways in which languages have categorized spatial configurations (e.g., Bohnemeyer & Brown, 2007; Bowerman, 1989, 1996; Brown, 1994; Levinson & Brown, 1994; Casad & Langacker, 1985; Talmy, 1975, 1985). For all these reasons, space has become an especially active arena of investigation for language and thought. The relational information that constitutes a given spatial configuration can be partitioned differently by different minds and different languages (Gentner, 1982). For example, one can think of an apple in a bowl as being supported by the bottom of the bowl, or as being contained inside the bowl, or as in loose contact with the bowl. All of these possibilities are reflected across human languages.

2.1 Frames of reference

Spatial relational terms provide framing structures for the encoding of events and experience. Across a range of languages, Levinson and his colleagues have identified three spatial frames of reference that speakers use to describe the location of an object (Levinson, 1996; Levinson et al., 2002). The *relative* (or *egocentric*) frame describes locations relative to the speaker, as in “the chair is left of the table.” The *intrinsic* (or *object-centered*) frame describes locations relative to a landmark object, as in “the chair is in front of the fireplace.” Finally the *absolute* (or *geocentric*) frame describes locations relative to a global frame, as in “the chair is in the northwest corner.” The term *allocentric* refers to both object-centered and geocentric frames, in contrast to egocentric frames. Languages may use more than one of these frames, but in many cases one frame is dominant. In particular, when discussing close-range locations, the egocentric frame is dominant in English, Dutch and German, while the geocentric frame predominates in many other languages, including Tzeltal (Mexico), Arrernte (Australia), and Hai||om (Namibia) (see Majid, Bowerman, Kita, Haun, & Levinson, 2004, for a comprehensive review).

The question here is whether the habitual use of a particular linguistic frame of reference has any more general effect on spatial cognition. Research by Levinson and colleagues (Levinson, 1996, 2003; Levinson & Brown, 1994; Levinson, et al., 2002; Pederson, 1995) suggests that the answer is yes; they find that people are influenced by their language’s dominant frame of reference even when carrying out a nonlinguistic spatial task, such as copying a scene or tracing a path through a maze (Majid et al., 2004; but see Li & Gleitman, 2002, for a dissenting view).

How do such effects arise in cognitive development? Do we begin life with natural proclivities or instead as 'blank slates' on which language, culture, and other experience impose spatial frames? This question is difficult to answer for a topic like frame of reference, because very young infants are limited in their response capabilities, while older infants and toddlers may already be influenced by culture and language. The Piagetian tradition has that there is an initial egocentric bias, and a shift from egocentric to allocentric over development (Piaget & Inhelder, 1967; Pick, 1993), although there is also some evidence for flexibility in infants (Acredolo, 1978; Bremner, 1978).

Haun, Rapold, Call, Janzen, & Levinson (2006) addressed this in a set of studies that combines cross-linguistic developmental comparisons with cross-species comparisons between humans and our close relatives, the great apes. For the cross-linguistic comparison, Haun et al. compared Dutch speakers, whose language (like English) primarily uses an egocentric frame of reference, with speakers of Hai||om (a Khoisan language spoken in Namibia), which primarily uses a geocentric frame. Haun et al. used two-dimensional arrays of five objects, which allowed them to distinguish the three frames of reference (see Figure 1).

Participants faced an array of five identical cups on Table 1 and watched as an object was hidden in one of the cups. They then moved around to Table 2, where they saw an identical array of cups, but from the opposite direction. Their task was to retrieve the hidden object. So far this task resembles prior frame-of-reference tasks. However, a salutary innovation in this research is that, whereas prior research had focused on speakers' preference for using one frame or another, this research utilized a training task, allowing the researchers to compare participants' facility in learning to use one frame over another. Participants received ten consecutive trials in which the correct answer required use of the egocentric frame, then (without any break) ten more using the geocentric frame, then ten using the object-centered frame. This technique thus tests whether people find it easier to learn a spatial task when it is set in the frame of reference that is dominant in their language. The results paralleled prior findings of language effects in adults: Dutch-speaking adults and 8-10-year-olds were more accurate in the egocentric condition than in the other two, while Hai||om-speaking adults and children were most accurate in the geocentric condition. The striking difference between these two groups is just what would be predicted from the dominant frame of reference of the respective languages. (Of course, these differences could have stemmed from other cultural or environmental differences; but see Majid et al. (2004) for arguments against this likelihood.)

--------Figure 1 –Five-object array adapted from TICS paper on Haun ---------

Haun et al. then went on to probe the development of frame of reference and to ask how it develops. Their studies built on the prior research of Call and Tomasello (Call, 2001; Tomasello & Call, 1997) comparing human patterns with those of our close cousins among the great apes. They gave both apes (3 orangutans, 2 gorillas, 3 bonobos, and 5 chimpanzees) and 4-5-year-olds German[1]-speaking children a simplified search task. Participants saw an object hidden under one of a line of three identical cups on Table 1. As in the prior study, they then moved around to Table 2, where they viewed an identical array from the opposite direction and looked for the hidden target. As before, participants had to discover the rule that determined the correct location on Table 2. There were two conditions: *egocentric*, where the hiding and finding cups maintained the same position relative to the participants' view point (left or right); and *allocentric*, where the hiding and finding cups maintained the same position relative to an external frame. (In this simplified task, we can distinguish between egocentric and allocentric responding, but not between the two kinds of allocentric response, because the geocentric (e.g., the west end) and object-centered (e.g., the end nearest to the experimenter) frames both yield the same response.) The results showed that great apes performed best in the allocentric condition, as is consistent with research showing that many species use allocentric spatial information to navigate (see Gallistel, 1990). But what is more surprising is that German-speaking children showed the same allocentric pattern; their performance resembled that of our simian cousins rather than that of older German-speakers. As Haun et al. note, this suggests a deep continuity between humans and the great apes in their native cognitive biases with respect to reference frame.

This finding of an allocentric preference in 4-year-olds dovetails with evidence that infants can adopt allocentric as well as egocentric frames (Acredolo, 1978; Bremner, 1978). At the same time, this cross-species allocentric bias in young humans and great apes renders the later cross-linguistic divergence all the more striking. By 8 years of age, children whose language favors an egocentric frame have diverged from their native pattern and now find the egocentric frame easier to use; while those whose language is geocentric show a correspondingly geocentric bias. Importantly, this entrainment by language is not absolute. For example, older Dutch children and adults performed above chance in the geocentric condition, and as Li and Gleitman (2002) note, speakers of a given language are also influenced by contextual factors (see also Gleitman & Papafragou, 2005). Nonetheless, the fact that each group performed better on the frame favored by their language is evidence for effects of habitual language on the way we most readily conceptualize space.

2.2 The semantics of containment and support

Within cognitive development, Bowerman (1980, 1989) was among the first to challenge the idea that concepts come first in human development and are simply mapped onto language. Noting the variability between languages in how spatial relations are lexicalized (e.g., Bowerman, 1981; 1996; Bowerman & Choi, 2003; Bowerman & Levinson, 2001; Levinson et al, 2002), Bowerman argued against the common assumption that certain words are acquired earlier than others because they correspond to preexisting conceptual categories. Instead, she suggested that concept learning might be guided by language from the start[2].

One striking example of such semantic diversity is the contrast between Korean and English spatial terms first documented by Choi and Bowerman (1991). In English, spatial attachment is divided into semantic categories of containment and support (*in* and *on)*. In contrast, Korean speakers organize spatial attachments according to how the two objects fit with one another, contrasting tight fit with loose fit. In English, putting a videocassette *in* its case or an apple *in* a bowl are both categorized as containment. However, Korean uses two different verbs: a videocassette/case event is described by the verb *kkita* (roughly, to join things tightly), and the apple/bowl event is described by the verb *nehta* (to join things loosely). In the other direction, the English distinction between containment and support is not lexicalized in Korean: for example, the same verb (*kkita*) is used for putting the top *on* a pen and for putting an earplug *into* an ear (Choi & Bowerman, 1991).

