

COMPARATIVE METAPHYSICS: THINKING ABOUT OBJECTS IN SPACE AND TIME

Trix Cacchione and Hannes Rakoczy

What is the most basic structure of the world as we think of it? What are the most fundamental perceptual and conceptual categories through which we see our surroundings? Which categories does a thinker need to have if he/she is to be credited with any form of thought about an objective world? And how are such categories shaped by the way our languages carve up the world? Such questions have a long history in philosophical inquiry under the rubric *descriptive metaphysics*, with roots going back at least to Kant (1781/1997). Questions of descriptive metaphysics have become a topic of empirical cognitive science in the last decades, investigating which categories and concepts people use (see Chapter 5, this volume), how these categories and concepts shape world views, how such world views may differ cross-culturally, and how world views develop over time in ontogeny (see Volume 1, Chapter 20, this handbook). In fact, it was Piaget (1952) who established descriptive metaphysics as a topic of cognitive science by exploring the developmental foundations of our basic world view. More recently, and inspired by Piaget's Kantian program and his followers in developmental psychology, questions of fundamental perceptual and conceptual structures have become a systematic focus of inquiry in comparative psychology: How similar are different types of creatures with regard to such world views, and how might these increasingly complex world views have evolved? These questions constitute the field of what could be called *comparative metaphysics* (see Mendes, Rakoczy, & Call, 2008; Rakoczy, 2014). The present chapter will give an

overview of this field focusing on what, arguably, is the most fundamental conceptual structure of our way of seeing the world: The capacity to segment the world into discrete objects that are independent from us, persist over time, and can be reidentified.

The most basic form of any objective thought—thought about a world out there that exists and persists independently from us and our perception of it—is representing the world as made up of enduring individual objects. But what does it mean to represent objects as enduring and perception-independent entities? And how can such cognitive capacities be measured empirically, particularly in the absence of language?

These questions have been approached from different perspectives in developmental and cognitive psychology, with diverging theoretical and methodological consequences. Piaget, setting the scene for the cognitive science of object concepts, assumed that the child starts off caught in booming and buzzing perceptual confusion, with no notion of objectivity whatsoever, and that a proper concept of “object” develops only slowly (Piaget, 1952). Methodologically, Piaget's research was built on the premise that a proper object concept reveals itself most clearly in the capacity to keep track of, reason about, and rationally act vis-à-vis (i.e., search for objects currently not perceived). Empirically, Piaget's findings suggest that such complex reasoning and searching competence—and thus a concept of object—develop during the first 2 years of life. And they develop in tandem with other cognitive competencies (e.g., language) that were considered

by Piaget to be diverse expressions of an underlying domain-general reasoning capacity.

More recent core knowledge and related accounts were strongly inspired by Piaget's questions, but departed substantially from his theoretical and methodological premises. In contrast to Piaget, such accounts assume that basic forms of object cognition might be a more fundamental property of our perceptual and cognitive makeup (Carey, 2009; Spelke, 1990). In particular, the most fundamental form of object perception and cognition might be the capacity to segment the world into bodies: discrete, solid, and cohesive bundles of matter that move continuously through space and time which we can keep track. In light of the seminal work in this area by the cognitive scientist Elizabeth Spelke, such a rudimentary notion of objects as solid, cohesive bodies moving continuously in space and time has been described as notion of *Spelke objects* (Carey, 2009). According to the core knowledge and related accounts, keeping track of Spelke objects as the foundational kind of object cognition may well be a domain-specific, even a modular, capacity. Such a capacity can thus be present in infants and other animals, without directly translating into systematic rational action (e.g., searching behavior) and without necessarily being integrated with other cognitive domains or with higher cognitive functions (e.g., logical reasoning; see Chapter 29, this volume). Methodologically, such accounts have therefore approached infant object cognition in very different ways, controlling more carefully for extraneous task demands. They have thus relied less on searching and other forms of action (which might mask cognitive capacities because of motoric, executive, and other task demands), and on tasks that require children to reason in complex ways about unseen objects. Rather, they have relied on habituation and other looking time measures, and on simplified action measures. As a consequence, the empirical conclusions drawn from this work have been very different from Piaget's, suggesting that a basic (Spelke) object concept is present very early in ontogeny (perhaps even at birth), long before it translates into systematic action and logical inference.

Turning to comparative metaphysics, it should be noted that different strands in the comparative psychology of object cognition have been informed by either of these two different traditions. This has

often resulted in diverging theoretical and methodological approaches, with findings that at first sight appear incompatible with each other. Another complication for a comprehensive study in comparative metaphysics is the fact that most of the existing experiments have largely used one or the other method with one or the other species. Unfortunately, this makes comparisons across studies and the extraction of a bigger picture difficult.

In the following, we will try to review and integrate the main results from such different lines of research on animals' object cognition. We will focus, in turn, on representations of continuity (i.e., representing objects as continuously existing in space and time), cohesion (i.e., representing objects as having a cohesive inner structure), solidity (i.e., representing objects as solid extended bodies), and identity (i.e., individuating and reidentifying objects). Because most of the animal work strongly builds on cognitive and developmental studies with humans (conceptually and methodologically), in most of the sections we will start in a somewhat anthropocentric fashion, from the relevant work with human infants.

CONTINUITY: THINKING OF OBJECTS AS CONTINUOUSLY EXISTING IN SPACE AND TIME

In his foundational work, Piaget assumed that the most basic form of object cognition, *object permanence* (i.e., the capacity to grasp objects as mind-independent enduring objects that move continuously in space and time), develops in stage-like fashion over the course of infancy. According to Piaget, cognitive development in infancy proceeded in six stages. In the first three of these, covering the first 8 months of life, the child lacks any insight into the permanence of objects once they are out of sight. Basic object permanence appears in stages 4 and 5 from around 8 months of age, when the child begins to keep track of and search for occluded objects. In stage 4 tasks, children search for objects that are hidden or otherwise occluded. Yet they commit a strange mistake, the so-called A-not-B error: After repeatedly seeing an object being hidden at location A and successfully retrieving it there, infants continue to search for it at location A, even when seeing

the object being hidden—right before their eyes—at location B. In stage 5 tasks, children overcome this mistake and track objects over such repeated *visible displacements*. However, according to Piaget, object permanence is still incomplete at this stage, because the infant cannot yet reason in systematic ways about the object's fate once it is out of view, failing to understand *invisible displacements*. In typical invisible displacement tasks, the infant sees an object being hidden in a hand. This hand then visits, for instance, locations A and B, reappears empty and finally visits location C. Mature reasoning leads to the conclusion that the object must be in location A or location B and therefore, if one starts to search at location A and finds it empty, it must be at location B. Children master such tasks by systematically and sequentially searching location A and location B, when they are in Piaget's stage 6, from around 18 months of age. In Piaget's view, stage 6 marks the emergence of truly representational thought (termed *semiotic function*), which reveals itself in proper object permanence as well as in other representational capacities, such as language or future planning.

