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On the Spatial Foundations of the Conceptual System and Its Enrichment

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Abstract

A theory of how concept formation begins is presented that accounts for conceptual activity in the first year of life, shows how increasing conceptual complexity comes about, and predicts the order in which new types of information accrue to the conceptual system. In a compromise between nativist and empiricist views, it offers a single domain-general mechanism that redescribes attended spatio-temporal information into an iconic form. The outputs of this mechanism consist of types of spatial information that we know infants attend to in the first months of life. These primitives form the initial basis of concept formation, allow explicit preverbal thought, such as recall, inferences, and simple mental problem solving, and support early language learning. The theory details how spatial concepts become associated with bodily feelings of force and trying. It also explains why concepts of emotions, sensory concepts such as color, and theory of mind concepts are necessarily later acquisitions because they lack contact with spatial descriptions to interpret unstructured internal experiences. Finally, commonalities between the concepts of preverbal infants and nonhuman primates are discussed.

Keywords: Cognitive architecture; Conceptual development; Infancy; Spatial primitives; Perceptual Meaning Analysis

1. Introduction

During the past two decades a wide range of studies of infant cognitive functioning has left little doubt that preverbal infants develop an extensive conceptual system during the first year of life. There are at least four kinds of evidence for conceptual activity during this period, some of it explicit in nature: generalizations that cannot be accounted for by perceptual processing alone, inferences about unseen events, recall of past events, and mental problem solving. These sources of evidence are discussed in Section 2.

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What has not been as frequently discussed is the architecture of the early conceptual system, detailing how concepts are generated and the nature of their format (but see Carey, 2009). One reason for the sparsity of theories is that, until relatively recently, the dominant theoretical influence in the field of infant cognition, inherited mainly from Piaget but abetted by the history of behaviorism in American psychology, was the belief that preverbal infants do not yet have a conceptual system and so before language must rely solely on learned perceptual information in their cognitive processing (Bogartz, Shinskey, & Speaker, 1997; Haith, 1998; see Sloutsky, 2010, for a current view taking a similar approach). However, theoretical proposals in the 1990s about infant concepts (Leslie, 1994; Mandler, 1992; Carey & Spelke, 1994; Spelke 1994) and two decades of research on infant cognition by these investigators and others have made such a view increasingly untenable.

Still, it is notable that much of this research has been accompanied by strongly nativist views of the origin of infant concepts, typically involving domain-specific modules. In contrast, the account presented here involves a single mechanism operating on perceptual information and shows how with its help a more traditional empiricist approach that takes into account the new database might be implemented. In Mandler (2004), I proposed an innate, domain-general mechanism of Perceptual Meaning Analysis (PMA) that generates concepts from attended perceptual data, discussed the format of the output of PMA in terms of image-schemas, and laid down some of the requirements for such a theory. The present article elaborates on this and subsequent work (Mandler, 2008, 2010) to form a more complete theory. It asserts that the primitives that PMA uses to form image-schemas and thus create accessible meanings are all spatial in nature. The present version reduces the primitives previously suggested to a minimal set that represent information infants attend to either from birth or in the first few months. It discusses in more detail how nonspatially based types of information such as other sensory and bodily information begin to accrue to the core conceptual system, and it predicts the order in which these kinds of enrichment occur. It also explains why mental concepts and concepts of emotion are so difficult to achieve.

The present account implies an architecture different from the views offered by Carey (2000, 2009), Leslie (1994, 2005), Spelke (1994), and Spelke and Kinsler (2007) in that it does not require separate innate modules or domain-specific learning to handle different kinds of information, such as the behavior of animate versus inanimate objects or caused versus self-starting motion. For example, Carey (2000) suggested that ''core knowledge derives from innate learning mechanisms in at least two domains: intuitive mechanics, with the concept of an object and contact causality at its core, and intuitive psychology, with the concept of an agent and intentional causality at its core'' (p. 41). In her 2009 book, she posits the existence of innate perceptual analyzers that identify the entities in three core domains: objects, agents, and number. Spelke (1994) proposed four innate modules involving physics, psychology, geometry, and number. Leslie (1994) thought that it is necessary to have separate innate modules to handle causality, animacy, and theory of mind.

In contrast to these views, PMA is a single mechanism that uses a small set of path, motion, and spatial relation primitives to interpret spatiotemporal information. Carey (2009) rejects this approach, because she says there is no way that PMA alone can transform ''representations of spatiotemporal properties into representations of intentional agency''

(p. 195). I agree! But that is not PMA's function. A major goal of the present study is to show how intentionality and other nonspatial concepts get added to the conceptual system that PMA begins.

The theory is that PMA forms the first core concepts on which later concepts are built. For example, it interprets certain kinds of paths as goal-directed, in the sense of going to a particular object or place, whether the moving object is animate or inanimate. There are three kinds of concepts it does not produce and that are not part of the core conceptual system: (a) It does not include innate understanding of intentionality, which requires interpretation of bodily and/or mental states; it only includes goal-directedness in terms of spatial paths. (b) It does not include innate appreciation of force (Leslie, 1994) to account for the first causal concept. (c) It does not include an innate concept of internal energy (Gelman, 1990; Luo, Kaufman, & Baillargeon, 2009) to account for self-starting and goal-directed behavior. Understanding mental states, force, and internal energy require enrichment of the initial spatially based conceptual system. How this is accomplished is discussed in Sections 5–7. (The present account does not consider the origins of number understanding. However, since spatial information is involved in early number understanding [e.g., Carey, 2009], it is possible that PMA also handles its early stages, in the sense of keeping track of up to three moving objects in a perceptual display.)

In the present approach, concepts are defined as units of meaning that are potentially accessible to conscious thought. They stand in contrast to perceptual information itself, which without conceptual interpretation does not enable recall or other forms of explicit thought. Forming concepts from perceptual data does not imply independent cognitive systems; rather it means that some perceptual information is interpreted in a way that allows thought in perception's absence. The concepts that PMA forms influence further perceptual learning, and perceptual learning in turn influences the attentional biases that control operation of PMA. However, the present article mainly discusses the innate perceptual biases that get conceptual processing started in the first place.

Both motions through space and static spatial information can be represented in image-schematic form (Mandler, 1992, 2004, 2005). Image-schemas are iconic representations. They are not themselves accessible, but they enable awareness in the form of sketchy spatial images that allow recall of past events, mental problem solving, and inferences about unseen objects and events. The processes taking place at the image-schema level would seem to be good candidates for the vocabulary of what has come to be called simulation in the literature (Barsalou, 1999; Wu & Barsalou, 2009). For example, image-schemas can represent an apple being put in a bowl. Depending on the conceptual knowledge and attentive state of the infant, the event may be specified further. Otherwise the interpretation will be a sketchy version of THING INTO CONTAINER. In this sketch, for example, at first the thing is apt to be a blob and the container a roughly circular outline open at the top. A learning system along the lines of the connectionist model used by Rogers and McClelland (2004) suggests how spatial details can be added. For example, a container can become a bottle-shape, and an animal become a dog-shape. Attended parts of objects, such as hands, can be learned in the same way.

Needless to say, just as for adults, much thought in infants occurs implicitly. To say that concepts (meanings) are accessible is to say that they *can* appear in conscious awareness, not that they always do so. There are certainly processes that cannot be made explicit, many of them perceptual or motor in nature. Others, such as the perception of motion moving from one object into another (Michotte, 1963/1948), operate implicitly but can be explicitly conceptualized as well. The extensive literature on semantic priming also tells us that implicit and explicit processing involve the same concepts. So it is a reasonable assumption that when infants make inferences, whether implicitly or explicitly, the same meanings (concepts) are operative.

In the sections that follow I lay out a theory of the preverbal conceptual system that infants use to interpret the world. To emphasize that the concepts being considered enable explicit thought, in Section 2, I first briefly discuss data relevant to this claim. In Section 3, I present the new version of PMA that has been simplified from prior specifications (Mandler, 2008, 2010). In the following sections, I show how this purely spatial system is adequate to account for conceptual activity in the first 6–7 months. Section 4 covers how concepts of animals and inanimate objects are formed during this period as well as concepts of spatial relations. Section 5 covers causality and Section 6 goal understanding. More thoroughly than in earlier work, how nonspatial information begins to be added to the initial spatial concepts of causality and goals is discussed in these sections. Section 7 expands the theory to explain why developing concepts about the mind is so difficult and late in developing. Section 8 summarizes what is known about order of acquisition, discusses emotion, and enrichment via analogy and language. In Section 9, commonalities between the conceptual system of preverbal infants and nonhuman primates are discussed. Finally, in the concluding section, the reasons compelling the view that the human conceptual system is founded on spatial information are summarized.