If children form particular spatial concepts that are then mapped onto language, then we would expect an advantage for whichever language best matches children's natural concepts. But in fact, Choi and Bowerman found that English and Korean children acquired their very different spatial systems at about the same rate. In both languages, the first relational terms appeared at about 14-16 months. In English these early relational words were *down, out, on, off*, and *open,* with *come, fall, walk, run, sit* and *ride* by 17-18 months. In Korean the early terms were *kkita* (fit), *ppayta* (unfit), *yelta* (open) and *tatta* (close), with *kata* (go), *ancta* (sit), *pwuthita* (juxtapose two surfaces), *kka(k)ta* (peel off), etc by 17-18 months. There are some commonalities: young children like to talk about opening and closing, and about moving around. But although both groups talk about spatial relations, they pick out very different parts of the spatial world to lexicalize, and this selection is guided by their language.

Further work has explored the early effects of language: that is, at what point do infants begin to form different semantic categories corresponding to their linguistic terms? Choi, McDonough, Bowerman, and Mandler (1999) found that as early as 18 months, infants are sensitive to language-specific spatial categories. In this study, upon hearing the spatial term *in*, English-speaking children selectively attended to scenes depicting containment (matching scene) as opposed to non-matching scenes. Similarly, Korean-speaking children attend to scenes depicting tight-fit relations upon hearing *kkita*. During control trials, where the children did not hear the target word (*in* for English or *kkita* for Korean), there was no preference for either the matching or non-matching scenes, suggesting the absence of nonlinguistic biases. Choi et al. used a variety of different spatial scenes—e.g., for the containment relation (*in)*, scenes included putting a peg in a hole, Lego blocks in a box, books in box-covers, and rings in a big basket. The fact that 18-month-olds could correctly map their respective linguistic spatial terms to this variety of scenes suggests that they have a generalized understanding of the containment relation entailed by the spatial term.

Another line of support for the role of spatial language in shaping spatial semantic categories is a study by Casasola (2005), in which 18-month-old English speaking infants formed an abstract category of support only when they heard the word *on* during habituation trials. Infants in this study were all habituated to four support events, two depicting tight support and two depicting loose support. Infants then viewed four test events in sequence: two depicting support relation (familiar) and two depicting containment (a new relation). Infants who had heard the spatial word *on* during habituation looked longer at the novel relation (containment) with *both* familiar and novel objects, indicating that they had formed an abstract representation of the support relation. In contrast, infants who had heard general phrases, novel words, or no words at all during habituation failed to notice the change in relations even for familiar objects; they attended to a change in objects, but not to a change in relations.

These studies suggest that language is instrumental in prompting infants to form stable spatial relational categories. Consistent with this claim, it appears that in the absence of linguistic guidance, young infants are ready to form a variety of spatial categories. McDonough, Choi and Mandler (2003) familiarized 9-14-month English- or Korean-learning infants with either pairs of tight containment events or pairs of loose containment events, accompanied only by music. Although the tight-loose distinction is far more central in Korean than in English, both groups of infants were able to extract the category during familiarization: both groups could distinguish the familiar category from the new category[3] when shown novel test pairs (with new objects) consisting of a tight containment event and a loose containment event.

Hespos and Spelke (2004) studied even younger infants and found that 5-month-old English-speaking infants can readily form either the English support/containment distinction or the Korean tight-fit/loose-fit distinction. The infants were habituated either with a single tight containment event or with a loose containment event: e.g., a cylinder entering another container that fit either tightly or loosely. They were then tested with both tight containment and loose containment events (shown sequentially). Infants habituated to tight containment looked longer at the loose containment event and vice versa, indicating that they had abstracted the respective category. More surprisingly, this pattern held up even when infants had to transfer the tight/loose distinction from support to containment. That is, when infants were habituated with either tight or loose *support* events, and then shown the tight *containment* and loose *containment* test events, they looked longer at the novel test event. This suggests that 5-month-old infants can form the Korean tight-loose distinction, even when it cuts across the English *in/on* distinction.

Lining up the developmental studies discussed so far, we have a rather perplexing contrast. Five-month-olds showed sensitivity to the tight-loose distinction unmarked in their native language in Hespos & Spelke's (2004) study. But in Casasola's (2005) study, which also used a habituation paradigm, 18-month-olds failed to show sensitivity to the support category which *is* marked in their language, unless they heard the requisite spatial term. We suggest that this difference may rely on the degree of generalization that the infants needed to make (see also Casasola, 2008). In Casasola's study, the habituation events were quite varied and the objects involved were perceptually rich and differed across trials; in the Hespos and Spelke study, the habituation trials utilized highly similar events, both in the motions involved and in the objects (which were varied only slightly). Likewise, the test trials were perceptually quite dissimilar from the habituation trials in Casasola's study (especially in the novel-object trials) and perceptually similar to the habituation trials in Hespos and Spelke's study.

One might then ask "So which study is right? When exactly do infants have the category of support?" We suggest that this is the wrong question. Rather, the better question is "When (and under what learning conditions) can infants form a category of support at a given level of abstraction?" If we consider that performance in these studies derives in part from abstractions formed during the study (rather than solely from pre-existing categories), then both kinds of study are informative. We can see these studies as spanning a range. At one pole are studies in which the intended relation is perfectly aligned across exemplars with few distracting surface differences (as exemplified in Hespos and Spelke's studies)—an ideal situation in which to form a generalization, albeit one that may not apply far beyond the initial stimuli. At the other pole are studies with complex learning conditions, in which the relation is instantiated over different kinds of objects (as in the Casasola studies). That infants form the abstraction under perfect conditions tells us that this potential is there prior to language; and indeed the Hespos and Spelke results show that infants are multi-potential learners at this early stage. But the variable learning experience given to the infant in the Casasola studies more closely matches real-life learning conditions, in which children encounter a given spatial relation instantiated over a wide variety of specific situations[4]. From this perspective, this range of studies from ideal abstraction conditions to perceptually variable conditions can be seen as putting bounds on the conditions under which infants will form the category.

2.3 Relational language and relational representation

Gentner and colleagues have theorized that spatial relational language—and relational language in general—can foster the learning and retention of relational patterns (Gentner, 2003, 2010; Loewenstein & Gentner, 2005), thus acting as a "cognitive toolkit". During initial learning, hearing a relational term used for two situations invites children to compare them and derive their common abstraction (*symbolic juxtaposition*). Once learned, a relational term can help to stabilize the abstraction. Gentner (2010) termed this *reification* (see also Lupyan, 2008, for discussions of this idea). The term can then be used to invite a particular construal of a given situation—one that may be advantageous for certain purposes. One particularly powerful kind of relational construal is a *systematic* representation: one in which the lower-order relations are interconnected by a higher-order constraining relation. For example, the set of terms *top, middle, bottom* form a systematic structure governed by the higher-order relation of monotonicity in the vertical dimension. This kind of connected relational system can be used to support inference and, as discussed below, analogical mapping and transfer.

Recent evidence for the benefit of spatial relational language—and especially of systematic relational language—was offered by Loewenstein and Gentner (2005) in a spatial mapping study. Preschool children saw two identical three-tiered boxes; they watched an item being hidden in one box and then searched for a similar item in the corresponding location at the second box (see Figure 2). Children's performance was better when they first heard the box described using spatial relational terms such as *on, in, under*. Further, when the task was made more difficult by introducing a competing object match (a *cross-mapping*, Gentner & Toupin, 1986), children performed far better with the terms *top, middle, bottom* (which convey a connected system of relations) than with the terms *on, in, under,* that lack a unifying higher-order structure. We infer that hearing *top, middle, bottom* invited a representation of the monotonic relational structure of the two boxes, and that this higher-order structure helped the children to achieve a relational mapping.

--Figure 2 – Boxes used in Loewenstein & Gentner's (2005) Spatial mapping task --

Further evidence of the influence of spatial relational language on spatial cognition comes from a study by Dessalegn and Landau (2008). In this study, 4-year-olds were tested with a well-known problem in vision: color and location conjunction (e.g., a split square, with red on the left and green on the right). Children were presented with a target example (e.g. a red (left)-green (right) square); their task was to find the exact match after a one second delay among three choices: the correct match (red-green square), the reflection (green-red square), or the distractor (red-green diagonal split square). Performance was best when children heard relational language (e.g. "the red is on the left"). Crucially, the advantage of hearing spatial language was not found for potentially salient nonlinguistic attentional cues (flashing, pointing, or changes in size of the red part), suggesting that relational language affected the spatial representation rather than simply increasing attention to the task[5].