Empirically, Piaget's findings have turned out to be surprisingly robust and reliable even under controlled experimental conditions, although they were gathered from natural observations on very small samples of children. Conceptually, however, they have been disputed in many respects (see Lourenço & Machado, 1996, for a review). First, many accounts would consider stage 4 capacities—a basic awareness of the continuity of bodies—as the first true and proper form of object permanence, whereas later competence in understanding invisible displacements would be merely secondary developments resulting from the integration of basic object cognition with more domain-general reasoning capacities. Second, it has been widely argued that Piaget's active action measures underestimate early cognitive competence because of motoric and executive performance factors, and that looking time and other less taxing measures are thus preferable for tapping precocious competence.

These different forms and levels of object permanence have been investigated with different methods borrowed from developmental inquiry. We will start with a section summarizing research on *basic*

skills, where we present data on the earliest manifestations of object representations at the interface of perception and cognition (Piaget's stages 1–3), and findings from search tasks with moderate task demands (i.e., search for visibly displaced objects; Piaget's stages 4–5). We will then present research on *advanced skills*, summarizing data on invisible displacement tasks which reveal more sophisticated reasoning abilities (Piaget's stage 6).

Basic Skills

Perception-based measures. Recent accounts of core cognition suggest that the nervous system is innately disposed for the conceptual decomposition of visual events (e.g., Carey, 2009). According to this view, the innate stock of primitives is not limited to perceptual representations, but also involves innate conceptual representations, sharing some structural similarity with perceptual representations. A core concept of continuity holds that physical bodies follow exactly one connected trajectory in space–time. A mind endowed with the notion of object continuity would therefore experience ambivalence when confronted with objects jumping in and out of existence (continuity violation) or moving through each other (solidity violation). There is ample evidence that infants from about 2.5 months appreciate object continuity, long before they are able to reach for objects (e.g., Baillargeon & DeVos, 1991; Spelke, Breinlinger, Macomber, & Jacobson, 1992). For example, infants significantly react to the sight of an object passing behind a screen and not reappearing in a large window (Baillargeon & DeVos, 1991).

Also in nonhuman animals there is ample evidence for rich representations of solid, three-dimensional and continuously existing objects (e.g., Fujita, 2001). Because most of these studies focus on object cohesion and solidity rather than on continuity per se, they will be discussed in the following sections.

Action-based measures. To locate visibly displaced objects, subjects must not only appreciate their permanence, but also deal with executive demands such as visually tracking the object to its final location, keeping up its memory trace, planning behavior and inhibiting prepotent false choices. Success in visible displacement tasks therefore not only indicates

whether an organism has a basic object representation, but also how successfully this representation can be implemented into search. In human infants, nearly every aspect of how executive demands and context factors affect performance in visible displacement tasks has been investigated, including the distinctiveness, distance, number, and transparency of the covers, the delay between hiding and search, whether the tasks involved manual search or just looking time, and the presence of landmarks in the

environment (see, e.g., Thelen, Schöner, Scheier, & Smith, 2001, for a review).

Searching for visibly displaced objects has also been investigated in many animal species. The basic finding has been that several species of primates, other mammals, and birds can reliably locate and search for visibly displaced objects (see Figure 26.1). However, whether these findings really indicate basic object knowledge in animals is still intensely debated. Criticism centers on methodological issues,