2. Explicit and implicit concepts in preverbal infants

Deferred imitation studies[1] have shown that by 6 months infants can recall single actions (Barr, Rovee-Collier, & Learmonth, 2011; Collie & Hayne, 1999). By 9 months (and possibly earlier), they can recall event sequences in correct order (Carver & Bauer, 1999). At neither of these ages is language available; there needs to be an accessible iconic form of representation to enable recall of past events. Deferred imitation of event sequences is particularly impressive evidence of explicit thought because the events must be brought to mind in order to carry out the actions in proper order, a task that amnesic adults, who cannot bring past events to awareness, cannot do (McDonough, Mandler, McKee, & Squire, 1995).

Although less studied, there is also evidence for explicit thought in problem solving by 8- to 9-month-olds. Willatts (1997) found evidence of planning in terms of carrying out multistep problem solving without overt trial and error by 8 months, and by 9 months behavioral signs of intention and lack of hesitation when stringing the parts of a solution together. In a very different paradigm, Coldren and Colombo (1994) report data from 9-month-olds strongly suggesting that the infants were generating and testing hypotheses in the discrimination learning tasks set for them. In both these examples, the problems could be solved by successive images of relevant actions and their results.

We only have data on explicit thought in preverbal infants by 6 months. However, there is evidence of either implicit or explicit conceptual activity in infants as young as 2½ months, namely, some of the inferences they make about unseen things. Baillargeon's laboratory has been devoted to showing infants' conceptual understanding of objects and their behavior. Much of her early work concerned infants' understanding of object permanence (sometimes called object persistence) as demonstrated by their understanding of what should happen when objects move behind a screen (Baillargeon, 1986) or their reaction to a screen moving down to the floor through the space where an object has just been placed (Baillargeon, Spelke, & Wasserman, 1985).

As this work involved measuring looking time to unusual sights, some researchers objected to invoking conceptualization because perceptual expectations alone might account for the results (e.g., Bogartz et al., 1997). In violation-of-expectation experiments involving object persistence or the continuity of object paths, it is difficult to tell whether it is perceptual expectations or conceptual interpretation (or both) that are being violated. Experiments with both infants and adults suggest that what has been called the mid-level visual system computes information about the persistence of objects moving behind screens (Cheries, Mitroff, Wynn, & Scholl, 2009). Scholl and Leslie (1999) call mid-level vision an ''attentional interface between perception and cognition'' (p. 2) and ''neither fully 'perceptual' nor fully 'conceptual' in nature'' (p. 16).

In some ways, the PMA mechanism described in this article is similar to the object files posited for object representation in mid-level vision that have been used to explain perception of object persistence behind screens (e.g., Cheries et al., 2009). In both cases, spatial motion is involved, and in both cases, it results in a level of representation (object files or image-schemas) that is not itself accessible to conscious awareness but that enables conscious interpretation. Because PMA makes use of primitives of MOVE INTO SIGHT and MOVE OUT OF SIGHT (see the next section), it is possible that PMA itself delivers object files or is part of a larger mechanism that includes both functions.

However, there are inferences which infants make that cannot be explained in terms of perceptual expectations or mid-level visual processing. The work of Aguiar and Baillargeon (1999) and Luo and Baillargeon (2005a) indicates functioning that goes beyond the spatiotemporal constraints that the visual system uses to compute objecthood. For example, they found that 2½- to 3-month-olds sometimes make false inferences about normal sights. If an object moves behind a screen that has an opening in it, infants do not expect to see the object appear in it even if the opening is very wide. Infants of this age seem to believe that if an object moves out of sight behind a screen it should not be seen. It is not until 3½ months that infants are surprised if the object does *not* appear in the opening. These data neither depend upon longer looking at an unusual sight nor result from information automatically processed by the visual system. Rather, they require a conceptual inference, even if an overly simple one, that one should not see an object when it goes behind a screen.

Infants in this age range have already seen objects briefly hidden as they move behind others. The question arises then as to why they should overgeneralize an inference that an object going behind a screen will not be seen. One likely reason is that, on the occasions when objects (especially people) disappear behind walls, they may be gone for some time, and so are attention-grabbing in a way that partial or brief obscuring is not. This matters, because the proposed mechanism of PMA is an attentionally guided mechanism. It is attended instances that activate PMA, and in the case of occlusion, those are very apt to be when a person (perhaps carrying an object as well) leaves a room. It is likely that much less attention if any is paid to the partial or brief obscuring of one object by another as the first one moves or is moved past the second. A great deal of perceptual learning occurs without benefit of attention, but the theory being espoused here is that to interpret perceptual information and turn it into a conceptually accessible form requires attention.

3. Perceptual Meaning Analysis and its primitives

PMA is an attentional mechanism dedicated to simplifying spatiotemporal information. It is activated by attention to objects, especially when they move, thus emphasizing the paths that objects take through space. Aside from the mechanism itself, what appears to be innate (as suggested by responsivity that has been measured in the first 2–3 months) are the kinds of perceptual information that arouse attention. Infants pay much more attention to some kinds of information than others. Although learning will change what is attended, examples of innately salient information are paths of object motion that change spatial relations, such as into or out of containers, objects going into or out of sight, and contingencies between paths, such as one object chasing another. So temporal aspects of paths are input to PMA, but its outputs are spatial, not temporal. For example, two primitives, START PATH and END PATH, imply to an adult thinker a temporal relation in that one occurs before the other; however, the image-schema representation is purely spatial, representing only the path itself.

Spatial information is most easily acquired visually but is also acquired through touch and audition, which means that vision is not required for PMA to operate. Nevertheless, even though PMA for the most part processes fairly gross aspects of space and motion, the absence of vision must be at least partially responsible for the developmental delays found in blind infants before language is learned (Fraiberg, 1968; Sandler & Hobson, 2001). Whereas vision normally delineates the scope of PMA, audition and touch delineate it for the congenitally blind. Audition provides path information and also the appearance or disappearance of objects, but it is cruder than visual information in many respects, making spatial interpretation difficult or in some cases impossible. For example, blind infants cannot perceive objects moving through space on goal-directed paths. This lack must delay their understanding of goal-directed behavior until they can engage in goal-directed reaching themselves, whereas 5-month-old sighted infants can understand goal-directedness from paths taken by others (see Section 6).

PMA puts information into a schematic form that is the interpretation or construal of the events that are being observed. Because the construals are spatial, the primitives output by PMA necessarily have structure; they can be dissected but are primitive with respect to the conceptual system. For example, the primitive INTO is represented by an image-schema of something moving into the opening of an otherwise closed shape. That the primitives (and their image-schematic format) have structure is part of what makes them meaningful (e.g., Garner, 1962). We have long known that accessibility of information and memory for it are deeply dependent on structure or organization. Unorganized or unstructured material is difficult and sometimes impossible to recall (G. Mandler, 1967, 2002; J. Mandler, 1984).

Unstructured sensory information may only become conceptual when it becomes integrated with structured spatial information or with language (a different structuring device). As an example, any particular color concept may merely consist of a label that points to a particular type of experience (Roberson, Davidoff, Davies, & Shapiro, 2005); only by its relationship to other colors does it attain more detailed meaning. Since at least by the second half of the first year infants are able to think, they must have at least some concepts they can bring to mind as images. Color and other unstructured sensory information like taste and touch are difficult to image, to say the least, whereas spatial information is easy. The only sensory information other than spatial that is easily imaginable is structured auditory information such as music or speech. Presumably auditory structure is analyzed by a different mechanism from PMA. We know that preverbal infants recognize tunes (Volkova, Trehub, & Schellenberg, 2006), but we have almost no information as to whether they conceptualize or recall them in their absence.