2.4 Habitual construals: Beyond thinking for speaking.

The studies reviewed so far suggest that spatial language can influence children's performance on spatial tasks. Some of these effects could be explained by the thinking-for–speaking account. For example, Dessalegn and Landau's (2008) findings could be accounted for by purely online, temporary effects of language. However, there are also findings that point to longer-term effects of language on the development of spatial representations. For example, the effects of language in the Loewenstein & Gentner (2005) spatial mapping task were durable, not fleeting. When children were brought back to the lab two days later to "play the same game," those who had heard systematic language (*top, middle, bottom*) outperformed those who had not, even though the spatial relational terms were never used during the second session. These children were also able to transfer the mapping task to new, rather different-looking boxes. These findings suggest that the relational terms induced a corresponding representation which delineated the internal structure of the boxes. Finally, in a recent study in Istanbul, Gentner, Ozyürek, Goldin-Meadow, and Gurcanli (2008) compared 5-year-old children who possess normal language with a group of deaf children who had not been taught a sign language, and whose self-developed homesign gestural system (Golden-Meadow, 2003) was deficient in spatial terms. Neither group was given any spatial language during the task. Nonetheless, the hearing children (who had good command of Turkish spatial terms) performed significantly better on the task than did the deaf children.

There is also evidence from adult studies that language can become internalized and come to influence our default conceptual construals, for instance the frame-of-reference studies discussed earlier. Studies of support relation provide another example: in contrast to infants, adults show a strong preference for the categories enshrined in their native language. McDonough et al. (2003) gave adults an oddity task in which they had to say which of four events was different from the others. English-speaking adults could do this readily (78% correct) when given three tight containment events and one loose support event; but when given three tight containment events and one loose containment event (so that the choice had to be based on the tight-loose distinction), only 38% chose successfully. In contrast, Koreans (for whom the tight-loose distinction is part of habitual language) readily chose the odd item in this latter task (80% correct). Likewise, Hespos and Spelke (2004) found that in making similarity judgments, English-speaking adults were sensitive only to the English containment-support distinction, and not to the Korean tight-loose distinction.

This development from equipotentiality in infants to linguistically biased similarity in adults suggests that we possess an early ability to form a large number of potential distinctions. Habitual usage of language renders certain spatial categories more dominant. This does not mean that adults cannot learn a new spatial category under favorable learning conditions (e.g., Boroditsky, Schmidt, & Phillips, 2003; Goldstone, 1998); but it does mean that such learning may be difficult in ordinary life. Which relations become easy to notice appears strongly influenced by the language we speak.

3 Number

Mathematical structure seems so compelling that it must be an inevitable aspect of human cognition. Dehaene (1997, p. 242) quotes the French mathematician Charles Hermite: “I believe that the numbers and functions of analysis are not the arbitrary product of our spirits; I believe that they exist outside of us with the same character of necessity as the objects of objective reality…” Yet there is evidence that even simple numerical insight is not inevitable, and that language plays a role in its development. We begin by describing two possible precursors of number concept, and then discuss how their interactions with language may give rise to number knowledge.

Two preverbal capacities that have been implicated in accounts of number development are the analog magnitude system and a system for keeping track of small numbers of items. The analog magnitude system is a system shared broadly with other species that allows approximate judgments of quantity. It is what allows us (or a hamster) to choose a larger pile of grain over a smaller pile, or to notice that the amount of liquid in a container has decreased. This skill operates over even very large quantities, but its accuracy is limited by Weber’s Law: the discriminability between two amounts is a function of their ratio. Thus, inaccuracies occur for magnitudes that are very close. The analog magnitude system is often modeled with the accumulator model (Meck & Church, 1985).

The other relevant nonverbal capacity is the ability to keep track of a small number of items. This ability can be thought of as a part of our general capacity for representing mental models of the world; some accounts (e.g., Carey, 2004; Spelke, 2000) have also linked it with Pylyshyn’s (2001) notion of a pre-attentive object file system. In contrast to the analog magnitude system, the object file system operates over discrete representations and is capacity-limited, to roughly three or four objects.

We will consider two main classes of theories that assign a major role to language in number development. One theory centers on language as a link between modules, while a second broad class of theories focuses on the count system and other number terms as a means of promoting numeric insight.

3.1 Language as link between modules

Spelke (2000; 2003) and her colleagues theorize that language serves as a combinatorial system that links the two preverbal numeric modules discussed above—the object file and the analog magnitude system. Since neither of these two preverbal modules deals with *exact* large numbers, the combinatorial power of language is needed for the ability to represent exact large numbers. One line of support for this theory comes from a study with adult Russian-English bilinguals (Spelke & Tsivkin, 2001), which showed effects of language in the performance of exact arithmetic calculations. Bilingual participants were trained in one language on two kinds of problems: exact calculation problems and approximation problems. Participants were later tested in similar problems in the other language. Spelke and Tsivkin reasoned that if language is necessary for representing exact large numbers, then performance in exact calculation problems should deteriorate. However, their approximate calculation skill should not be affected. This is indeed what they found: bilinguals were able to transfer the new approximation skills across languages, but not the exact calculation skills.

3.2 Number language as cognitive toolkit

While the view that language acts as a link between modules recruits both the object file and the accumulator system, another view of how language-learning supports number development relies primarily on the object file capacity (Carey, 2004; Mix, 2002). These accounts recognize that knowledge of the count routine does not by itself confer an understanding of number, but hold that learning the linguistic count sequence is crucial in the development of number. The binding of the numbers words to cardinal sets occurs slowly. A child may understand that *one* refers to an individual, but still regard *two, three,* and so on as referring to undefined larger sets. Counting seems to begin as a social routine, akin to a chant, and only later to become linked to cardinal numbers (Fuson, 1988; Wynn, 1990). A striking demonstration of this lag is the fact that even when a young child has just correctly counted a set of objects ("1, 2, 3, 4"), she typically cannot respond "four" to the question "So how many are there?"

This suggests an intriguing possibility: that the linguistic count routine serves as an analogy that invites children to organize numerical quantities into an ordinal sequence. This possibility is most clearly articulated by Carey (2004, 2009) in her bootstrapping account (see also Gentner, 2010). According to this account, children first learn the counting routine as a kind of game, with no understanding of how it connects to cardinal numbers. Gradually, the child learns to attach number words to very small set sizes. The learning is at first piecemeal—even after binding *two* to sets of cardinality two, weeks or months may ensue before the child realizes that *three* refers to a set with three items (Mix, 2002; Mix, Sandhofer, & Baroody, 2005; Carey, 2004). But once a child reaches an understanding of roughly *three,* or sometimes *four*, the pattern changes. The child rapidly binds succeeding numbers to their cardinalities, and shows understanding of the successor principle, that every (natural) number has a natural successor. This insight—that "If number word X refers to a set with cardinal value n, the next number word in the list refers to a set with cardinal value n + 1" (Carey, 2004)—occurs via an analogy between *counting one further* in the verbal count sequence and *increasing by one* in the set size.

But the analogy between the *counting one further in the count sequence* and *adding one in quantity* is very abstract. As Mix (2002, Mix et al., 2005) documents, children's early insights into how numbers connect to set size are often concrete and context-specific. For example, in Mix's (2002) diary study, at 20 months Spencer spontaneously brought from another room exactly two treats for the family's two dogs, and repeated this feat with perfect accuracy several times over the next few weeks. But he failed when asked to go get "train treats" for his two toy trains, suggesting that his command of "twoness" is highly context-bound.