TASKS	SPECIES	STUDIES (AND REPORTED PERFORMANCE ACROSS TASKS)
1. Single visible displacement 	Apes: <i>Gorilla gorilla</i> , <i>Pan troglodytes</i> , <i>P. paniscus</i> , <i>Pongo abelii</i> , <i>Hylobates lar</i> , <i>H. leucogenys</i> , <i>Nomascus gabriellae</i> , <i>Symphalangus syndactylus</i>	Albiach-Serrano, Call, Barth, 2010, <i>AJP</i> 72:349 (9); Anderson, 2012, <i>BE</i> 149:441 (1,8); Barth, Call, 2006, <i>JEP</i> 32:239 (2,3,4,6,7,8,9); Beran, Minahan, 2000, <i>IJCP</i> 13:1 (1,8,9); Beran, Beran, Menzel, 2005, <i>JCP</i> 119:14 (1,3,9); Beran, Beran, Menzel, 2005, <i>PR</i> 46:255 (9); Call, 2001, <i>JCP</i> 115:159 (1,3,5,6,7); Call, 2003, <i>PR</i> 44:347 (8,9); Collier-Baker, Davis, Nielsen, Suddendorf, 2006, <i>AC</i> 9:55 (6,10,11); Collier-Baker, Suddendorf, 2006, <i>JCP</i> 120:89 (7); de Blois, Novak, Bond, 1998, <i>JCP</i> 112:137 (1,4,5,6,7,10); Fedor, Skollar, Szerencsy, Ujhelyi, 2008, <i>JCP</i> 122:403 (1,4,6,7,10); Hoffman, Beran, 2006, <i>JCP</i> 120:389 (9); Hribar, Call, 2011, <i>AC</i> 14:623 (2); Mallavarapu, Stoinski, Perdue, Maple, 2014, <i>PR</i> 55:549 (7); Mathieu, Bouchard, Granger, Herscovitch, 1976, <i>AB</i> 24:585 (1,5,7); Natale, Antinucci, Spinazzi, Poti, 1986, <i>JCP</i> 100:335 (6,10); Okamoto-Barth, Call, 2008, <i>DP</i> 44:1396 (9); Redshaw, 1978, <i>JHE</i> 7:133 (1,4,5,6,7); Rooijakkers, Kaminski, Call, 2009, <i>AC</i> 12:789 (8); Wood, Moriarty, Gardner, Gardner, 1980, <i>ALB</i> 8:3 (1,4,5,6,7)
2. Delayed response (or memory) As in 1, with delay between baiting and retrieval 		
3. Non-adjacent displacement 		
4. A-not-B error 	Old world monkeys: <i>Macaca fascicularis</i> , <i>M. fuscata</i> , <i>M. mulatta</i> , <i>Mandrillus sphinx</i>	Amici, Call, Aureli, 2008, <i>CB</i> 18:1415 (3,4); Amici, Aureli, Call, 2010, <i>AJPA</i> 143:188 (8); de Blois, Novak, 1994, <i>JCP</i> 108:318 (1,4,5,6,7,10); Gabel et al, 2009, <i>OBJ</i> 2:137 (1,5,8); Hughes, Santos, 2012, <i>JCP</i> 126:421 (9); Natale, Antinucci, Spinazzi, Poti, 1986, <i>JCP</i> 100:335 (6,10); Schino, Spinazzi, Berlinguer, 1990, <i>PR</i> 31:537 (6,7,10); Wise, Wise, Zimmermann, 1974, <i>DP</i> 10:429 (1,4,5,6,9)
5. Successive visible displacements 	New world monkeys: <i>Ateles geoffroyi</i> , <i>Callithrix jacchus</i> , <i>Cebus capucinus</i> , <i>Lagothrix flavicauda</i> , <i>Saguinus oedipus</i> , <i>Saimiri sciureus</i> , <i>Sapajus apella</i>	Amici, Aureli, Call, 2010, <i>AJPA</i> 143:188 (8); Amici, Call, Aureli, 2008, <i>CB</i> 18:1415 (3,4); de Blois, Novak, Bond, 1998, <i>JCP</i> 112:137 (1,4,5,6,7,10); Kis, Gacsi, Range, Viranyi, 2012, <i>AC</i> 15:97 (4); Mathieu, Bouchard, Granger, Herscovitch, 1976, <i>AB</i> 24:585 (1,5,7); Mendes, Huber, 2004, <i>JCP</i> 118:103 (1,4,5,6,7,10); Neiworth et al, 2003, <i>AC</i> 6:27 (1,4,5,6,7,10); Schino, Spinazzi, Berlinguer, 1990, <i>PR</i> 31:537 (6,7,10); Vaughter, Smotherman, Ordy, 1972, <i>DP</i> 7:34 (1)
6. Invisible displacements: Piagetian task 	Leopards: <i>Eulemur fulvus</i> , <i>E. mongoz</i> , <i>Hapalelemur griseus</i> , <i>Lemur catta</i> , <i>Varecia variegata</i>	Deppe, Wright, Szelistowski, 2009, <i>AC</i> 12:381 (1,4,2,5,6,7,10); Mallavarapu, Perdue, Stoinski, Maple, 2013, <i>AJP</i> 75:376 (1,5,6,7,10)
7. Successive invisible displacements 	Dogs and wolves: <i>Canis lupus familiaris</i> , <i>C. lupus</i>	Ashton, De Lillo, 2011, <i>JCP</i> 125:194 (1,4); Collier-Baker, Davis, Suddendorf, 2004, <i>JCP</i> 118:421 (1,6,10,11); Doré, Fiset, Goulet, Dumas, Gagnon, 1996, <i>ALB</i> 24:142 (8); Fiset, Beaulieu, Landry, 2003, <i>AC</i> 6:1 (2); Fiset, Beaulieu, Le Blanc, Dubé, 2007, <i>JEP</i> 33:497 (1,6); Fiset, Gagnon, Beaulieu, 2000, <i>JCP</i> 114:315 (8); Fiset, Le Blanc, 2007, <i>AC</i> 19:211 (1,6,10); Fiset, Plourde, 2013, <i>JCP</i> 127:115 (1,4,5,8); Gagnon, Doré, 1992, <i>JCP</i> 106:58 (1,4,5,6,7,10,11); Gagnon, Doré, 1993, <i>ALB</i> 21:246 (1,2,5,6,7); Gagnon, Doré, 1994, <i>JCP</i> 108:220 (1,4,5,6,7); Kis et al, 2012, <i>AC</i> 15:737 (4); Miller, Gipson, Vaughan, Rayburn-Reeves, Zentall, 2009, <i>PBR</i> 16:150 (9); Rooijakkers, Kaminski, Call, 2009, <i>AC</i> 12:789 (8); Triana, Pasnak, 1981, <i>ALB</i> 9:135 (1,5,6,7)
8. Invisible displacements: transpositions 	Cats: <i>Felis catus</i>	Doré, Fiset, Goulet, Dumas, Gagnon, 1996, <i>ALB</i> 24:142 (8); Doré, 1986, <i>JCP</i> 100:340 (1,4,5,6,7); Dumas, Doré, 1989, <i>JCP</i> 103:191 (1,4,5,6,7); Dumas, 1992, <i>JCP</i> 106:404 (6); Goulet, Doré, Rousseau, 1994, <i>JEP</i> 20:347 (1,5,6,7); Triana, Pasnak, 1981, <i>ALB</i> 9:135 (1,5,6,7); Fiset, Doré, 2006, <i>AC</i> 9:62 (2)
9. Invisible displacements: rotations 	Dolphins: <i>Tursiops truncatus</i>	Jaakkola, Guarino, Rodriguez, Erb, Trone, 2010, <i>AC</i> 13:103 (1,5,6,8,10,11)
10. Control test: last container 	Corvids: <i>Aphelocoma californica</i> , <i>Corvus corone</i> , <i>C. corax</i> , <i>C. monedula</i> , <i>Garrulus glandarius</i> , <i>Pica pica</i>	Bugnyar, Stoewe, Heinrich, 2007, <i>AB</i> 74:757 (1,4,5,6,7); Hoffman, Ruettler, Nieder, 2011, <i>AB</i> 82:359 (1,4,5,6,7,8,9); Pollak, Prior, Guntürkün, 2000, <i>JCP</i> 114:148 (1,4,5,6,7,10); Salwiczek, Emery, Schlinger, Clayton, 2009, <i>JCP</i> 123:295 (1); Ujfalussy, Miklosi, Bugnyar, 2013, <i>AC</i> 16:405 (1,4,5,6,7,10); Zucca, Milos, Vallortigara, 2007, <i>AC</i> 10:243 (1,4,5,6,7)
	Parrots: <i>Ara macacana</i> , <i>Cacatua goffini</i> , <i>Cyanoramphus auriceps</i> , <i>Psittacus erithacus</i> , <i>Melopsittacus undulatus</i> , <i>Nymphicus hollandicus</i>	Auersperg, Szabo, von Bayern, Bugnyar, 2014, <i>JCP</i> 128:88 (1,5,6,7,8,9); Funk, Matteson, 2004, <i>LB</i> 32:427 (1,4,5,6,7); Funk, 1996, <i>ALB</i> 24:375 (1,4,5,6,7); Pepperberg, Kozak, 1986, <i>ALB</i> 14:322 (1,4,5,6,7); Pepperberg, Funk, 1990, <i>ALB</i> 18:97 (1,4,5,6,7); Pepperberg, Willner, Gravitz, 1997, <i>JCP</i> 111:63 (1,4,5,6,7)
	Other birds: <i>Columba livia</i> , <i>Gallus gallus</i> , <i>Gracula religiosa</i> , <i>Streptopelia risoria</i>	Dumas, Wilkie, 1995, <i>JCP</i> 109:142 (1,4); Regolin, Vallortigara, Zanfortin, 1995, <i>AB</i> 49:195 (1); Plowright, Reid, Kilian, 1988, <i>JCP</i> 112:13 (1,6)

FIGURE 26.1. Illustrations of the tasks most commonly used to test for continuity and object permanence. White dots indicate initial (and intermediate) positions of rewards and black dots indicate the final position. Small gray arrows indicate that only food is moved, thick white arrows indicate that the containers/substrate are moved. Successive displacements (tasks 5 and 7) also control for selections of first cups visited by the experimenter. Task 10 controls for selections of last cups visited by experimenter. For each group of species, the most important studies investigating object permanence are reported (numbers in parentheses = task used; in bold if successful). Procedures across tasks were highly different (e.g., in terms of type, number, and saliency of cups; training; handling; number of trials; implementation of controls) and results are not directly comparable. AB: Animal Behavior; AC: Animal Cognition; AJP: American Journal of Primatology; AJPA: American Journal of Physical Anthropology; ALB: Animal Learning & Behavior; BE: Behavior; CB: Current Biology; DP: Developmental Psychology; IJP: International Journal of Comparative Psychology; JCP: Journal of Comparative Psychology; JEP: Journal of Experimental Psychology; JHE: Journal of Human Evolution; LB: Learning & Behavior; OPB: Open Biology Journal; PBR: Psychonomic Bulletin & Review; PR: Primates; PRSB: Proceedings of the Royal Society B.

and especially on the often large number of trials administered, on the use of fixed protocols allowing for associative learning, and on the lack of controls (e.g., sensory cues, associative cues, social cueing).