A tentative list of PMA outputs (primitives) is shown in Table 1. Each is discussed in the following sections. They are a minimal set for which we have reason to believe even young infants use to interpret the world. The list is tentative. There may be others, such as *cover* and *under*, as well as *open* and *close* (discussed in sections 4 and 8), but the claim is that not many more will be needed to account for early conceptualization. For example, as we will see in Section 6, goal concepts can be built out of the primitives listed in Table 1. And of course primitives combine to produce other concepts, such as *animal* and *inanimate thing* (discussed in the next section).

A potentially controversial aspect of the set of primitives is the inclusion of ±SEEN. Because of the nonperceptually based inferences of 2½-month-olds about when objects should not be seen, SEEN and −SEEN were added as state primitives that result from MOVE INTO SIGHT or OUT OF SIGHT. Although ± SEEN is itself not spatial information, it is required by a mechanism that records when objects appear and disappear from

Table 1
Innate outputs from Perceptual Meaning Analysis (conceptual primitives)

PATH	THING
START PATH	±MOTION
END PATH	BLOCKED MOTION
PATH TO	±CONTACT
LINK	LOCATION
CONTAINER	MOVE (BEHIND)
(IN)TO	MOVE OUT OF SIGHT (−SEEN)
(OUT) OF	MOVE INTO SIGHT (SEEN)

Note. States associated with paths and motion are in parentheses.

sight. This must be expressible in the image-schema representations that underlie infants' conceptual understanding so that any resulting imagery will either show an object being there or not. It is in this sense that PMA enables conceptualizing ''seeability'' as a property of objects, even though it is not a spatial description. As mentioned in the previous section, PMA may itself, or as part of a larger mechanism, build the object files that keep track of what is seen and not seen. However, the only claim here is that objects being seen or not is an early kind of conceptualization.

It is possible that conceptualizing seeing stems instead from a conceptual primitive of eyes. Eyes are of intense interest to infants from birth (Johnson & Morton, 1991), and newborns look longer at eyes that look at them than at eyes that look elsewhere (Farroni, Csibra, Simion, & Johnson, 2002). Attention to eyes and the direction of where eyes look may be a separate innate mechanism (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000). So this might be an additional or alternative route to the concept of seeing. Still, as attention to eyes is not the same as understanding seeing, the minimal solution is to ascribe ±SEEN to PMA without adding eyes as a conceptual primitive.

4. The first object and relational concepts are based on attention to paths and spatial relations

Infants are attentive to motion from birth and preferentially look at biological motion over nonbiological motion (Simion, Regolin, & Bulf, 2008). Although this preference does not mean they conceptualize what the difference is, it nevertheless directs attention to people and their actions (and the hands that carry them out). Even at 5 months, infants remember the actions taking place in events better than the objects being used or the faces of the people involved (Bahrick, Gogate, & Ruiz, 2002). Five-month-olds also are more accurate in encoding the spatial location of objects they watch being hidden than what the objects look like (Newcombe, Huttenlocher, & Learmonth, 1999). Six-month-olds are more apt to remember what a hand does to an object than the sound that the action produces (Perone, Madole, Ross-Sheehy, Carey, & Oakes, 2008). Aside from particular interest in what people do, object motion in general attracts attention and attention activates PMA, which in turn produces a schematic summary of an object's path in relation to other objects that is the beginning of understanding what an object is doing.

Not surprisingly then, concepts of moving things are among the first to be formed. (*Furniture* is another early concept, but at first it may mean no more than ''things that don't move''). Object examination tasks have shown that, as early as 7 months, infants categorize animals, vehicles, and furniture as different kinds of things even though these global categories vary a great deal in the perceptual features of the objects within them (e.g., Mandler & McDonough, 1993, 1998b; Pauen, 2002). For example, 9-month-olds differentiate birds from airplanes, which move through space quite differently, but do not treat dogs as different from rabbits, or chairs as different from tables or beds. It is not that infants do not perceive differences among various animals or pieces of furniture; even 3-month-olds if shown a series of cats will then look longer at a dog, and if shown a series of chairs will look longer at a table (Behl-Chadha, 1996; Quinn, Eimas, & Rosenkrantz, 1993). Hence, we know that even for infants perceiving things as different is not the same as conceptualizing them as different.

The technique of generalized imitation is especially useful in specifying infant concepts. In a series of studies, we found that 9- to 14-month-old infants still interpret animals, vehicles, and furniture broadly, or globally. For example, all mammals tend to be treated as if they are the same kind of thing. So if a dog is shown being given a drink or being put to bed, when infants are given various animal models to use to imitate the events they have seen, they pick any mammal randomly, hence being as likely to use a cat or a rabbit to imitate the event as another dog (Mandler & McDonough, 1998a). Differentiation into finer conceptual categories occurs gradually over the course of the second year (Mandler & McDonough, 2000) and beyond (Bornstein & Arterberry, 2010; Mandler, Bauer, & McDonough, 1991).

These data tell us that it is what animals and vehicles do that makes their exemplars the same kind of thing for infants. What things do is at first understood in terms of how they move and interact with other objects rather than details of their appearance. And what people and other animals do is to start motion by themselves and interact with other people or animals even from a distance. Vehicles move as well but do not start by themselves or interact from a distance as animals do.[2] Furniture does not move at all and does not respond to interactions with people.

The PMA output primitives needed to conceptually differentiate animals from inanimate things are the following: THING refers to any perceptually bounded cohesive object. PATH refers to any object's MOTION trajectory through space. START PATH refers to the onset of MOTION along a path and END PATH to its cessation. CONTACT refers to one object touching another. LINK refers to a variety of contingent interactions between objects as when a hand picks an object up, back and forth interactions of people, or between paths as when one object chases another. Even 3-month-olds are sensitive to such contingencies (Frye, Rawling, Moore, & Myers, 1983; Rochat, Morgan, & Carpenter, 1997).

In the characteristic events that animals engage in, they start paths by themselves without contact with another object, and they initiate links with other objects in a contingent fashion, often from a distance. It is hypothesized that the first concept of animal (animate thing) is formed by combining the following primitives into a more complex image-schema of a self-starting interactor: THING, START PATH, −CONTACT, and LINK (even without contact). This is in contrast to nonanimals (inanimates) that do not move at all, or if they do, only when contacted by another object, and that also do not interact with other objects from a distance, a concept comprised of THING, and either −MOVE, or [START PATH, CONTACT], and −LINK. (A minus sign is used to indicate absence of a primitive. Attention is often paid to whether objects start moving with or without contact and to whether they interact with other objects.)

These motion and interaction characteristics are hypothesized to form the initial concepts of animal and nonanimal to which other properties of animals and nonanimals accrue. For example, infants learn by a few months of age what people look like, that hands move objects around (Leslie, 1984; Woodward, 1998), and categorize animals and vehicles on the basis of how they move (Arterberry & Bornstein, 2001).

In Mandler (1992), I assumed that animate and inanimate motion were also PMA primitives. Biological motion, as mentioned above, is perceived from birth, but that does not tell us its role in early concept formation, even though it is known to attract the attention that is needed for PMA. It may be that animate and inanimate motion are indeed early concepts, although it is not easy even for adults to conceptualize the difference and such concepts do not appear to be required in infant conceptual life. For example, a concept of animate motion is not necessary for the concept of goal-directed behavior. Even though infants learn to associate biological motion with goal-directedness at least by 6 months (Schlottmann & Ray, 2010), as early as 5 months they also attribute goal-directedness to inert objects if they follow certain kinds of paths (Luo & Baillargeon, 2005b). Perceptual associations can be learned about objects' motion (people move differently from cats) without requiring the conceptual status that allows inferences and thought. This is one of the great difficulties of infant research. Infants would presumably look longer at a person moving like a cat than at normal motion for a person, but that does not mean they conceptualize what the difference is. The goal of the present approach is to assume the minimum number of innate primitives needed to get the conceptual system started, and conceptualizing biological motion is not one of them.