Mix and colleagues have noted several kinds of early nonverbal experience that contribute to the gradual acquisition of numerical insight, including several kinds of routines that promote one-to-one correspondence (such as distributing candies among several people). They also suggest an important role for language in the development of cardinality: namely, that hearing two sets labeled with the same count word could prompt a comparison process that leads the child to notice their common number (Mix et al., 2005). This line is consistent with the idea that common language invites comparison (Gentner, 2003; Gentner & Namy, 1999; Loewenstein & Gentner, 2005) which in turn can support categorization (Gelman & Markman, 1987; Waxman & Klibanoff, 2000).

In opposition to the above proposals, Gelman and Gallistel argue that language has little if any role in the development of number. In their account, the analog magnitude system is the cognitive foundation of number knowledge (Dehaene, 1997; Gallistel & Gelman, 1992). Gallistel, Gelman, & Cordes (2005) argue further that the analog magnitude system, whose output is continuous rather than discrete, represents the real numbers. As how to language may play a role in number development, Gallistel and Gelman posit that "… a system for arithmetic reasoning with real numbers evolved before language evolved. When language evolved, it picked out from the real numbers only the integers… " (Gallistel, Gelman, & Cordes, 2005, p. 247). This position reverses the usual supposition of developmentalists and historians that understanding of the natural numbers appears first, followed by the integers, the rationals and the reals.

3.3 Research on languages that lack full count systems

One line of support for the hypothesis that count terms are causally related to the development of number knowledge comes from studies of the Pirahã (Everett, 2005; Gordon, 2004), an Amazonian tribal group, who use what has been described as a "one-two-many" system of counting (*hói, hoí, baagi (or aibai)*). (See also Pica et al., 2005, for similar results for the Munduruku). Gordon administered several numerical tasks using objects familiar to the Pirahã, over numbers between 1 and 10. For example, the experimenter would place, say, five batteries on the table, and asked the participant to "make it the same" with another set of batteries. In another task, some nuts were put in a can, and then nuts were drawn out of the can one by one by the experimenter. After each withdrawal, participants were asked whether the can still contained nuts or was empty. The results were striking. The Pirahã participants performed with good accuracy for up to

3 items, but performance became merely approximate after 3 items. Nevertheless, performance beyond 3 was not random; it was consistent with the Weber fraction found in results of people performing magnitude estimation tasks. The Pirahã have the same ability to estimate numerosity as do English or French speakers; what they lack is a verbal counting system.

Striking as it is, this finding has been replicated by a later study of the Pirahã (Frank et al., 2008). Frank et al. conducted the same tasks as in Gordon's study and again found only approximate performance for numbers beyond 3 in tasks like nuts-in-the-can task (though this time the Pirahã performed better on the simpler versions of the one-to-one matching task than they had in Gordon's study). Interestingly, an additional linguistic task administered by Frank et al. suggests that the count system of the Pirahã is even less precise than the previously suggested one-two-many system. In a numeral elicitation task, speakers were shown a series of either increasing (from 1—10) or decreasing (from 10—1) objects, and asked at each stage "how much/many are there?" While in the increasing elicitation condition the word *hói* was used only for one item, in the decreasing condition the same word was used for quantities as large as six. It appears that the Pirahã terms are not true numbers, but are relative to the size of the set—something more like "a few, more than a few, lots."

3.4 Effects of language on later development of mathematics.

If number words are indeed crucial in the development of the number concept, then we might see different developmental patterns in number acquisition depending on the characteristics of number words in a given language. Miller and Stigler (1987) suggest that one important difference is the regularity of the number system. They noted that Chinese is more systematic than English in an important respect: whereas both languages have unique words for 1 through 10, Chinese is far more regular in its two-digit numbers than is English. In Chinese, eleven is “ten one”, twelve is “ten two” and so on throughout the teens, and the system continues in this regular fashion with “twenty-one”, “twenty-two”, and so on. Contrast this system with English, in which *eleven* and *twelve* are opaque and although *thirteen* through *nineteen* are partly transparent (if the child recognizes “teen” as “ten”), in addition, the order of tens and units reverses after 20 – we say *twenty-one*, *twenty-two*, and so on. Miller and Stigler hypothesized that a regular system like Chinese would be easier to learn and use (see also Fuson & Kwon, 1992). Consistent with this prediction, they found that Chinese preschoolers (aged 4 and 5) were significantly better than their English-speaking peers in a counting task in which they had to count as high as they could (Miller, Smith, Zhu, & Zhang, 1995). Both American children (94%) and Chinese children (92%) could count to 10, but while 74% of Chinese children could count to 20, only 48% of American children could do so.

What about the effects of linguistic variability *within* a language—does the amount and quality of mathematical language influence children’s learning of that domain? To find out, Klibanoff et al. (2006) recorded the kind of mathematical language used by preschool or day-care teachers and related it to measures of the growth of children’s conventional mathematical knowledge over the school year. They included language for ordinality (e.g., “Point to the one that has more”) and cardinality (e.g., “Point to four,” given cards with varying numbers of items), as well as names for geometric shapes, the term “half” and so on. The results showed that there were dramatic differences in how much math-related talk teachers provided, and further, that the amount of teachers' math-related talk was significantly related to the growth of preschoolers' conventional mathematical knowledge over the school year, and unrelated to their math knowledge at the start of the school year.

4 Theory of Mind

Theory of mind refers the ability to reason about mental states – beliefs, desires, intentions, and emotions. In large part, mental states are expressed via language, and hearing conversations about desires and intentions is one way of learning about others' mental states. But some researchers have taken the link between language and theory of mind further and have proposed that language plays a fundamental role in the development of theory of mind. Theories that invoke language differ as to which aspects of language—whether pragmatics and discourse structure, lexical semantics, or syntactic structure—are most fundamental for developing a theory of mind.

A key question in the development of theory of mind is how and when children become aware that other people's minds may not contain the same beliefs as their own mind. Performance on false-belief tasks is one standard way of assessing whether children have this understanding. One classic false belief task, first introduced by Wimmer and Perner (1983), is the unseen displacement scenario. For example, 3- to 9-year-old children are presented with a story in which Maxi puts his chocolate in the kitchen cupboard. While Maxi is away, his mother moves the chocolate to the drawer. Children are then asked where Maxi will look for his chocolate when he returns—in the cupboard or in the drawer. None of the three-year-olds correctly said that Maxi would look at the cupboard, whereas a majority of four-year-olds gave the correct answer.

Another type of false-belief task is the "smarties" study (Perner, Leekham, & Wimmer, 1987; Gopnik & Astington, 1988), which can be used to assess children's insight into their own minds. In this task, the child is shown a smarties box (smarties being a type of candy), and asked what was in the box. The child readily answers "candy" and is then allowed to look inside, whereupon she discovers to her surprise that the box actually contains crayons. When the experimenter asks what the child originally thought was in the box, 5-year-olds correctly say "candy;" but most 3-year-olds insist that they initially expected the candy box to contain crayons; some even claim to have said so out loud.

Many results from theory of mind studies suggest that the ability to represent people's epistemic states does not become firmly established until around 4-6 years of age[6]. By this age, many cognitive and linguistic skills are already quite advanced. Many theorists emphasize the importance of these skills without assigning language a special role (e.g., Gopnik & Wellman, 1992; Perner 1991). Others have argued that it is theory of mind that precedes language, rather than the reverse. In one version of this position, theory of mind stems from an innately developing module (Baron-Cohen, 1999); which may support children's understanding of mental language but does not require language for its development. A weaker position is that some degree of interpersonal insight—notably a sense of when joint attention is called for—is critical for language development (Baldwin, 1991; Tomasello, 1998).

However, a sizable body of research has argued for a role of language in the development of theory of mind. For example, Milligan, Astington and Dack (2007) found in a meta-analysis of 104 false-belief studies for children under age 7, that language ability is a significant predictor of false-belief understanding even when age is controlled. Overall, three major views have been proposed for how language may contribute to the development of theory of mind: the discourse-pragmatic, the lexical semantic, and the complementation syntax view. Although these three views are not mutually exclusive, they make different bets as to which aspect of language play a role in the development of theory of mind.