In many studies, variations of the original Piagetian tasks have been used (e.g., the scales developed by de Blois & Novak, 1994, and Uzgiris & Hunt, 1975). Especially Uzgiris and Hunt's (1975) battery has often been criticized, because it involves systematic tests on progressively complex tasks over large numbers of sessions, thus providing ample possibilities to learn associative strategies (e.g., selecting the location first/last touched, or the nearest location; see Jaakkola, 2014). Studies including a limited number of trials (e.g., 20–30) were suggested to provide a certain quality benchmark by evidencing spontaneous capacities (see, e.g., Jaakkola, 2014). Up to now, however, few studies meet this quality standard. Moreover, even if few trials were administered, subjects often needed extensive training to understand the testing procedure. Furthermore, among the studies including few trials, very few have also implemented controls to rule out the use of low-level alternative strategies (e.g., selecting the first/last location touched).

We summarize the current state of research on nonhuman animals' search for visibly displaced objects in the following section, focusing on four aspects that were also found to significantly affect human infants' search performance: (a) the time delay between hiding and searching, (b) the number and relative position of hiding places, (c) the number of consecutive searches at the same location, and (d) sequential displacements to multiple locations.

Time delay between hiding and searching. Numerous species have been tested with a delayed response task, which increases executive demands in terms of working memory (see Figure 26.1). In this task, a food item is usually hidden below one of 2–4 cups, and the participant has to wait for a specific time interval before starting the search. To successfully locate the object, the animal must not only maintain an active mental representation of the hiding location and later recall it, but also manage to reset the encoded information after each trial and build up a representation for the new position (see Zosh & Feigenson, 2009, on the interaction between memory capacity and the resolution of object representations). Barth

and Call (2006) presented great apes and 2.5-year-old human children with 30 s delays between hiding and retrieval. All apes and children reliably located the reward after the delay, but made more errors than in conditions without delay. Similar results were found in other primates (e.g., chimpanzees [*Pan troglodytes*], bonobos [*P. paniscus*], orangutans [*Pongo abelii*]; Hribar & Call, 2011; capuchin monkeys [*Sapajus apella*], spider monkeys [*Ateles geoffroyi*], long-tailed macaques [*Macaca fascicularis*]; Amici, Aureli, & Call, 2010; red-fronted lemurs [*Eulemur fulvus rufus*], mongoose lemurs [*E. Mongoose*], ring-tailed lemurs [*Lemur catta*], gentle bamboo lemurs [*Hapalemur griseus*]; Deppe, Wright, & Szelistowski, 2009), although differences in the number of locations and length of delay make it hard to compare performances across taxa. Also dogs (*Canis familiaris*) and cats (*Felis catus*) successfully find rewards after delays, and their performance declines with increasing time intervals (Fiset, Beaulieu, & Landry, 2003; Fiset & Doré, 2006). In both species, errors did not depend on failure to successively encode and reset new locations (as subjects did not tend to select the previously rewarded box), but rather on the deteriorating effect of delays on memory (as errors occurred as a function of proximity to the actual hiding location).

Number and relative position of hiding places. The number of potential hiding places is certainly a factor affecting search, and must be kept in mind when comparing studies carried out across different species. To our knowledge, however, no comparative study directly examined its influence in an object permanence context. Some studies have instead investigated the impact of the relative position of the hiding location on the performance of different species, by, for example, baiting either two adjacent or nonadjacent locations (see Figure 26.1). Chimpanzees, orangutans, and human infants, for example, perform reliably better when three cups are horizontally aligned and the two baited locations are adjacent rather than nonadjacent, in nonadjacent trials they tend to successfully select the first cup and then choose the middle empty cup (Call, 2001), like dogs (Müller, Riemer, Range, & Huber, 2014a) and Goffin cockatoos (*Cacatua goffini*; Auersperg, Szabo, von Bayern, & Bugnyar, 2014).

The relative position of the locations is a factor that substantially affects choices in single visible displacement tasks, when multiple locations are baited (*inhibition task*), but also in multiple visible and invisible displacements. There are two contrasting explanations as to why nonadjacent trials are more difficult than adjacent ones. First, there might be a memory deficit when more locations are baited (e.g., Beran, Beran, & Menzel, 2005). Adjacent trials might thus be easier, because participants fail to remember the second exact location, search in proximity of previously visited locations, and, more likely, find the reward in the adjacent trials (at least in three location arrays). Second, nonadjacent trials might be especially demanding by requiring inhibition of a prepotent response (Amici, Aureli, & Call, 2008; Barth & Call, 2006). In particular, errors in nonadjacent trials occur because of a typical left-biased search pattern found in some apes, who tend to just continue their search in a row from left to right without skipping containers (Call, 2001). Beran and colleagues (2005) provided support for the first hypothesis showing that in arrays with five or seven aligned containers search success for the second reward varies as a function of the distance between the baited locations. Moreover, performance steadily recovered proportionally to the distance between the baited cups (see also Hribar & Call, 2011), increasing if more empty cups were between the baited ones. These results supported the hypothesis that apes search in proximity of the exact position, as the inhibition hypothesis would have instead predicted that error distribution is independent of the distance between the baited containers. However, the observed search pattern does not completely rule out some impact of inhibition: If memory failure alone were responsible for erroneous searches, these would have been equally distributed to the left and right of the baited locations, and not more often to the right, as instead shown by Barth & Call (2006; but see Hribar & Call, 2011).

Number of consecutive successful searches at the same location. Around 12 months of age (Piagetian stage 4), human infants show a characteristic transitional error, the A-not-B error. Although they can successfully retrieve a hidden toy, when the toy is repeatedly hidden (and found) at the same location A, the child will continue to search at location A,

even if the toy is visibly transferred to a second location B. In the past decades, this phenomenon has been replicated in laboratories all over the world, and many different explanations have been offered as to the causes of this error (see, e.g., review by Marcovitch & Zelazo, 1999).

In the infant literature there is a general consensus that the A-not-B error is not a conceptual problem. Instead, it might be related to immature executive functions (Munakata, McClelland, Johnson, & Siegler, 1997). In particular, after reaching several times to location A, infants are unable to inhibit the prepotent motor response to reach again for location A, even if they know that the object is at location B (e.g., Diamond, 1990). Indeed, the likelihood of the error increases with the number of trials at location A (e.g., Marcovitch, Zelazo, & Schmuckler, 2002), as well as with the delay between hiding at location B and searching (because the memory of location B as a hiding place and the ability to inhibit reaching to location A decline over time). Successful performance after 12 months would thus emerge as a consequence of advances in inhibitory control, but the A-not-B error may reappear when the cognitive demands of the task increase, even in human adults (see Thelen et al., 2001). The investigation of A-not-B errors is therefore not only relevant from a developmental perspective, but is also crucial to assess differential susceptibility to perseveration across taxa.