Not surprisingly, given the spatial basis of early concepts, spatial relational concepts are also early. As discussed in Section 2, the concept of behind, based on objects becoming occluded, appears to be formed at least by 2½ months. It can be described by two primitives, MOVE BEHIND, and MOVE OUT OF SIGHT, or disappear. Another way that objects sometimes MOVE OUT OF SIGHT is into containers. Containment concepts derived from CONTAINER and the relational paths of INTO and OUT OF are apparently also formed by 2½–3 months (Hespos & Baillargeon, 2001). The states associated with occluders and containers, BEHIND and IN, are primitives as well; infants are able to make inferences about these states from early on, such as inferring that an object having gone behind a screen or into a container and not reappeared (MOVE INTO SIGHT) is still located there.

At first glance, a concept of support would also appear to be early. Baillargeon, Kotovsky, and Needham (1995) showed that infants develop expectations about one object being ''on'' another as early as 3 months. However, in the earliest stages, they interpret objects as ''supported'' on vertical surfaces (perhaps not surprising in our culture, given pictures on walls and refrigerator doors). Furthermore, support is not as salient as containment even for older infants and toddlers (Casasola & Cohen, 2002; Choi, McDonough, Bowerman, & Mandler, 1999). So I hypothesized that, in its earliest manifestation, support is no more than attachment, in that it means only that an object contacts something and does not move, even when the surface is vertical (Mandler, 2008). That means that attachment itself need not be a primitive; it is made up of CONTACT and −MOVE. These considerations make it unlikely that ''on'' (i.e., support) is an innate primitive, as I originally assumed, but rather a ubiquitous aspect of experience that does not draw attention. Indeed, a concept of support would seem to involve at least a primitive notion of force, which is not part of the first conceptual repertoire (see next section).

It may be that in addition to going behind and containment 2½- to 3- month-olds also interpret covering as conceptually different from containment. Wang, Baillargeon, and Paterson (2005) found that infants infer that when an object is covered, slid along the floor, and the cover raised after it goes behind a screen, the object will be left behind. They also showed that the time course of learning some of the variables that matter to covering and containment are different. However, the tests they performed with very young infants are similar to those carried out with containers (if a container moves, it takes the contained object along with it, and if it does not have a bottom, the object will drop out), so we cannot yet tell whether initially there is a single concept of containers that includes covers. For this reason, I have not listed cover and under as conceptual primitives. I originally assumed that there would also be primitives of UP and DOWN, because infants perceive these relations (Quinn, 2003). However, the assumption that they conceptualize them as well has not been tested.

I will not go further into the data supporting the presence of spatial relational concepts in young infants, because they are discussed at length elsewhere (Baillargeon, 2004; Baillargeon et al., 1995). The hypothesized primitives required to conceptualize going behind, containment, and attachment are as follows: MOVE BEHIND, MOVE OUT OF SIGHT, MOVE INTO SIGHT, CONTAINER, INTO, OUT OF, CONTACT, and −MOVE. The state concepts that result from the relevant motions are BEHIND, −SEEN, SEEN, IN, and OUT. Various other early spatial concepts arise through combinations of these primitives, such as tight-fitting containment, a combination of IN and BLOCKED MOTION (see Spelke & Hespos, 2002, for data on 5-month-olds).

A primitive of LOCATION is also needed to account for recall of places in space. In the Newcombe et al. (1999) study mentioned earlier, 5-month-olds maintained memory for where an object had been hidden for about 40 s, although whether they continued to attend to the place during the interim was not discussed (Newcombe et al., 1999). However, 7-month-olds can recall where an object has been hidden after delays of more than a minute, during which they are distracted from the event (McDonough, 1999). That places in space are conceptually differentiated even earlier is suggested by data such as those of Spelke, Breinlinger, Macomber, and Jacobson (1992) showing that 2½-month-olds are surprised when a moving object ends up in an impossible location. Although it seems clear that some conceptualization of spatial location is happening in the first year, little work has been done on this topic. So unfortunately, we do not yet know how precisely locations are defined for infants. Spatial relational primitives such as BEHIND or IN are used, but there may also be locational understanding such as ''next to.''

Fourteen-month-olds in our culture categorize objects on the basis of the rooms in the house where they are found (Mandler, Fivush, & Reznick, 1987), and indoors versus outdoors is another locational conception shown at 16 months (Mandler, 2004). Locational understanding begins quite early in infancy, but more research is needed to specify what it consists of in detail, as well as its cultural variance.

5. Spatial concepts precede dynamic concepts: The case of causality

Since the work of Michotte (1963/1948), we have known that causation, in the sense of one object making another move, can be directly perceived. White (1988) described how this perception results from the temporal integration function of the eye, the relevant parameters of which fit what Michotte called ''ampliation,'' a perception of the motion of one object being transferred into another. Leslie (1982) showed that 4-month-olds perceive caused motion. (To my knowledge this has not been specifically tested with younger infants, although Leslie's youngest subjects were 13 weeks.) He speculated that there is a domain-specific module (TOBY, or Theory of Body mechanism) that receives inputs from vision and analyzes motion with respect to force dynamics (Leslie, 1994). Leslie recognized that the visual perceptual system delivers kinetic rather than dynamic (force) information, so he thought an innate module was necessary to account for our ascribing force to causal events.

I propose a different solution, since we have no evidence that young infants ascribe force to their causal perceptions; perceiving motion transferred from one object into another may be enough. PMA can use the primitives of MOTION INTO to begin a conceptual interpretation of *cause*, to which understanding force can be added later. In this view, there is no need for a separate innate mechanism like TOBY. Rather, dynamic information is an add-on to the core spatial motion concept of cause. In this view, a sense of force begins to become associated with MOTION INTO only when infants begin to move themselves around and engage in the behaviors that result in feelings of force being applied to objects. As infants begin to push against things, they also begin to experience for the first time strong feelings of pressure and resistance—what I have called a feeling of ''umph'' (Mandler, 2010).

Understanding that force is needed to cause objects to move is the first example I discuss of the enrichment of the spatial conceptual base that occurs with development. At the same time, it reinforces the primacy of spatial motion. Spatial information is easy to process; dynamic information is difficult. As Proffitt and Bertenthal (1990) put it in their discussion of the crude and often mistaken intuitions adults have of the dynamics of object motion, it is ''likely that, throughout the life span, motions are perceptually represented in terms of kinematic parameters, and dynamical intuitions are largely formed from these parameters as they are structured by experience-based heuristics'' (p. 8). The ''heuristics'' in my view consist of associations of internal feelings of pressure with the structured spatial conceptions that already exist.

Similar comments can be made about conceptualizing blocked motion. As young as 2½ months, infants expect an object to stop rather than to pass through another (Spelke et al., 1992), so they are surprised when a ball shown rolling on a path ends up on the other side of a block placed on the route. Baillargeon (1986) showed 6- to 8-month-olds a car running down a track; then a block was placed either on the track or behind or in front of it. When a screen occluded the track, and a car again ran down the track, infants expected it not to appear on the other side of the screen if the block was placed on the track, but that it would appear if the block was behind or in front of the track. These kinds of inferences require a conceptual interpretation of BLOCKED MOTION. However, again the data are silent about force. I suggest that it is not until infants begin to push against rigid objects themselves, such as struggling against parental arms holding them or trying to move heavy objects around, that the feeling of pressure such activities generate begins to be associated with the structured spatial representation of blocked motion.

We are hampered in attempting to estimate exactly when such bodily associations begin to accrue to conceptualizations of caused and blocked motion by lack of data. Infants certainly learn that hands do things to objects, but that in itself does not speak to force. Similarly, Luo et al. (2009) found that 5- to 6-month-old infants were not surprised to see a self-propelled box remain stationary and aloft when released in midair. Perhaps, they assumed that the self-moving object was something like a bird, because infants of this age know that animals start themselves. Luo and colleagues suggest that infants ''endow self-propelled objects with an internal source of energy'' that enables them to remain in the air. The conclusion that self-starters are endowed with energy has a considerable history, with similar suggestions being proposed by Gelman (1990) and Leslie (1994). However, no one has yet provided any data showing that infants either perceive or conceive force or energy when objects move themselves, move other objects, or do not move when another object contacts them. A core concept of animal need not speak to the issue of force or energy at all.