4.1 Discourse pragmatics

On the discourse-pragmatic account, conversational pragmatics is critical in developing an understanding of other minds (Harris, 1999). Children first become aware of their own mental states, and through simulation or role-taking processes, they use this awareness to infer the mental states of others. Back-and- forth discourse allows children to realize that they sometimes know what others do not, and vice versa. One line of support for this view comes from a correlational study that showed that deaf children who had more opportunities to participate in rich discourse interactions with others also performed better in false belief tasks (Peterson & Siegal, 2000). In another study, Dunn et al. (1991) observed naturalistic conversations between 2-year-olds and their mothers. Seven months later, the children were queried on the understanding of other minds. They found that children's engagement in family conversation about feeling states was positively correlated with the ability to give correct explanations of false belief behaviors.

4.2 Lexical semantics

In the lexical semantics view, the acquisition of mental state terms such as *think*, *know*, and *believe* plays a crucial role in the development of the understanding of false beliefs (Astington, 1996; Bartsch & Wellman, 1995; Bretherton & Beeghly, 1982)

Children begin to use mental state terms at about age 2, especially perceptual and emotional terms (*see*, *hear*; *happy*, *sad*, *angry*). Starting at age 3, children also begin to produce cognitive terms such as *think* and *know*, but it is not until the early school years that children show clear discrimination among terms such as *think*, *know*, and *guess* (Bartsch & Wellman, 1995; Bretherton & Beeghly, 1982). The lexical hypothesis is that children acquire these mental state terms in conversation; parents use them to refer to the mental states that the child is experiencing, allowing the child to attach the terms to her own mental states. The child also notices that these terms can apply to other people, inviting the child to attribute the corresponding mental states to others as well as to herself (Astington, 1996).

To test whether mothers' language influences the development of theory of mind, Ruffman, Slade, and Crowe (2002) conducted a longitudinal study in which they asked mothers to describe pictures to 82 children at three time points spanning a one-year period. They found that mothers' use of mental state utterances at early time points was correlated with children's later theory-of-mind understanding. The result held true even when a number of potential intervening factors were accounted for, such as children's age, their language ability, their own use of mental state language, their earlier theory-of-mind understanding, and also mothers' education and other kinds of mothers' utterances. Ruffman et al. concluded that mothers' mental state utterances play a causal role in the development of theory of mind.

4.3 Complementation syntax

Another prominent view is that acquiring the syntax of sentential complements is a critical factor in the development of false belief understanding (de Villiers & de

Villiers, 2000). In a sentential complement construction, a sentence takes a full clause as its object complement: e.g., “Mary thinks that John is at school.” This construction makes it relatively transparent to see that the truth value of the sentence as a whole can differ from that of the embedded proposition: that is, the fact that Mary *thinks* that John is at home does not necessarily mean that John *is* at home. De Villiers and de Villiers note that communication constructions such as *“x says that p”* provide overt evidence for this disassociation when *p* is known to be untrue. In this way, communication verbs can serve to bootstrap children’s understanding of the use of *think*: children learn to deal with false complements via *say,* and by analogy come to understand that *think* too can take a false complement.

One line of evidence for this hypothesis comes from a longitudinal study with preschool children that found that performance on false belief tasks was predicted by performance in interpreting sentences containing mental and communication verbs with complements (de Villiers & Pyers, 2002). To gauge mastery of sentential complements, children were given scenarios like the following: “She said she found a monster under her chair, but it was really the neighbor’s dog” and then were asked “What did she say?” Children’s responses were counted correct as long as they said “a monster.” The children also carried out false belief tasks such as the unseen displacement task and the unexpected content task described earlier. A positive correlation was found between mastery of sentential complements and success in false belief tasks.

Further evidence was found among oral deaf children who are delayed in language learning (de Villiers and de Villiers, 2003). To control for any effects of language required by the false belief tasks themselves, nonverbal false belief tasks were used. In one task, the experimenter hid a sticker in one of the four identical boxes while a screen obscured the hiding from the child. On the test trial, two “helping” adults—one wearing a blindfold and one who could see the hiding event--each pointed to a box after the screen was raised, and the child had to choose whose advice to follow. In the other task, children were shown a sequence of pictures depicting an unexpected content event and had to complete the sequence with either a surprise face (correct) or a neutral face. The performance of these children on false belief tasks was predicted by their performance in the complement comprehension task.

Most recently, Pyers and Senghas (2009) took advantage of a naturally occurring change in the linguistic affordances of an emerging language—Nicaraguan Sign Language (NSL) –to test whether language promotes false-belief understanding over and above social experience. NSL first appeared in the 1970s among deaf children entering special education schools (Senghas, Kita, & Özyürek, 2004). When the roughly 50 original children (who typically had developed their own idiosyncratic ‘homesign’ gesture systems Goldin-Meadow, 2003) were brought together, they developed an early form of NSL as a common language. This was further enriched by the second cohort of children in the mid-1980s. Senghas and colleagues report that even today, the second cohort exhibits a more developed form of the language than the older first cohort (Senghas & Coppola, 2001; Senghas, Kita, & Özyürek, 2004). In particular, the second-cohort’s language includes more mental-state verbs than the first cohort version—setting the stage for a test of whether possession of mental state verbs supports reasoning about others’ mental states. Importantly, aside from their language differences, the two cohorts have similar histories of schooling and social interaction.

Pyers and Senghas used a low-verbal false-belief task to test speakers from the two cohorts of Nicaraguan signers: Participants were given a sequence of pictures depicting unseen displacement events (following a false-belief plot), and then had to choose which of two final pictures correctly depicted the final event. The results showed a strong effect of language: The second cohort (average age 17.5 years) by far outperformed the first cohort (average age 26.8 years). Out of four test trials, the second cohort solved on average 3.5 trials, as contrasted with .5 trials for the first cohort. Interestingly, when tested 2 years later, some of the first cohort who had gained mental-state verbs also performed better in the false belief task. Overall, these results support the idea that language provides cognitive tools that support theory of mind, even well into adulthood.

5 Summary

While the issues are far from resolved, the evidence reviewed here suggests that language may influence the development of conceptions of space, mind, and number. Language can foster cognitive development through various routes. The language we speak provides us with tools for dissecting space into finer categories, and for connecting those concepts into systems that permit combinatorial inferences. Language can also invite a systematic representation (as in the Chinese numerals, or in the fluent numerical abilities of English speakers as compared to the Pirahã speakers). These representations can support real-world tasks such as navigation and calculation. They also support abstract thinking, such as using spatial relations to reason about time, to plot kinship relations, or to comprehend graphs and other figures that use spatial patterns to depict nonspatial phenomena.

An interesting further question is, what is the time course of this linguistic influence? The available research suggests that language effects are not immediate. It is not enough to simply learn a set of terms (even supposing that their full meanings are understood—a dubious assumption in early development). We suspect that some degree of entrenchment must occur before the new representation is sufficiently robust to have cognitive effects. For example, in the Loewenstein and Gentner (2005) spatial mapping task, hearing spatial terms such as *top, middle, bottom* improved the performance of younger, but not older, children. Apparently, the younger children knew the terms well enough to benefit from hearing them, but not well enough to access them spontaneously. The performance of the older children is consistent with the possibility that the spatial system conveyed by the terms was sufficiently entrenched to come to mind with or without the terms.

In some cases linguistic patterns may give rise to a habitual mode of construal. But in general, the evidence suggests that the influence of language is far from absolute. Human representation is rich and varied, and no one system of encoding is able to govern all of human representation. There is also reason to believe that there is influence in the reverse direction, from cognition to language. Some systems of categories are more natural—easier to learn and use—than others. For example, Gentner and Bowerman (2009) have suggested that the typological prevalence of a given semantic system across languages may afford an estimate of its cognitive naturalness and concomitant ease of learning.

There are many open questions. For example, in which semantic arenas do we find the largest effects of language—are there larger effects of language in relatively abstract arenas, such as mathematics and time, than in more concrete domains such as color? Does language for emotions and for thought processes influence the way in which we construe our own minds? Does learning a technical language influence adult cognition in ways similar to the developmental patterns discussed here? Addressing these questions will give us a deeper understanding of how language affects the development of thought.

References

Acredolo, L. P. (1978). Development of spatial orientation in infancy. *Developmental Psychology*, *14*, 224-234.