Like humans, most adult primates do not continue searching in previously rewarded locations (see Figure 26.1). They overcome the A-not-B error at different stages during development (e.g., rhesus macaques [*Macaca mulatta*] at about 4 months and apes at 8 months; Gómez, 2005), evidencing a similar ability to build up new representations of objects' position and inhibiting the competing motor response to reach for previously rewarded locations. The same is true for lemurs, who can overcome the A-not-B error, but show perseveration errors in more complex tasks (Deppe et al., 2009; Mallavarapu, Perdue, Stoinski, & Maple, 2013). Recent studies clearly evidence that inhibitory control varies among primate species (Amici et al., 2008), and it is connected to their varying susceptibility to perseveration. Finally, birds usually show a transitional phase with A-not-B errors before reaching varying degrees of inhibitory control as adults (e.g., ravens [*Corvus*

corax]; Bugnyar, Stöwe, & Heinrich, 2007; carrion crows [*C. corone*]; Hoffmann, Rüttler, & Nieder, 2011; jackdaws [*C. monedula*]; Ujfalussy, Miklósi, & Bugnyar, 2013; grey parrots [*Psittacus erithacus*]; Pepperberg, Willner, & Gravit, 1997; grey parrots, Illiger mini macaws [*Ara maracana*], parakeets [*Melopsittacus undulatus*], cockatiels [*Nymphicus hollandicus*]; Pepperberg & Funk, 1990; but see Pollok, Prior, & Güntürkün, 2000, in magpies [*Pica pica*] and Zucca et al., 2007, in Eurasian jays [*Garrulus glandarius*] for lack of A-not-B errors).

In contrast to that, the A-not-B error appears to be absent in the development of dogs (see Gagnon & Doré, 1994) and cats (Dumas & Doré, 1989). More recent studies with dogs and wolves (*Canis lupus*) found no A-not-B errors in canid species (Fiset & Plourde, 2013), or very few (Müller et al., 2014a). However, dogs obviously show perseverative searches in other situations, selecting the previously rewarded location in invisible displacements (Fiset & Plourde, 2013), failing to switch to a new location when tested in a spatial version of the mediational learning paradigm (Ashton & De Lillo, 2011), or after the experimenter gave ostensive-communicative cues during the hiding (Topál, Gergely, Erdohegyi, Csibra, & Miklósi, 2009; but see Sümegi, Kis, Miklósi, & Topál, 2014; see also Volume 1, Chapter 33, this handbook). The lack of such errors in the traditional task might thus be connected to procedural aspects of the task rather than lack of preservative action in dogs.

Sequential displacements within one trial. In multiple visible displacements an object is first placed into a container and then swapped to another container within the same trial. Multiple displacements are more challenging than single displacements in terms of visual tracking, remembering, and inhibiting successive locations, and probably require more mature representations (for results with children, see Piaget, 1954). Also primates perform worse in conditions involving one swap (great apes; Call, 2001) or two (marmosets [*Callithrix jacchus*]; Mendes & Huber, 2004), although most primates were successful with single and double swaps (great apes; Call, 2001; tamarins [*Saguinus oedipus*]; Neiwirth et al., 2003; lemurs; Deppe et al., 2009). Data on birds are more difficult to interpret, as birds were usually tested with the Uzgiris–Hunt task, double swap conditions always followed conditions

without swaps and the effect of experience was confounded with the effect of task difficulty. In general, sequential displacements were rather challenging for some birds (e.g., magpies; Pollok et al., 2000). Double swap transpositions were demanding for carrion crows, which experienced problems to keep the attentional span during displacements and made many errors (Hoffmann et al., 2011). Dogs and cats could generally solve swap conditions, but earlier studies either confounded number of swaps with test order or involved very high numbers of trials (e.g., Gagnon & Doré, 1994; Goulet, Doré, & Rousseau, 1994). More recently, Fiset and Plourde (2013) found that dogs and wolves succeed with single visible swaps, even though rewards were moved inside a bowl that passed behind two screens (which complicates the task and hardly qualifies it as a fully visible displacement, given that the use of even transparent containers can affect performance in cats and dogs; Goulet et al., 1994; Müller, Riemer, Range, & Huber, 2014b). The only study with dolphins (*Tursiops truncatus*) revealed that they fail to find the reward after a single swap (Jaakkola, Guarino, Rodriguez, Erb, & Trone, 2010).

Advanced Skills

The capacity to deal with invisible displacements may be viewed as a second quantum leap in cognitive development. In invisible displacement tasks, objects are hidden at some locations and then invisibly moved to a different location. Mastering such tasks goes way beyond a basic awareness of continuously existing objects. It involves the mental reconstruction of an unseen trajectory and therefore advanced spatial reasoning skills. Moreover, it involves the adoption of multiple hypothetical models of a situation and requires rudimentary logical reasoning (i.e., understanding disjunction—“It must be in A or B”—and reasoning from negated disjuncts—“It is not in B, therefore it must be in A”; see Chapter 29, this volume). Localizing invisibly displaced objects therefore requires a rich object concept and advanced reasoning skills, as well as advanced inhibitory and memory capacities. Children develop the capacity to deal with invisible displacements around 18–24 months. At the same time, they acquire various other cognitive capacities such as self-concept, language and instrumental

problem-solving—all of which have been considered to be expressions of the newly emerging underlying capacity to coordinate multiple representations of reality (Perner, 1991). Conceptually, evidencing the prevalence of such advanced reasoning capacities across species has thus important implications in modelling the evolution of higher cognition (Suddendorf & Whiten, 2001; see also Volume 1, Chapter 20, this handbook). Empirically, however, unambiguous interpretation of available data is often difficult, because invisible displacement tasks involve a conglomerate of executive demands (inhibition, memory; see Chapter 27, this volume), reasoning demands (coordinate representation, logical inference, spatial reasoning; see Chapter 21, this volume) and context factors (number and spatial relation of locations, use of displacement devices, number of trials, aspects of presentation).

In general, there is wide-reaching consensus that humans, great apes, and parrots understand invisible displacements (e.g., Barth & Call, 2006; Collier-Baker, Davis, Nielsen, & Suddendorf, 2006; Pepperberg et al., 1997), whereas findings on other species are more controversial (but see Jaakkola, 2014). Following, we summarize recent research using three types of invisible displacement tasks (see Figure 26.1), in which the object always moves hidden inside a repository, either (a) with a hiding device (*standard Piagetian task*), (b) with the baited container (*transposition task*), or (c) with the full array (*rotation task*). In the standard Piagetian task, the object is hidden in a device (e.g., cup or hand), moved to one of a set of containers and secretly left under it. The device is then removed from the container and shown to be empty. The device may visit only one container or multiple containers (single, double swaps). In the transposition task, the object is visibly placed into the container and the container moved to another location, either one or multiple times (swaps). In the rotation task, the full array is moved by rotating the platform with the containers (e.g., 90°, 180°, or 360°). The difficulties of these tasks are (a) to understand that the object continues to exist, (b) to infer that it moves with the containing repository, (c) to infer that it must have been deposited along the invisible trajectory after the empty repository is shown, (d) to continuously