For several reasons, gaining understanding of force or energy probably requires more personal experience than 5- to 6-month-olds have yet had. Even when they begin to move themselves and objects around, we do not know how soon they begin to attend to the feelings of pressure and resistance that result, let alone the much more nebulous feeling of energy. We also do not know how long it takes for internal experiences of pressure to become associated with particular kinds of events and the existing spatial concepts that interpret them. Nevertheless, pressure information (the feeling of ''umph'' when one's own motion is blocked or one is shoved) can be quite dramatic once infants begin to explore the physical world and meet up with heavy objects, and it is predicted to be the first internal feeling to become integrated with a spatial concept.

Association of force with BLOCKED MOTION can be expected to precede association of pressure with MOTION INTO, because the internal feeling of ''umph'' is only experienced when one's own motion is blocked. Therefore, infants should appreciate the role of force in events in which they push a heavy obstacle before they understand its role in one object hitting another and making it move. It may be noted that I am assuming that attention must be paid to feelings for them to become integrated with spatial conceptualizations. Associations can be made without attention, but in the conceptual domain, more may be required; integration of an internal feeling with a concept may need attentively experiencing both spatial and bodily information at the same time. In either case, the existing spatial concepts enable the infant to *interpret* the bodily feeling. When the association is established, a representation of the relevant situation can activate a remnant of the feeling experienced at the time, and vice versa.

In sum, the spatial aspects of caused or blocked motion are structured external observables, whereas the forceful aspects are neither. This is why kinetics are understood before (and also in more detail) than dynamics. Force information only becomes conceptualized when it is integrated into structured spatial representations that are already accessible. To be more specific: You can feel pressure but you cannot image it. Only when integration of the spatial concept and the feeling has occurred, can the feeling arouse spatial imagery, which in turn can reactivate the feeling (presumably in highly reduced form).

Because forceful causality can be learned, it is not necessary to assume that interpreting events as forceful or as due to internal energy is innate. If it is not observable and not necessary to account for the available data, it seems better not to assume that force is an innate understanding. The same thing may be said for the assumption that internal force, or energy, is involved in early concepts of agency or goal-directed behavior (Gelman, Durgin, & Kaufman, 1995; Leslie, 1994; Luo et al., 2009).

Caused motion is, of course, not the only kind of causality to be conceptualized. However, I propose it is the only one that is innate. Carey (2009) has suggested that change of state causality is innate to the same extent as caused motion, as indicated by the fact that both emerge at the same time in infancy. There are actually very few data on infants' interpretation of change of state causality, and the data she cites are with 8-month-olds (Muentener & Carey, 2010). That is considerably later than the 3–4 months of age at which Ball (1973) and Leslie (1982) found perception of caused motion (and a large difference in terms of infant cognitive development).[3] Muentener and Carey studied 8-month-olds' reactions to a train going behind a screen that partially hid a block at the other end, after which the block moved, collapsed, or began to play music. Then the screen was removed and the infants saw the same events but with the train either touching the block or stopping before reaching it. The infants looked longer when there was a spatial gap in the case of the box beginning to move, but not at either of the state changes. However, when the experiment was repeated using a hand instead of the train (and playing music or a collapse as the state changes), the infants now looked longer on test trials when there was a gap between hand and box. Muentener and Carey concluded that infants inferred a causal connection between hand and a state change in a box.

I agree that 8-month-olds know that hands manipulate objects only when they touch them. It is less clear, however, that they understand the state changes as being caused by the hand. I suggest that what is innate about this understanding is only responsivity to contingency or LINK. Contingency means going together or happening together, which does not necessarily produce a causal interpretation. Walking hand in hand and peekaboo games involve contingency but are not causal. There is no doubt that infants know that hands pick up objects, but before the notion of force is integrated with their innate understanding of cause it is not obvious that they interpret this kind of link as causal. As Leslie (1982, p. 181) put it, ''The ability to notice a spatial contact relation between hand and object is probably a necessary (though not sufficient) condition of a perception of causality.'' By 8 months, infants are beginning to learn about the role that force plays in making state changes happen from their own forays into the world, but the prediction from the present theory is that the Muentener and Carey data on state changes will not be found at this or younger ages unless hands are involved.

6. Spatial concepts precede mental concepts: The case of goal

The traditional understanding of the concept of a goal is a mental state of intentionality held by an animate being, with goal-directed action understood as behavior carried out by an animate being to achieve a goal. Thus, learning about goals might seem particularly problematic for a spatial theory of early concept formation, because if goals are mental states, they cannot be perceived in the same way as caused motion and other spatial information (Mandler, 2010). However, as discussed in Section 4, even 3-month-olds are sensitive to contingent responding of objects and paths, both of which are fundamental to understanding goals and goal-directed behavior. Furthermore, understanding goal-directed behavior need not require either a mental state or an animate actor.

Understanding of goal-directed behavior has been shown in 5-month-olds (Woodward, 1998). The most typical goal path involves an animal (animate thing) moving toward an object and at the end of the path interacting with it, and it is surely the only type of goal-directed behavior that infants of this age have seen. Indeed, Woodward found that infants are more apt to attribute goal-directedness to hands than to tool-like claws. Nevertheless, Luo and Baillargeon (2005b) showed that 5-month-olds also interpret inanimate objects as goal-directed if they start by themselves and show persistent direct paths to another object. Interaction (LINK) at the end of a path does not need to be more than the actor coming to rest against the object. Similarly, if a self-starting box takes varied but contingent routes to the same object, contingent in that each one avoids a barrier, 6-month-olds treat it as goal-directed (Biro & Leslie, 2007; Csibra, 2008).

There is nothing in these descriptions that speaks about mind or intentions. They are descriptions of ''moving to'' something, rather than just moving. These considerations indicate that the first concept of goal is not derived from ascribing intentionality to an animate agent, but rather from two types of spatial patterns of action. These patterns consist of combinations of the primitives of START PATH, PATH TO, END OF PATH, and LINK.[4] A self-starting object that moves on a direct PATH TO an object at its end and links with it gives rise to a concept of ''move to.'' Similarly, an object that goes on different but linked PATHS TO (linked in that they are contingent on going around a blockage in a direct path) to a particular end point or object also gives rise to a concept of ''move to.'' At age 5 or 6 months, all three beginning, path, and end aspects may be required to elicit this first goal interpretation: self-starting, direct or linked paths, and a particular location or object at end of path (Biro & Leslie, 2007). At slightly older ages, only two out of three are needed (e.g., self-starting is not necessary for 9-month-olds, but still may be for 6-month-olds; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999).

Csibra and Gergely (1998) interpret their results as indicating a teleological stance that is the forerunner of mentalistic interpretations of goals. The primitives discussed here describe the components of a teleological stance. Learning to limit this stance to animates takes developmental time. Indeed, the most likely reason that the phenomenon known as ''animacy,'' in which goal-directed behavior is ascribed to inanimate objects, has occurred in various cultures and times is because of the innate reactivity to the contingency of paths linked to places and things. Infants see certain kinds of paths as goal-directed whether they are paths to an object or merely a place. Adults often do the same, even when they know better.

When do infants learn to think of goals as mental states? It is easy enough to learn the observable features, such as hands and legs, that are associated with objects that engage in self-starting motion (Pauen & Träuble, 2009) and linked paths (Biro & Leslie, 2007). The present thesis is that to achieve concepts of *mental* goals first requires attending to and integrating the feeling of *trying* with the already structured spatial conceptions of goal-directed behavior. It has been hypothesized before that personal experience of goal-directed behavior is important in infants' learning about intentionality (e.g., Barresi & Moore, 1996; Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998; Meltzoff, 2007), and there is evidence that engaging in such behaviors influences how they are understood in others. Three-month-olds, who have been given Velcro-covered ''sticky mittens'' and trained to capture objects, are more able to recognize reaching by others as goal-directed than 3-month-olds without such experience (Sommerville, Woodward, & Needham, 2005). However, even at 6 months of age, infants who have not received such training do not yet know the difference in what their own reaching behavior looks like when it is on a path to an object or on a path that will miss it, although they recognize the difference when watching others perform the same actions (Daum, Prinz, & Aschersleben, 2008).