Astington, J. W. (1996). What is theoretical about the child's understanding of mind? A Vygotskian view of its development. In P. Carruthers and P.K. Smith (Eds.), *Theories of theories of mind* (pp. 184-199). Cambridge University Press.

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development, 62,* 875-890.

Bartsch, K., & Wellman, H. (1995). *Children talk about the mind*. New York: Oxford University Press.

Baron-Cohen, S. (1999). The evolution of a theory of mind. In M. C. Corballis & S. E. G. Lea (Eds.), *The descent of mind: Psychological perspectives on hominid evolution* (pp. 261-277). New York: Oxford University Press.

Bohnemeyer, J., & Brown, P. (2007). Standing divided: dispositional predicates and locative predications in two Mayan languages. *Linguistics, 45*(5).

Boroditsky, L. (2001). Does language shape thought? Mandarin and English speakers' conceptions of time. *Cognitive Psychology*, 43(1), 1–22.

Boroditsky, L., Schmidt, L., & Phillips, W. (2003). Sex, Syntax, and Semantics. In Gentner & Goldin-Meadow (Eds.), *Language in Mind: Advances in the study of Language and Cognition* (pp. 61-80). Cambridge: MIT Press.

Bowerman, M. (1980). The structure and origin of semantic categories in the language-learning child. In M. L. Foster & S. Brande (Eds.), *Symbol as sense* (pp. 277-299). New York: Academic Press.

Bowerman, M. (1981). The child's expression of meaning: Expanding relationships among lexicon, syntax and morphology. In H. Winitz (Ed.), *Native language and foreign language acquisition* (Vol. 379, pp. 172-189). New York: New York Academy of Sciences.

Bowerman, M. (1989). Learning a semantic system: What role do cognitive predispositions play? In M. L. Rice & R. L. Schiefelbusch (Eds.), *The teachability of language (*pp 133 -169). Baltimore, MD: Paul H. Brooks.

Bowerman, M. (1996). Learning how to structure space for language: A crosslinguistic perspective. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 385-436). Cambridge: MIT Press.

Bowerman, M. and Choi, S. (2003). Space under construction: Language specific spatial categorization in first language acquisition. In D. Gentner and S. Goldin-Meadow (Eds) *Language in Mind: Advances in the study of Language and Cognition* (pp. 387-428). Cambridge: MIT Press.

Bowerman, M., & Levinson, S. (Eds.). (2001). *Language acquisition and conceptual development* [preface, introduction]. Cambridge, UK: Cambridge University Press.

Bremner, J.G. (1978). Egocentric versus allocentric spatial coding in nine-month-old infants: factors influencing the choice of code. *Developmental Psychology, 14*, 346–355.

Bretherton, I., & Beeghly, M. (1982). Talking about internal states: The acquisition of an explicit theory of mind. *Developmental Psychology, 18*, 906-921.

Brown, P. (1994). The INS and ONS of Tzeltal locative expressions: The semantics of static descriptions of location. *Linguistics, 32,* 743-790.

Call, J. (2001). Object permanence in orangutans (Pongopygmaeus), chimpanzees (Pantroglodytes), and children (Homosapiens). *Journal of Comparative Psychology, 115*, 159–171.

Carey, S. (2004). Bootstrapping and the origin of concepts. *Daedalus, 133.*

Carey, S. (2009). *The origin of concepts*. Oxford University Press, USA.

Casad, E. H., & Langacker, R. W. (1985). "Inside" and "outside" in Cora Grammar. *International Journal of American Linguistics, 51*, 247-281.

Casasola, M. (2005). Can language do the driving? The effect of linguistic input on infants' categorization of support spatial relations. *Developmental Psychology*, *41,* 183-192.

Casasola, M. (2008). The development of infants' spatial categories. Current Directions in *Psychological Science*, 17, 21-25.

Choi, S., & Bowerman, M. (1991). Learning to express motion events in English and Korean: The influence of language-specific lexicalization patterns. *Cognition, 41*, 83-121.

Choi, S., McDonough, L., Bowerman, M., & Mandler, J. M. (1999). Early sensitivity to language-specific spatial categories in English and Korean. *Cognitive Development, 14,* 241-268.

Dehaene, S. (1997). *The number sense: How the mind creates mathematics.* New York: Oxford University Press.

Dessalegn, B., & Landau, B. (2008). More than meets the eye: the role of language in binding and maintaining feature conjunctions. *Psychological Science, 19*, 189 - 195.

de Villiers, J., & de Villiers, P. (2000). Linguistic determinism and the understanding of false beliefs. In P. Mitchell & K. J. Riggs (Eds.) *Children's reasoning and the mind* (pp. 191–228). Hove, England: Psychology Press.

de Villiers, J., & de Villiers, P. (2003) 'Language for thought: Coming to understand false beliefs', in: D. Gentner and S. Goldin-Meadow (eds.) *Language in Mind: Advances in the Study of Language and Thought* (pp. 335-384). Cambridge, MA: MIT Press.

de Villiers, J. G., & Pyers, J. E. (2002). Complements to cognition: a longitudinal study of the relationship between complex syntax and false-belief understanding. *Cognitive Development, 17*, 1037–1060.

Dunn, J., Brown, J. R., Slomkowski, C., Tesla, C., & Youngblade, L. (1991). Young children's understanding of other people's feelings and beliefs: Individual differences and their antecedents. *Child Development, 62,* 1352-1366.

Everett, D. (2005). Cultural constraints on grammar and cognition in Pirahã: Another look at the design features of human language. *Current Anthropology*, *76*, 621-646.

Frank, M.C., Everett, D., Fedorenko, E., & Gibson, E. (2008). Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition, 108*, 819-824.

Fuson, K. C. (1988). *Children's counting and concepts of number.* New York: Springer Verlag.

Fuson, K.C., & Kwon, Y. (1992). Learning addition and subtraction: Effects of number words and other cultural tools. In J. Bideaud, C. Meljac, & J.-P. Fischer (Eds.), *Pathways to number: Children's developing numerical abilities* (pp. 283-306). Hillsdale, NJ : Erlbaum.

Gallistel, C.R. (1990). *The organization of learning.* MIT Press, Cambridge, Mass.

Gallistel, C. R., & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition, 44*, 43-74

Gallistel, C. R., Gelman, R., & Cordes, S. (2005). The cultural and evolutionary history of the real numbers. In S. Levinson & P. Jaisson (Eds.), *Culture and evolution*. Cambridge, MA: MIT Press.

Gelman, S. A., & Markman, E. M. (1987). Young children's inductions from natural kinds: The role of categories and appearances. *Child Development, 58*, 1532-1541.

Gentner, D. (1982). Why nouns are learned before verbs: Linguistic relativity versus natural partitioning. In S. A. Kuczaj (Ed.), *Language development: Vol. 2. Language, thought and culture* (pp. 301-334). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gentner, D. (2003). Why we're so smart. In D. Gentner and S. Goldin-Meadow (Eds). *Language in mind: Advances in the study of language and thought* (pp. 195-236). Cambridge, MA: MIT Press.

Gentner, D. (2010). Bootstrapping children's learning: Analogical processes and symbol systems. *Cognitive Science*, 34 (5). 752-775.

Gentner, D., & Bowerman, M. (2009). Why some spatial semantic categories are harder to learn than others: The Typological Prevalence hypothesis. In J. Guo, E. Lieven, S. Ervin-Tripp, N. Budwig, S. Özçaliskan, & K. Nakamura (eds.). *Crosslinguistic approaches to the psychology of language: Research in the tradition of Dan Isaac Slobin*. (pp. 465-480). NY, New York: Lawrence Erlbaum Associates.

Gentner, D. & Christie, S. (2010). Mutual bootstrapping between language and analogical processing. *Language and Cognition*, 2(2). 261-283.

Gentner, D., & Goldin-Meadow, S. (2003). Whither Whorf. In D. Gentner and S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and thought* (pp. 3-14). Cambridge, MA: MIT Press.

Gentner, D., & Namy, L. (1999). Comparison in the development of categories. *Cognitive Development, 14*, 487-513.