update locations during its journey, and (e) to inhibit prepotent responses. The three tasks vary in demands on cognitive processing: The standard task involves complex nested movements/transfers and is logically challenging, whereas transpositions and rotations are more demanding in terms of tracking and spatial reasoning. Great apes pass all three tasks (see Figure 26.1). Although for human children the standard task is easier than the transposition task (Barth & Call, 2006), great apes perform equally well in both tasks, although chimpanzees and bonobos outperform gorillas and orangutans (Barth & Call, 2006). For 30-month-old children and apes, however, 180° rotations are most challenging (Barth & Call, 2006). Further studies revealed that apes' performance increases if persisting landmarks (e.g., differently colored cups) are added, but only if rotations are observed, suggesting that apes' judgment is based on tracking the opaque repository rather than on posthoc logical inferences (Okamoto-Barth & Call, 2008). Also gibbons (*Symphalangus syndactylus*, *Hylobates lar*, *Nomascus gabriellae*, and *Nomascus leucogenys*) succeed with the standard task and transpositions (Fedor, Skollár, Szerencsy, & Ujhelyi, 2008), but data on monkeys and prosimians do not allow any conclusion. Although some studies suggest that monkeys do not understand invisible displacements (de Blois & Novak, 1994; de Blois, Novak, & Bond, 1998), other studies reported success (Amici et al., 2010; Neiworth et al., 2003; Mendes & Huber, 2004). However, most of these studies failed to include proper controls (but see Neiworth et al., 2003), included too many trials, graded series of increasingly difficult tasks, or failed to interpret results from a more integral perspective. Therefore, no conclusion can be drawn on monkeys and prosimians' ability to master invisible displacements. To date, only one study investigated monkeys' performance on transpositions, comparing macaques, spider monkeys, and capuchin monkeys (Amici et al., 2010). Although macaques' performance equalled that of apes (mastering single and double transpositions), spider monkeys and capuchin monkeys were only successful with single transpositions. Data are scarce on monkeys' understanding of rotation. Using an expectancy-violation rotational displacement task, Hughes and Santos

(2012) found that adult but not infant or juvenile rhesus macaques expected the object at the correct location after a 180° rotation. Finally, a recent study on spatial reasoning suggests that rotations are harder for monkeys than transpositions (Nekovarova, Nedvidek, Klement, Rokyta, & Bures, 2013).

Whereas earlier studies reported success in standard tasks for cats and dogs (Triana & Pasnak, 1981; Gagnon & Doré, 1992, 1993), later studies suggested success with visible displacements only (Collier-Baker, Davis, & Suddendorf, 2004; Dumas & Doré, 1989; Goulet et al., 1994). In invisible displacement tasks, dogs were typically found to search the final location of the displacement device (Collier-Baker et al., 2004), suggesting that they used an associative strategy to select the location. A recent study, however, suggests that the use of a displacement device probably complicates the task for dogs, because it introduces a salient and potentially misleading cue. Müller and colleagues (2014b) found that also in a visible displacement task, the use of a displacement device reliably impaired dogs' performance, either because of the strong associative cues overriding location information or because of the dogs' failure to individuate the reward as separate from device (see Goulet et al., 1994, for a similar effect in cats). Even though this does not show that dogs would master invisible displacements if distracting cues were removed, it certainly highlights the importance of carefully considering whether task demands might mask conceptual abilities. To our knowledge, only one study tested cat's ability to deal with transpositions (Doré, Fiset, Goulet, Dumas, & Gagnon, 1996), whereas dogs were tested with transpositions and rotations (Doré et al., 1996; Fiset & Plourde, 2013; Miller, Gipson, Vaughan, Rayburn-Reeves, & Zentall, 2009; Miller, Rayburn-Reeves, & Zentall, 2009; Rooijakkers, Kaminski, & Call, 2009). Cats and dogs were successful only in simple lateral transpositions, but failed if containers were transposed along more complex (e.g., crossing) paths (Doré et al., 1996; Fiset & Plourde, 2013). A direct comparison of dogs with apes confirmed that dogs are clearly outperformed by apes (Rooijakkers et al., 2009). Finally, dogs managed to locate rewards after 90° but not 180° rotations (Miller, Gipson, et al., 2009; Miller, Rayburn-Reeves, & Zentall, 2009).

To our knowledge, the only other mammals that have been tested are dolphins, who failed the standard task (Jaakkola et al., 2010), and wild and domestic pigs (*Sus scrofa scrofa*, *S. s. domestica*), who failed transpositions (Albiach-Serrano, Bräuer, Cacchione, Zickert, & Amici, 2012).

Finally, five species of the corvid family and five of the psittacid family were reported to pass invisible displacements (see Figure 26.1). However, most of them used the Uzgiri–Hunt scale, and only four studies implemented associative controls (Auersperg et al., 2014; Funk, 1996; Pepperberg et al., 1997; Zucca et al., 2007). Corvids and parrots were also tested with transpositions (corvids; Hoffmann et al., 2011; Ujfalussy et al., 2013; Zucca et al., 2007; parrots; Auersperg et al., 2014; Pepperberg et al., 1997), and all of them succeeded, with the exception of crows (Hoffmann et al., 2011). Finally, 90°, 180°, and 360° rotations were implemented for crows and cockatoos. Whereas crows managed only 90° rotations (Hoffmann et al., 2011), cockatoos passed all of them, and also 270° (Auersperg et al., 2014). However, because the rewards were moved by magnets and many birds are able to perceive magnetism (see Chapter 22, this volume) this was suggested as an alternative source of success (Jaakkola, 2014).

Conclusion

The general picture that emerges from decades of comparative research on object permanence is the following: Many mammals and birds successfully solve visible displacement tasks; yet so far we have positive evidence for an understanding of invisible displacement only in great apes and some birds. However, the validity and proper interpretation of these findings remain controversial in light of fundamental methodological complications. On the one hand, conservative approaches point out the danger of false positives: In the absence of stringent control conditions, associative strategies might be mistaken for conceptual capacities (e.g., Jaakkola, 2014). On the other hand, core knowledge and related accounts have argued that many traditional searching measures radically underestimate conceptual competence because of extraneous (e.g., motoric, executive) performance factors.

Future research should thus use different methodological approaches with multiple species to yield a more comprehensive picture. One particularly exciting open question in this context, for instance, is whether the emergence of complex object-based reasoning (as indicated in invisible displacement tasks) goes along with a structurally comparable cognitive revolution (e.g., coemerging self-concept, hypothetical reasoning, imagination, etc.) also in species other than humans.

COHESION: THINKING OF OBJECTS AS HAVING A COHESIVE INNER STRUCTURE

In the past decades, infant research has revealed that core object concepts provide intuitions about spatio-temporal properties (object continuity) and featural properties (object size, shape, volume, solidity, etc.). Also, comparative research has increasingly focused on animals' knowledge about object properties (i.e., cohesion, spatial extension, and solidity). In the following two sections, we will summarize comparative research investigating knowledge of object cohesion and solidity.

Perception-Based Measures

Even in very young infants, the foundation for the perception of objects is present. It builds on core object principles such as the principle of cohesion, on which infants rely when tracking and identifying objects. The cohesion principle works as a pattern-detector defining objecthood (Pinker, 1997): All portions of matter that move as bounded cohesive units are indexed as objects.