Personal experience with reaching clearly helps, but by itself it is not enough to conceptualize intentionality. The present hypothesis is that engaging in goal-directed behavior can only become useful in understanding mental intentions if infants attend to and have available a conceptual interpretation that structures their experience. Interestingly, it is likely to be *failed* goal attempts that are most apt to draw infants' attention to the feelings involved in personal goal-directed behavior. Typically, infants achieve goals without thinking about the process; they reach for their bottle and bring it to their mouth, and there is no reason for them to think about trying or intending. But when such activity fails, attention is drawn to it. By around 10 months, infants understand failed goal attempts in others (Brandone & Wellman, 2009), and under some circumstances even by 8 months (Hamlin, Newman, & Wynn, 2009), although these studies do not tell us when infants begin to interpret their own failures. In any case, more than attention is required: One must be able to interpret what has happened and that is what the initial spatial conceptions allow, for example, that a path was blocked or did not contact the goal object. A feeling of trying is not a straightforward observation, and preverbal infants have limited resources to use to form a conceptual interpretation of it. But when the feeling becomes associated with an existing structured spatial understanding of goal-directed behavior, the result is an enriched conceptual package.

In short, it is not enough just to experience a feeling of trying (or the more nebulous feeling of wanting) while engaging in goal-directed behavior. Feelings are not concepts; one has to interpret them. The only available resource is to use the already established spatial concept of goal-directed behavior—for example, that one's reach missed the object it was on a PATH TO. Just as for adding force to spatial understanding of causality, adding an attribution of intentionality to goal-directed behavior requires attending to and interpreting one's own internal states via existing spatial understanding. This is clearly an extended process, in that to develop a full understanding of intentionality takes years to achieve (Wellman, 1990; Wellman & Liu, 2004), but the present theory is that this is how infants begin the process.

7. Why mental concepts of knowing and belief are so difficult

Until now in this discussion, there has been no need to be concerned with mental concepts or what is usually called theory of mind. Understanding intentionality, however, brings us to the question of when intention as a mental state begins to be understood. It may actually be the easiest of mental state concepts to acquire, because it can be related to existing spatial concepts. The concept of goal-directed behavior is entrenched quite early and provides familiar image-schemas that can be used to begin to conceptualize the mental state involved.

More difficult should be a concept of knowing as a mental state. As discussed in Section 2, infants understand something about seeing from an early age, and seeing provides the most likely route to understanding something about knowing. Seeing is grounded in observables, not only that one sees when one's eyes are open but also when one does and does not see objects. In addition, between 6 and 9 months, infants begin to recall past event sequences via imaging, and by 11 months, can recall such experiences after several months, indicating that recall processes have become well established (e.g., Mandler & McDonough, 1995). Recall, although a poverty-stricken form of sight is nonetheless a form of seeing, in that it reproduces in some form what has been seen in current awareness.[5] This kind of ''seeing'' should be important for beginning to equate seeing with knowing. Infants presumably learn during the course of the first year many implications of seeing; if you see your cup in front of you, you can reach it, and importantly, if you want to find something that is missing, go to where you picture it to be.[6]

It is highly likely that relationships between where other people's eyes are directed and how they behave are learned over the course of the first year (Perner & Ruffman, 2005). However, we do not yet know how long it takes for babies to make a connection between others' eyes and their own seeing. Meltzoff (2007) suggests that infants generalize their own head turns and their own experience of the difference between open and closed eyes to understand other people's head turns and eyes. However, Piaget's (1951) description of the lengthy practice his infants needed when they were almost a year old to be able to imitate blinking eyes gives an indication of the difficulty in relating one's own eyes to those of others.

A recent study suggested that infants understand what others have seen as early as 7 months (Kovacs, Teglas, & Endress, 2010). Infants and an observer watched a ball roll behind a screen and out the other side. The observer left the scene and then, in his absence, the ball returned behind the screen. The observer came back, and the screen was lowered so that they both could see what was there. Even though infants presumably expected to see the ball because they had watched it return behind the screen, they looked a few seconds longer than they did when *both* infant and observer had seen the ball return. The authors describe their finding in terms of understanding others' beliefs, but more conservatively it can be described as a response (possibly checking) to where the observer is now looking. Alternatively, as mentioned in Section 3, computing what others see may be an automatic process that operates independently of infants' acquiring the concepts necessary to understand either seeing or others' beliefs (see Samson & Apperly, 2010).

Even if computing what others see is an automatic process that does not imply anything mental, there is evidence that a concept that can be termed *seeing as knowing* begins to be applied to others early in the second year. At least by 12 months, infants have generalized the difference between open and closed eyes to others, and understand that others with covered eyes do not see (Brooks & Meltzoff, 2002). Onishi and Baillargeon (2005) showed that 15-month-olds use information about where another person last saw an object to anticipate where they will look for it, a finding replicated for 13-month-olds (Surian, Caldi, & Sperber, 2007). Both the latter sets of authors, and by now a number of other researchers, claim that such results are evidence for a mental concept of belief. However, infants at these ages may merely think that the other person has seen something and will make use of that to locate it, just as they do themselves. Infants of this age also use what other people see to predict their actions even if it differs from what the infants themselves see (Luo & Baillargeon, 2007; Sodian, Thoermer, & Metz, 2007). All of this is seeing as knowing, and it does not imply theory of mind.

All the data that have been used to support the view that infants in the second year have mental concepts of belief and false belief rely on infants' responses to where a person saw something now hidden. In addition to the experiments just mentioned, when someone has not seen that an object has been moved from one box to another, and points to the box where they last saw the object while asking the infant to get the object, 17-month-olds choose the correct box for them (Southgate, Chevallier, & Csibra, 2009). Similarly, 18-month-olds help an adult find an object when unbeknownst to the adult it has been moved and they are trying unsuccessfully to get it where they last saw it (Buttelmann, Carpenter, & Tomasello, 2009). However, when a given person does not see that an object has been moved from one box to another, but is told so by a more knowledgeable person, 18-month-olds expect the person to go to the correct box instead of where they last saw it (Song, Onishi, Baillargeon, & Fisher, 2008).

The last experiment suggests that growing language understanding is useful in understanding mistaken knowledge. However, none of the above experiments provide sufficient evidence that the achievements in understanding others' behavior in the second year are due to conceptualizing either knowing or belief as mental states (see Perner & Ruffman, 2005 and Sodian & Thoermer, 2008, who also espouse this view). Infants have learned that seeing is knowing in the sense that if you have seen where something is located that is where you are apt to find it. They have also learned that the object may have been moved since it was last seen. The data cited above indicate that, in the second year, infants know that other people also have such knowledge and that they may look in the wrong place when an object has been moved in the interim. However, such understanding is not the same as that people have minds. Seeing or having seen does not require an attribution of mental states even to oneself, let alone to others.

Verbal ''mentalizing'' has been shown to be reduced or inappropriate in adults with high-functioning autism when viewing social interactions even when their eye movements are normal (Zwickel, White, Coniston, Senju, & Frith, 2011), suggesting that one cannot assume concepts of mental states from looking data alone.[7] Even considering helping behavior (e.g., Warneken & Tomasello, 2007), we do not yet know that, in the second year, infants have moved beyond understanding seeing as knowing to knowing as a mental state, or as discussed in Section 9, whether they still are operating at the lesser level assumed by many researchers for primates (Gomez, 1991; Heyes, 1998; Povinelli & Vonk, 2003).

Developing a concept of knowing independent of seeing is a truly difficult task. The concept of belief should be even more difficult, and indeed there is evidence that it is slower to develop (Wellman & Liu, 2004). There are no spatial core concepts and no imagery to help conceptualize belief as a state of mind. What resources can be used? I have suggested that when infants experience their own mistaken beliefs about where things are, they may recall what they have seen, which would simultaneously bring to their attention two differing views. And by 18 months, infants engage in pretend play, in which they simultaneously engage in true and false ideas about something, such as acting as if a banana were a telephone (Leslie, 1987). In my view, pretense is better evidence for a beginning understanding of mind than the false belief experiments cited above, and it stems from simultaneously maintaining two different views of the same thing. However, even this may not be enough to create a concept of belief.