Gentner, D., Ozyürek, A., Goldin-Meadow, S. & Gurcanli, O. (2008, February) *Spatial language potentiates spatial cognition: Evidence from deaf homesigners*. Presented at the American Association for the Advancement of Science annual meeting.

Gentner, D., & Toupin, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science, 10*, 277-300.

Gleitman, L., & Papafragou, A. (2005). Language and thought. In K. Holyoak & B. Morrison (eds.), *Cambridge Handbook of Thinking and Reasoning*, 633-661. Cambridge: Cambridge University Press.

Goldin-Meadow, S. (2003). *The resilience of language: What gesture creation in deaf children can tell us about how all children learn language*. (J. Werker & H. M. Wellman, Eds.). New York: Psychology Press.

Goldstone, R. L. (1998). Perceptual learning. *Annual Review Psychology, 49*, 585-612.

Gopnik, A. & Astington, J. W. (1988). Children's understanding of representational change and its relation to the understanding of false belief and the appearance-reality distinction. *Child Developm*ent, *59*, 26-37.

Gopnik, A. & Wellman, H. (1992). Why the child's theory of mind really is a theory. *Mind and Language, 7*, 145-171.

Gordon, P. (2004). Numerical cognition without words: evidence from Amazonia. *Science, 306*, 406-499

Gumperz, J. J., & Levinson, S. C. (1996). *Rethinking linguistic relativity.* Cambridge, England: Cambridge University Press.

Harris, P.L. (1999). Individual differences in understanding emotion: the role of attachment status and psychological discourse. *Attachment & Human Development, 3*, 307-324.

Haun, D.B.M., Rapold, C., Call, J., Janzen, G., Levinson, S.C. (2006). Cognitive cladistics and cultural override in Hominid spatial cognition. *Proceedings of the National Academy of Sciences*, *103*, 17568-17573.

Hespos, S. & Spelke, E. (2004). Conceptual precursors to language. *Nature*, *430*, 453-456.

Hunt, E., & Agnoli, F. (1991). The Whorfian hypothesis: A cognitive psychology perspective. *Psychological Review, 98,* 377-389.

Imai, M., & Gentner, D. (1997). A crosslinguistic study of early word meaning: Universal ontology and linguistic influence. *Cognition*, 62, 169-200.

Imai, M., & Mazuka, R. (2003). Reevaluating linguistic relativity: Language-specific categories and the role of universal ontological knowledge in the construal of individuation. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 429-464). Cambridge, MA: MIT Press.

Klibanoff, R. S., Levine, S. C., Huttenlocher, J., Vasilyeva, M., & Hedges, L. V. (2006). Preschool children's mathematical knowledge: The effect of teacher "math talk". *Developmental Psychology, 42*, 50-69.

Levinson, S. C. (1996). Relativity in spatial conception and description. In J. J. Gumperz & S. C. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 177-202). Cambridge, MA: Cambridge University Press.

Levinson, S. C. (2003). Language and mind: Let's get the issues straight! In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 25-46). Cambridge, MA: MIT Press.

Levinson, S., Kita, S., Haun, D. & Rasch, B. (2002). Returning the tables: Language affects spatial reasoning. *Cognition*, *84*, 155-188.

Levinson, S. C., & Brown, P. (1994). Immanuel Kant among the Tenejapans: Anthropology as applied philosophy. *Ethos, 22(1),* 3-41.

Loewenstein, J., & Gentner, D. (2005). Relational language and the development of relational mapping. *Cognitive Psychology, 50*, 315-353.

Li, P., & Gleitman, L. (2002). Turning the tables: Language and spatial reasoning. *Cognition, 83,* 265-294.

Lucy, J. A. (1994). *Grammatical categories and cognition.* Cambridge: Cambridge University Press.

Lupyan, G. (2008). From chair to 'chair:' A representational shift account of object labeling effects on memory. *Journal of Experimental Psychology: General*, *137*(2), 348-369.

Lupyan, G., Rakison, D.H., & McClelland, J.L. (2007). Language is not just for talking: labels facilitate learning of novel categories. *Psychological Science* 18(12): 1077-1083.

Majid, A., Bowerman, M., Kita, S., Haun, D. B. M., & Levinson, S. C. (2004) Can language restructure cognition? The case for space. *TRENDS in Cognitive Sciences 8,* 108-114.

Markman, E. M. (1989). *Categorization and naming in children: Problems of induction*. Cambridge, MA: MIT Press.

McDonough, L., Choi, S., Mandler, J. (2003). Understanding spatial relations: Flexible infants, lexical adults. *Cognitive Psychology*, *46,* 229-259.

Meck, W.H., Church, R.M., & Gibbon, J. (1985). Temporal integration in duration and number discrimination. *Journal of Experimental Psychology: Animal Behavior Processes*, *11*, 591-597.

Miller, K. F., & Stigler, J. W. (1987). Counting in Chinese: Cultural variation in a basic cognitive skill. *Cognitive Development, 2,* 279-305.

Miller, K.F., Smith, C.M., Zhu, J. & Zhang, H. (1995). Preschool origins of cross-national differences in mathematical competence: The role of number-naming systems. *Psychological Science, 6*, 56-60.

Milligan, K., Astington, J. W., & Dack, L. A. (2007*).* Language and theory of mind: Meta-analysis of the relation between language ability and false-belief understanding. *Child Development*, *77*, 622–646.

Mix, K. S. (2002). The construction of number concepts. *Cognitive Development, 17.* 1345-1363.

Mix, K.S., Sandhofer, C. M., & Baroody, A. J. (2005) Number words and number concepts: the interplay of verbal and nonverbal quantification in early childhood. In R.V. Kail (Ed.), *Advances in Child Development and Behavior, Volume 33*, (pp 305-346). New York: Academic Press.

Oakes, L. M., & Ribar, R. J. (2005). A comparison of infants' categorization in paired and successive presentation familiarization tasks. *Infancy, 7*, 85-98.

Onishi, K. H., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science, 308*, 255–258.

Pederson, E. (1995). Language as context, language as means: Spatial cognition and habitual language use. *Cognitive Linguistics, 6*, 33-62.

Perner, J. (1991). *Understanding the representational mind.* Cambridge, MA: MIT Press.

Perner, J., Leekham, S. R., & Wimmer, H. (1987). Three-year-olds' difficulty with false belief: The case for a conceptual deficit. *British Journal of Developmental Psychology, 5*. 125-137.

Peterson, C. C., & Siegal, M. (2000). Insights into a theory of mind from deafness and autism. *Mind & Language, 15*, 123 – 145.

Pica, P. Lemer, C., Izard, V. and Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigene group. *Science, 306*, 499-503.

Piaget, J. & Inhelder, B. (1967). *The child's conception of space*. New York: Norton.

Pick, H. L. Jr. (1993). Organization of spatial knowledge in children. In N. Eilan, R. McCarthy, and B. Brewer (Eds.), *Spatial Representation: Problems in Philosophy and Psychology* (pp 31-42). Blackwell Publishing.

Pyers, J. & Senghas, A. (2009). Language promotes false-belief understanding: Evidence from Nicaraguan Sign Language. *Psychological Science, 20*, 805-812.

Pylyshyn, Z. (2001). Visual indexes, preconceptual objects, and situated vision. *Cognition, 80*, 127-158.

Ruffman, T., Slade, L., & Crowe, E. (2002). The relation between children's and mothers' mental state language and theory of mind understanding. *Child Development, 73,* 734-751.

Senghas, A. & Coppola, M. (2001). Children creating language: How Nicaraguan Sign Language acquired a spatial grammar. *Psychological Science, 12,* 323-328.

Senghas, A., Kita, S., & Özyürek, A. (2004). Children creating core properties of language: Evidence from an emerging sign language in Nicaragua. *Science*, *305*, 1779-1782.

Slobin, D. I. (1996). From "thought and language" to "thinking for speaking". In J. J. Gumperz & S. C. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 70-96). Cambridge, MA: Cambridge University Press.

Slobin, D. I. (2003). Language and thought online: Cognitive consequences of linguistic relativity. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 157-192). Cambridge, MA: MIT Press.