A basic manifestation of the capacity to perceive objects as cohesive wholes is called *perceptual completion* (e.g., mentally bridging the gaps when perceiving the unity of partially occluded objects). From about 2 month of age, human infants integrate motion patterns to perceive center-occluded objects as unitary connected wholes (e.g., Johnson, 2004). Indeed, the perception of object unity appears to be a more basic ability than the perception of object form. In a seminal study, 4-month-old human infants were first habituated to a three-dimensional object whose ends were visible but whose center was occluded, and were then shown two test displays

with no occluder present (Kellman, Spelke, & Short, 1986; see Figure 26.2). In one display, the two ends of the object were connected in the place where the occluder had been, although in the other display, the two ends were separated by a gap. Infants looked longer at the second display (while perceiving it as different from the occluded object), suggesting that they perceive center-occluded objects as being connected behind the occluder, when their visible ends share a common lateral translation in space (Kellman et al., 1986). These results show that from a very early age humans perceive objects according to the principles governing the motions of material bodies (e.g., coherence of motion), depending on an inherent conception of what are objects (Kellman et al., 1986).

Just like human infants, chimpanzees and capuchin monkeys engage in perceptual completion and thus in the perception of objects as cohesive entities (Fujita & Giersch, 2005; Sato, Kanazawa, & Fujita, 1997; see also Chapter 8, this volume). When matching the sample with a center-occluded rod, for instance, monkeys largely selected a straight rod over disconnected rods and rods with irregular shapes at their center, even when their visible ends did not share a common motion (Fujita & Giersch, 2005). Similarly, rhesus macaques, like adult humans, overestimate the length of a bar that abuts the edge of a large rectangle, suggesting that they believe it continues behind the rectangle and they represent the rod beyond perception (Fujita, 2001). It should be noted, however, that methodological differences make direct comparisons to human studies difficult: The latter usually monitor spontaneous looking behavior in infants in the absence of any training, whereas nonhuman primates often underwent extensive training before they could be tested with match-to-sample or related tasks.

Action-Based Measures

For Piaget, object permanence was the first step in direction of a more general understanding of physical constancy, including the understanding that also many featural object properties such as mass, volume, size, and shape are constant across different spatial arrangements (e.g., splitting an object or filling liquid in another container does not change the

mass of the transformed entity). Also the core cognition approach considers that appreciating cohesion and appreciating continuity are logically linked, albeit in other ways. Once infants have recognized a given portion of matter as an object, they expect this object to continue existing and keep up its boundaries and inner structure while moving (e.g., Spelke, 1990). An open question is whether perceived object cohesion is really crucial for appreciating the permanence of matter per se. An alternative possibility would be that it is rather a prerequisite to appreciate the permanence of a given entity or spatial arrangement of matter. Several studies suggest that at an early age, the first might be true, and that for young infants the notion of permanence pertains to object-like entities only, whereas non-solid substances (e.g., water, sand) or decomposed (noncohesive) objects are not recognized as continuously existing (e.g., Cheries, Mitroff, Wynn, & Scholl, 2008; Huntley-Fenner, Carey, & Solimando, 2002). In a typical forced choice paradigm, infants were presented with two cups baited with crackers of different size (e.g., Cheries et al., 2008; see Figure 26.2). Although 12-month-old human infants usually chose the bigger cracker, they failed to do so if the cracker was fragmented before being hidden, suggesting that they failed to further represent it. Later studies, however, revealed that infants appreciated that also a fragmented cracker is composed of permanent material, but they failed to update the featural information needed to estimate its size (Cacchione, 2013). That is, while appreciating that the manipulation does not alter crackers' continuity (i.e., crumbs of a fragmented cracker do not stop existing), infants fail to appreciate that their mass remains constant through the transformation.

From an evolutionary perspective, it is indeed hard to understand why the notion of permanence should not pertain to the class of matter per se. In the context of foraging, for example, representing and localizing all kinds of substances and objects should have the same adaptive value. Recently, two studies modelled after the infant forced choice methodology (e.g., Cacchione, 2013) questioned whether great apes would appreciate that fragmented (noncohesive) objects are still composed of permanent matter (Cacchione & Call, 2010;

Cacchione, Hrubesch, & Call, 2013). In these studies, great apes were presented with different conditions in which a solid food object (cracker) was visibly fragmented into increasingly noncohesive patterns (i.e., from two halves into uncountable smithereens), and then hidden. Apes could then choose between the bigger (fragmented) cracker and a smaller not fragmented one. As human infants, great apes further represented the permanence of the fragmented crackers, but failed to estimate their size if they were heavily fragmented. As human infants, apes therefore appreciated the permanence of noncohesive objects, but failed to process their featural properties (e.g., the amount of mass), suggesting that they do not have an advanced understanding of physical constancy.

SOLIDITY: THINKING OF OBJECTS AS SOLID EXTENDED BODIES

Understanding object continuity also is logically linked to understanding their solidity: each object follows exactly one trajectory, and two objects can never occupy exactly the same coordinate in space-time (e.g., Spelke et al., 1992). At the very basic level, therefore, grasping object solidity means little more than tacitly expecting that solid objects may not move through each other.

Basic Skills

Perception-based measures. In their now classical drawbridge experiment, Baillargeon, Spelke, and Wasserman (1985) presented 5-month-old human infants with a screen that moved back and forth through a 180-degree arc. Then a solid box was placed on the stage and the screen set in motion. Infants looked longer at an event where the screen continued moving until it reached the stage, as compared to an event where the screen stopped when reaching the box. This suggests that infants realize that solid objects (screen) cannot move through the space occupied by other solid objects (box). Later experiments revealed that from 2 months of age human infants perform in accord with solidity (e.g., looking longer if an invisibly falling object reappears on the lower of two solid surfaces; Spelke et al., 1992).

If tested with perceptual measures, rhesus macaques appear to appreciate object solidity: They tend to look longer at an event where an apple appeared to fall through a solid shelf, as compared to an event where this was not the case (Santos & Hauser, 2002; see Figure 26.2). As with infants, dogs who were tested with a looking time version of the drawbridge paradigm looked reliably longer at impossible events (i.e., a screen rotating 180° through a bone) as compared to possible events (i.e., a screen stopping when reaching the bone; Pattison, Miller, Rayburn-Reeves, & Zentall, 2010).