Having accepted the possibility of beginning to think about mind in the second year, it nevertheless seems highly likely that it requires the help of language and adult scaffolding as well. The initial core of spatial concepts does not provide any vocabulary to represent the mind, and the imagery that image-schemas support does not speak to beliefs and at best only to knowing as seeing. It would seem that the preverbal infant has few if any resources to allow either implicit or explicit thought about such concepts. Indeed, there is evidence that delayed language is associated with delay in acquiring a theory of mind (Peterson & Siegal, 2000). Autistic children (who have no trouble with spatial concepts) are delayed in language acquisition and deficient in acquiring a theory of mind (Baron-Cohen, 1995), and they also have trouble in understanding emotions (Hobson, 2002). Such findings suggest a relationship between language and those concepts of mental states that have no association with spatial information.

8. Age of acquisition of enrichments to spatially based concepts

To summarize, although the exact ages remain to be determined, the present theory states not only that spatially based concepts are the first kind of concepts to be formed, but that those that can be enriched by bodily feelings precede mental concepts that do not have bodily feelings associated with them. Including force in the concept of caused motion should be the first enrichment, not only because of a strong spatial core but also because of the attention demanding and clear-cut nature of feelings of pushing and being pushed. This process is predicted to start around 7 months as infants begin to manipulate a wider range of objects than previously, and to increase around 8 months as they begin to move themselves around in the environment, where they encounter heavier objects than can be manipulated. Adding a feeling of trying to spatial concepts of goal-directed behavior should be later, because trying is a vaguer feeling than force, and because feeling force when pushing an object to make it move or pushing unsuccessfully may be required to construct an intentional version of trying to reach a goal. The available evidence suggests that this happens between 8 and 10 months.

By 12–13 months, infants show understanding of knowing, in the sense of having seen, by applying it to other people. This equation must rest on the conceptual primitive of *SEEN*, but we have little information about the course of development of seeing as knowing before the concept is applied to other people. I suggested such understanding may be dependent on the ability to recall events one has seen, and so may occur late in the first year, but that remains to be tested. Finally, developing concepts of knowing and belief as mental states should be the most difficult of all, given the lack of relevant internal feelings and no spatial imagery to interpret them. This is where language is crucial as a way of organizing and structuring ideas about what cannot be seen or felt, a development not occurring until language becomes sufficiently complex in the second year or later.

The detrimental effects on early conceptualization of lack of spatial structure must also apply to understanding emotions as well as sensory experiences such as colors, tastes, and smells; these have no associated spatial base to help interpret arousal and lack the structure that makes experiences reproducible in memory. Emotions are difficult for 2- to 3-year-olds to identify (Widen & Russell, 2008), and even then seem to be understood only as good or bad and more or less intense. Even in adulthood, emotions are typically understood analogically via spatial or forceful metaphors, such as anger as blowing one's top, wanting as being drawn toward something, and so forth (Gibbs, 2005). Although colors are perceived virtually from birth, infants do not use color to individuate objects until 11 or 12 months (Wilcox, 1999; Xu, Carey, & Quint, 2004) and are difficult words for children to learn. Even then, color terms remain little more than words attached to a particular perceptual dimension (Roberson et al., 2005). The most memorable nonspatial sensory input in infancy is likely to be auditory, such as music or prosody, but we have virtually no information as to its conceptual development in infancy. In general, however, it is predicted that sensory information not associated with spatial structure must await language to become conceptualized.

Language, of course, is a great conceptual enricher as is analogical thinking. Both exemplify the importance of structure when learning new concepts (Gentner, 1983; Gentner & Namy, 2006). Unfortunately, analogical learning has rarely been studied in the first year, although analogical transfer has been shown around a year of age (Brown, 1990; Chen, Sanchez, & Campbell, 1997). It probably begins earlier: Piaget (1951) provided several observations of his infants from 10 to 12 months trying to imitate his blinking his eyes, by opening and closing their hands or mouths, and Huttenlocher (1974) provided a similar example of a 10-month-old using a bowl to play peekaboo when no cloth was available.

A classic example of the use of analogy to extend spatial concepts to nonspatial realms is that of time. Temporal words themselves are thoroughly spatialized (Clark, 1973).

Linguists have shown that temporal terms in virtually all languages are based on paths through space (e.g., Traugott, 1978). We experience duration, but when we think about it we invariably use spatial metaphor. We conceive of time in terms of a path from then to now to then, and durations as long or short, just like paths. I assume that one of the reasons why temporal terms are so closely linked to spatial ones is because our understanding of time is at least partly based on space. The link between time and space has been shown to affect processing in several ways; spatial information primes temporal interpretation (Boroditsky, 2000) and people can not ignore spatial information when judging duration (Casasanto & Boroditsky, 2008). Srinivasan and Carey (2010) found that 9-month-old infants are sensitive to perceptual correlations between spatial and temporal lengths but not between temporal lengths and loudness magnitudes. Time does not associate with intensity in our conceptualizations nor apparently in our perceptions either. Instead, it is associated with paths through space.

There are certainly temporal aspects of motion that infants perceive; some objects move faster than others and/or get to the end of a path before others. However, as discussed earlier for the conceptual primitive of LINK, the present theory of infant concepts is that the spatiotemporal information involved in motion along paths is processed by PMA, but the conceptual output is spatial. There is no evidence that young infants conceptualize any of the temporal aspects of paths, although it is possible that they might associate perceived differences in speed with their existing concepts of paths through space, thus enabling some integration of the two kinds of information to begin preverbally. We are hampered by lack of data in the infancy period, but the long slow course of development of children's understanding temporal concepts (e.g., Nelson, 1996) suggests that language may be required to get the process started. Infants do learn expectations about event sequences, and it is possible that becoming able to recall event sequences correctly late in the first year may be one of the routes to conceptualizing notions like before and after. Equally likely, however, such concepts may require adult scaffolding as well as language.

9. Some representational comparisons of infants with primates

It is plausible that the same spatially based conceptual system as described here can account for various primates' conceptualization. For example, adult chimpanzees can recall where objects are hidden (Menzel, 1999), do simple problem solving (Povinelli, 2000), and make use of where others are looking (Call, 2001). Extensive work by Tomasello, Call, and their colleagues has shown that the chimpanzee conceptual system also contains a concept of *goal-directed behavior* (e.g., Tomasello, Carpenter, Call, Behne, & Moll, 2005). An important question, then, is do chimpanzees represent caused motion as involving force, and goals as intentional states? Or do they operate at the level of conceptualizing observables without including feelings of forceful trying or mental states, the latter claimed by many (Gomez, 1991; Heyes, 1998; Povinelli & Vonk, 2003)? If so, they would seem to have a representational system resembling the system that I have suggested infants start out with—a spatially based system not yet enriched by information from bodily states.

Call and Tomasello (2008) and Call and Santos (in press) list a number of studies showing that chimpanzees and rhesus monkeys understand what others see or hear and use that knowledge to guide their own behavior. They conclude that these primates can know what others know and in that sense have a theory of mind. This theory of mind does not include understanding false beliefs (Kaminski, Call, & Tomasello, 2008), but still it is an understanding that others have mental states. However, as discussed in Section 7, the status of knowing is often ambiguous. All of the studies of knowing in chimps involve seeing or hearing. Just as for human infants, there is no spatial core for them to use to think about knowing, but instead there may be an equation made between seeing and knowing. If you see, you can do various things, and if you do not see (or hear) you cannot. One does not have to think about minds to reach such a conclusion. For both species, as suggested earlier, experiencing recall of the past should help this connection to be made. Seeing is also observable in the sense of recognizing eyes and where they are pointed, as both infants and chimpanzees do, so when adult primates make use of a concept of seeing, that does not necessarily mean they are mind-reading in the usual sense of that term. Whiten (1996) calls primate knowing an ''intermediate variable'' that is based on seeing. Another way of describing it is a ''behavioral abstraction,'' a category of behaviors involving eyes that make common predictions (Povinelli & Vonk, 2003). Such generalizations about others' behavior based on seeing can be generalized to hearing. For example, hearing a fellow primate tells you where that primate is located and perhaps whether he might be seeing you as well.