Spelke, E. S. (2000). Core knowledge. *American Psychologist, 55*(11), 1233-1243.

Spelke, E. S. (2003). What makes us smart? Core knowledge and natural language. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 277-312). Cambridge, MA: MIT Press.

Spelke, E. S., & Tsivkin, S. (2001). Initial knowledge and conceptual change: space and number. In M. Bowerman & S. C. Levinson (Eds.), *Language acquisition and conceptual development* (pp. 70-100). Cambridge, UK: Cambridge University Press.

Talmy, L. (1975). Semantics and syntax of motion. In J. Kimball (Ed.), *Syntax and semantics* (Vol. 4, pp. 181-238). New York: Academic Press.

Talmy, L. (1985). Lexicalization patterns: Semantic structure in lexical forms. In T. Shopen (Ed.), *Language, typology and syntactic description: Vol. 3. Grammatical categories and the lexicon* (pp. 57-149). New York: Cambridge University Press.

Tomasello, M. (1998). Reference: Intending that others jointly attend. *Pragmatics and Cognition, 6*, 229-243.

Tomasello, M., and Call, J. (1997). *Primate Cognition*. New York, NY: Oxford University Press.

Vygotsky, L. S. (1962). *Thought and language.* Cambridge, MA: MIT Press. (Original work published 1934).

Waxman, S. R. (2002). Links between object categorization and naming: Origins and emergence in human infants. In D. H. Rakison, & L. M. Oakes (Eds.), *Early category and concept development: Making sense of the blooming, buzzing confusion* (pp 213-241). NY, New York: Oxford University Press.

Waxman, S. R., & Klibanoff, R. S. (2000). The role of comparison in the extension of novel adjectives. *Developmental Psychology, 36,* 571-581.

Waxman, S. R., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology, 29*(3), 257-302.

Whorf, B. L. (1956). Language*, thought and reality: Selected writings*. Cambridge, MA: Technology Press of Massachusetts Institute of Technology.

Wimmer, H. & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, *13*, 41-68.

Wolff, P., & Holmes, K. (in press). Linguistic Relativity. To appear in *WIREs Cognitive Science.*

Wynn, K. (1990). Children's understanding of counting. *Cognition, 36,* 155-193.

Xu, F. (2002). The role of language in acquiring object kind concepts in infancy. *Cognition, 85*, 223-250.

Endnotes

[1] Dutch and German (and also English) use basically the same system of spatial reference, with the egocentric spatial reference frame as dominant.

[2] Bowerman's recent research has also explored the other direction: that some categories are more natural than others, and that these categories will both be more frequent in the world's language and more readily learned by children (the typological prevalence hypothesis) (Gentner & Bowerman, 2009).

[3] All ages showed a familiarity preference in both languages.

[4] The McDonough et al study also belongs on the "rich and varied" end of the continuum, with the added important feature that they showed infants pairs of events (for example, two tight containment events) during familiarization. Their finding that even 9-month-old infants given pairs of events can abstract common relations from rich, complex stimuli is consistent with evidence that comparing two exemplars fosters the abstraction of commonalities, particularly common relations (Gentner & Namy, 1999; Oakes & Ribar, 2005).

[5] However, interestingly, other asymmetric terms such as "prettier" also aided performance—possibly via metaphor mapping to the actual spatial situation.

[6] However, some studies have found evidence of an ability to represent at least some mental states of others as early as fifteen months (Onishi & Baillargeon, 2005). How these early sensitivities relate to later patterns remain to be worked out.

Figure Captions

Figure 1: Experimental setup for an example trial in Haun et al., 2006. Ten identical cups were placed on two tables (five cups on each table). The participant watched while a target was hidden under the cup depicted as white (HIDING). Then participants moved to the other table and indicated where they thought a second target might be hidden (FINDING).

Figure 2: Experimental setup for the two versions of the Loewenstein and Gentner (2005) spatial mapping task. Children watched the experimenter place the “winner” card in the left box and searched for it in the right box.

Figure 1.

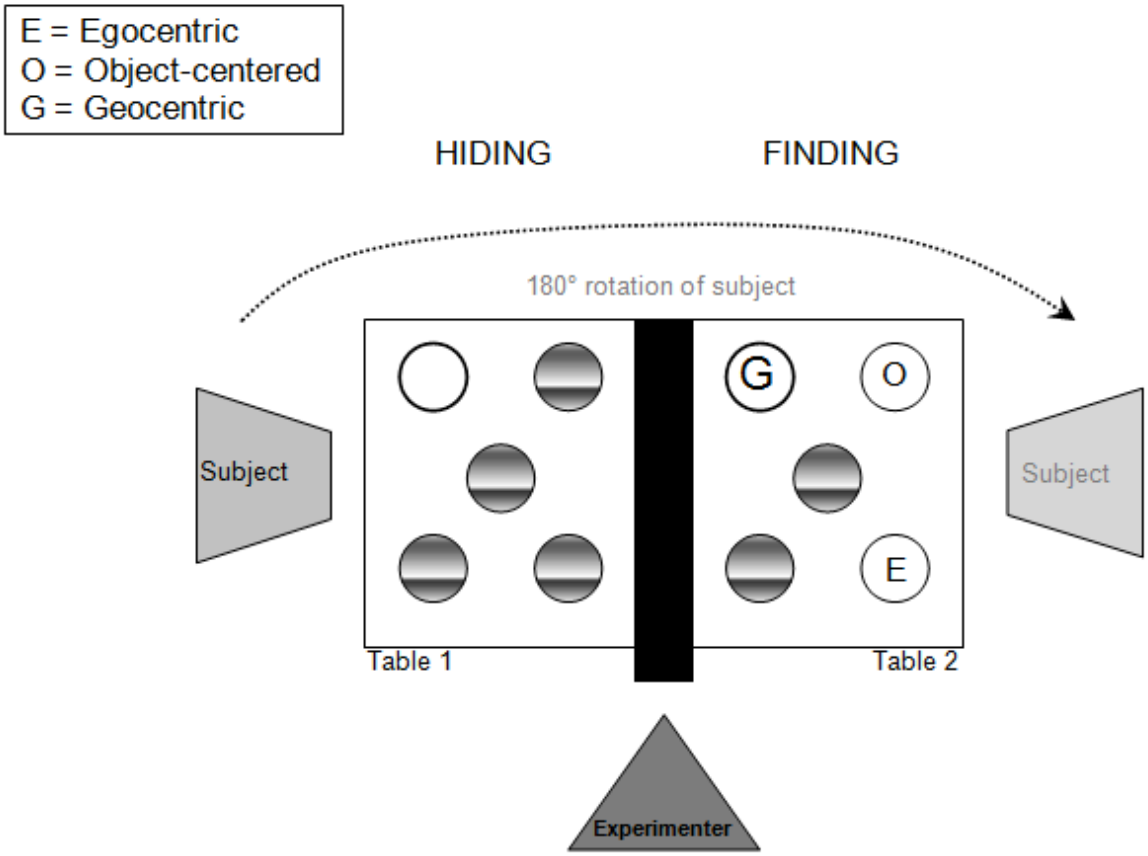
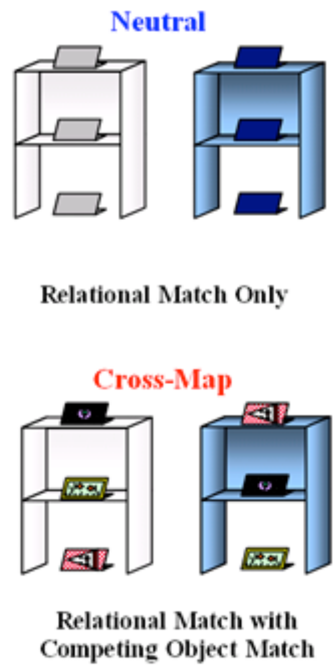

E = Egocentric
O = Object-centered
G = Geocentric
HIDING
FINDING
180° rotation of subject
Subject
G
O
E
Subject
Table 1
Table 2
Experimenter

Figure 2.


Neutral
Relational Match Only
Cross-Map
Relational Match with
Competing Object Match