In this view, chimpanzees and rhesus monkeys have concepts of goals, seeing (and hearing) as knowing, but not yet any concept of mind, beliefs, or mental versions of intentionality. If this speculation has merit, then an interesting question becomes why chimpanzees do not mature into creating mental concepts the way that infants eventually do. There are many possible reasons, of course. Nonhuman primates do not have language, which may well be required for entertaining concepts of mental states such as belief. They also do not have the same motivation for shared communication as humans do; for example, chimpanzees do not point or show things to each other (Tomasello et al., 2005), or point to request an absent object that both self and others know about (i.e., have seen), as 12-month-old month human infants do (Liszkowski, Schäfer, Carpenter, & Tomasello, 2009).

The present theory suggests a further reason, having to do with kinds of information that can neither be seen nor heard. Chimpanzees and rhesus monkeys have good spatial knowledge but are bad at understanding invisible aspects of causality such as force, support, and solidity in their problem solving (Penn & Povinelli, 2007; Santos, 2004). This suggests they have not integrated their spatial knowledge of causality with their own experiences of forceful action. The same thing may be true of integrating feelings of trying with spatial concepts of goal-directed behavior. As for mental states, such as knowing and belief, these cannot be seen, heard, or felt. Human infants supplement the spatial foundations of their conceptual system by adding internal feelings of force and trying to them, but nonhuman primates may not engage in such enrichment. They may be hampered in integrating their internal feelings with their spatial concepts, perhaps because they do not attend to them as much (with the likely exception of pain), or for some other reason, are missing this integrative step.

10. Conclusions

The theory of early concept formation presented here recognizes the need for some innate propensities to get concept formation started, but it is equally based on the proposition that if something is easily learnable there is no need for it to be built in. For example, there is no need for innate knowledge of animates and inanimate objects, because the world provides ample spatial information to conceptualize the ways in which they differ. There is no need to build in a concept of *intentionality* because it can be built out of more basic concepts of types of paths. Especially, there is no reason to build in a concept of animates that includes goal-directed behavior, not only because the association is easily learned but also because infants (and even adults on occasion) apply the concept more broadly than would be the case if goal-directed behavior were innately restricted to animates.

To my knowledge, there are no comprehensive empiricist theories of concept formation in infancy, but the present theory is something of a compromise between nativist and empiricist views. It provides a single domain-general mechanism (PMA) that applies to all objects, not just animate or inanimate ones, and that analyzes only a few kinds of spatiotemporal information from the huge amount of information that the perceptual system delivers. It starts the conceptual system by directing attention to and representing simplified versions of things moving on paths through space, as well as a few spatial relations and spatial contingencies. Although much perceptual learning occurs without attention, it is these representations based on attended information that provide interpretation of things and events potentially accessible in the absence of perception itself.

The mechanism does make use of temporal information but translates it into iconic spatial form by means of LINK, a relationship between objects and/or paths that is understood in spatial terms. LINK is, of course, only a beginning. To form temporal concepts that are independent of spatial representations requires learning about ordered event sequences, the ability to recall such sequences, and probably the help of language. Not surprisingly, then, the first relational vocabulary is spatial in nature, not temporal. Words like ''in'' and ''gone'' appear before words like ''before'' and ''after.''

The spatial conceptual system I have described does not have to go far—just until internal experiences are added to it, along with learning and language to enrich the innate conceptual base. Why are various internal feelings like force or fear not part of the innate base in the first place? Merely experiencing a feeling does not mean that it can be conceptually interpreted. Internal experiences must be described in some way to be thought or thought about, and the only suitable vocabulary available to preverbal infants consists of spatial information that enables imagery. Without such a description, there is no way to recall force or fear after it is no longer felt (and even with language, the feeling can often not be recreated). The spatial conceptual system is also adequate to enable early word understanding—names of things and places, spatial relations, and verbs describing various motions through space (see Mandler, 2005, for details). Needless to say, this view of early concept formation does not speak to the innate source of language itself; it only says that given a capacity for language, the early spatial system provides sufficient conceptual resources to get it started.

I have emphasized the notion of structure as being crucial to the development of a conceptual system. Concepts must be memorable and accessible to awareness if thought, recall, and problem solving are to occur. In turn, to be memorable requires structure. Spatial information is ideally suited for this purpose. Its structure is so obvious that it appears to be the most common form used for of analogical and metaphorical thought. In contrast, most bodily information has little accessible structure of its own, although some kinds, such as feelings of force or trying, can become accessible by becoming blended with spatial conceptual structure. Exactly what is required for this integration (often termed embodiment) to take place is unknown. I have suggested that it requires attention, but that is speculative. Perhaps it only requires ordinary, slowly accumulating, associative processes, which can work outside of awareness as well, such as those described in the connectionist theory of Rogers and McClelland (2004).

It is also important to note that the sensorimotor system, as Piaget insisted, takes care of a great deal of infant functioning without the need for conceptual thought. But because conceptualization is not needed to learn to reach or crawl or anticipate what will happen next in a familiar sequence does not mean it is absent. Research of the last several decades has made clear that infants live a rich conceptual life. Indeed, their interpretations of the objects and events they experience not only lay the foundations for adult conceptual functioning, they last through life and are the last to be lost when the conceptual system breaks down in semantic dementia (Patterson & Hodges, 1995).

In sum, there are a number of reasons why the conceptual system starts out as a spatial system. First, paths through space are highly salient to infants, attracting attention from birth. Second, spatial information can both be seen and more easily understood than dynamics or mental states. Third, spatial representations are sufficient to form a viable conceptual system that enables interpretations of objects and events without involving other kinds of information. It is possible to understand what is going on around one with a purely spatial conceptual system even though it ignores other perceptual properties and force dynamics, and lacks experience of doing actions. Fourth, spatial representations are structured, which makes them memorable, an indispensable requirement for building a conceptual system and for inferences about absent objects and events. In contrast, other kinds of perceptual information are either unstructured or minimally structured (other than auditory sequences, which are limited in their applicability to objects and events). For example, bodily feelings such as force and trying are virtually one-dimensional, varying primarily in intensity. Fifth, before language the only way to bring conceptual information to mind is via imagery. Spatial information can be imaged (whether formed through sight, movement, or touch), but sensory information such as color or smell, or feelings such as emotions, either cannot be imaged at all or only vaguely, which means that although they can be recognized they cannot be recalled.

These considerations suggest that nonspatial kinds of information are secondary, and at least to some extent, remain so throughout life. Embodied cognition is an accomplishment, not a starting point. One must use spatial information to understand actions, but one can do without other information entirely. Thus, it is not surprising that infants begin with a spatial conceptual system and can wait for other kinds of information to be added. Experience in handling objects and moving around in the world will bring feelings of force much more dramatically to attention. Experience in carrying out their own goal-directed actions will make attention to internal feelings of trying possible. Finally, language will teach what PMA and experience alone can only partially supply.

There are notable advantages to this architecture. It does not require separate innate conceptual modules or domain-specific learning. Instead, a single domain-general mechanism and a few known attentional proclivities suffice. The architecture relates the outputs of PMA to other sources of information, explaining both the concepts that are known to appear early in life and why other kinds of concepts are slower to come on the scene. It accounts for the order of acquisition of various kinds of concepts. Finally, the architecture provides a way of characterizing some of the commonalities and differences between human and other primates' conceptual lives.

Notes

1. Deferred imitation is a nonverbal technique in which infants are shown an event and at a later time encouraged to reproduce it.
2. Infants may at first ascribe self-starting to vehicles, but in our culture infants quickly learn that cars start themselves only when they have a person in them doing something.
3. Leslie's (1982) experiments differ in detail from his later definitive work with 6-month-olds, but the outcomes at 4 months are essentially the same.
4. PATH TO was formerly termed DIRECT PATH (Mandler, 2010). The name has been changed because paths that go around an obstacle on a direct path are also understood as ''moving to.''
5. Visual imagery is the most common form of spatial imagery, but even congenitally blind people form images of spatial information based on sensorimotor activity (Afonso, Blum, Katz, & Tarroux, 2010).
6. That is not necessarily the last place you saw it. The most frequent place may be recalled instead.
7. Adults with high-functioning autism, however, do not show normal anticipatory eye movements in Onishi and Baillargeon's type of task (Senju, Southgate, White, & Frith, 2009), in contrast to the normal eye movements in the social understanding tasks used by Zwickle et al. This suggests that others' ''knowing'' in the sense of having seen may not develop in the normal way in individuals with autism.

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