Action-based measures. Inspired by infant research, various recent comparative studies designed action tasks with low demands. As in traditional tasks, the animals are required to locate hidden objects, but must do so with the help of various sensory cues (e.g., visible, acoustic, tactile). These cues, however, are only informative to the animal, if it appreciates that solid objects relate causally to each other as a function of their properties (mass, weight, extension; see Chapter 29, this volume). Call (2007), for example, modelled an action task after the drawbridge paradigm used by Baillargeon and colleagues (1985). When presented with two small rectangular boards on a platform, one of which was inclined because of the presence of a hidden food reward under it, apes preferentially selected the inclined board (see Figure 26.2). This suggests that apes appreciated the solidity and continuous existence of hidden food, and used the different orientation of the boards as index to infer its current position (Call, 2007). However, apes' performance in the inclined board task also had limits. For instance, when presented with two equally inclined boards and only one was visibly supported by a wooden block, apes failed to logically infer that food was hidden under the unsupported board (Call, 2007). Moreover, apes could infer the location of a food reward in a similar task (the noisy-cup task), which provided acoustic rather than visual cues to solidity (Call, 2004; see Figure 26.2). When presented with two identical cups, apes selected the one that produced a rattling sound when shaken, or the opposite cup when the shaken cup produced no noise, suggesting that apes understand that

solid objects cause noise (Call, 2004). Finally, in a similar situation apes were also able to infer the position of a hidden reward using weight information (Schrauf & Call, 2011). In particular, when presented with two opaque cups and only one was baited, apes successfully localized the food by lifting the cups and comparing their weight.

Recent studies report similar findings in long-tailed macaques, who successfully used the boards' inclination to localize food (Schloegl, Waldmann, & Fischer, 2013). However, macaques failed to use the lack of inclination as a cue, showing a rather rudimentary understanding of causal object relations. Further, low demanding action tasks were also implemented with domestic pigs (Albiach-Serrano et al., 2012) and chicks (*Gallus gallus*; Chiandetti & Vallortigara, 2011). Albiach-Serrano and colleagues (2012) compared wild boars and two groups of domestic pigs living in more and less enriched conditions, using the inclined board and the noisy-cup tasks. Enriched pigs successfully located rewards only in the noisy cups, nonenriched pigs only located rewards below inclined boards, and wild boars failed in both tasks, suggesting that experience with specific stimuli during ontogeny influences performance in these tasks. Finally, Chiandetti and Vallortigara (2011) imprinted newborn chicks with a plastic cylinder and accustomed them to rejoin it when it was hidden behind an opaque screen. In the test, chicks were faced with two screens of different slants, height or width, that were either compatible or incompatible with the presence of the cylinder behind them. Chicks consistently chose the screen behind which the cylinder could possibly hide (disregarding flat-to-floor- screens or too small screens). These highly interesting findings suggest that chicks not only represent the physical properties of the imprinting object, but can also match them to the proportion of the hiding screen to infer its location. This is especially remarkable, because human infants before 3.5 months are not able to use height to infer an object's potential presence behind a screen (Luo & Baillargeon, 2005).

Advanced Skills

Although children appear to appreciate object solidity from early on, only much later do they

systematically use this knowledge in action tasks (e.g., Hood, Carey, & Prasada, 2000). In a typical action task on children's understanding of object solidity, an object moves along a certain trajectory, first visibly and then under occlusion (e.g., falling behind a screen; rolling along a plane). The invisible trajectory of the object is visibly blocked by some solid barrier (e.g., by a horizontal plane behind the screen on which the object falls; by a vertical wall along the horizontal plane where the object rolls), and the question is whether infants indicate an understanding of the obstacle's solidity and search for the object there (rather than at the location where the object would have ended up without the barrier; see Figure 26.2). Empirically, children have been found to show such systematic searching behavior only from around 2.5 years of age (Hood et al., 2000), although 4- to 6-month-olds show sensitivity to a very similar scenario with looking time measures (e.g., Spelke et al., 1992).

Beside executive demands, the difficulty in such action-based invisible displacement tasks is that they typically involve feedforward logic-causal inferences. Because the object is invisibly displaced, its final location must be logically inferred by mentally reconstructing the causal impact of solidity on its movements (e.g., a barrier stopping it). This might render search tasks much harder than looking tasks, where noticing the anomaly after revealing the object location is sufficient for success.

The perception–action dissociation, as observed in very young children, was also observed in rhesus macaques (e.g., Hauser, 2003; Gómez, 2005). Rhesus macaques, for instance, failed to implement solidity knowledge to localize an invisibly falling apple on top of a shelf, instead of below it (Hauser, 2001). When tested with an expectancy violation version of the same task, however, macaques looked longer when the apple appeared to move through solid barriers (Santos & Hauser, 2002). Moreover, searches were more successful if objects invisibly moved along the horizontal plane (Hauser, 2003). Failure in the vertical version of the task might therefore also depend on monkeys' susceptibility to gravity errors (i.e., on perseverative searching at the lowest point of the falling line; see Gómez, 2005).

Comparable findings were also obtained when the four great ape species were tested in a similar search task (Cacchione, Call, & Zingg, 2009). In particular, apes correctly inferred the position of objects after horizontal but not vertical displacements, although they showed no reliable gravity bias. In the more demanding tube task (where a food item is dropped down a tube connected to one of multiple opaque cups, and subjects must infer that the trajectory of the falling object is constrained by the solid tube; see Figure 26.2), apes failed to understand the object–tube interaction, despite integrating some tube-related causal information (Cacchione & Call, 2010). Finally, Hanus and Call (2008) also tested apes' use of weight cues in an invisible displacement task. A food item was hidden in one of two cups mounted on opposite sides of a balanced beam, and apes observed the balance beam tilting to one side. Apes successfully inferred the presence of the bait in the lower cup (despite having no baseline preference for lower cups). Together these findings show that apes and rhesus macaques appreciate that objects are solid, extended, and causally related to each other, but fail in conditions imposing high demands on logic-causal processing (see Chapters 27 and 29, this volume).

Dogs also mostly failed to implement solidity knowledge to logically infer the location of an invisibly displaced object, and instead resorted to associative strategies (e.g., Osthaus, Slater, & Lea, 2003; Müller et al., 2014a). One recent study, however, reported surprising performance in a modified tube task posing high demands on logic-causal reasoning (Kundey, De Los Reyes, Taglang, Baruch, & German, 2010). In this task, a food item was rolled down a slanted transparent tube into an opaque box, in the middle of which a wall could be inserted. From the first trial, dogs successfully located the food in the far location (in trials where the wall was not inserted) or in the near location (in trials where the wall was inserted and blocked the trajectory of the food). However, dogs in this study might have used perceptual movement cues (e.g., acoustic cues, small movement cues on the doors) to locate the food, as suggested by another study in which dogs failed with a similar set-up involving no object movements (Müller et al., 2014a). At present,

however, no clear conclusion may be drawn, as the two studies importantly differed in other ways (e.g., no ostensive cues were used in the latter study to attract dogs' attention to the barrier, and the final position of the object had to be inferred before it actually moved to it). More studies are surely needed to get a clearer picture of dogs' understanding of solidity.

IDENTITY: INDIVIDUATING AND REIDENTIFYING OBJECTS

Impressive as it is, keeping track of the spatio-temporal history of continuously moving, cohesive, and solid bodies constitutes only the most rudimentary form of how humans think of objects. As adult humans, we do not just see portions of matter moving around us through space and time. Rather, we see the world around us as made up of specific objects of certain kinds—trees, dogs, stones, and so on. Rather than just tracking spatio-temporal trajectories of bodies, we more generally engage in object individuation (“How many dogs are there?”) and object identification (“Is this the same dog as the one I saw there before?”). Tracking Spelke objects by object files enables some simple form of object individuation on the basis of spatio-temporal information, yet with clear and characteristic signature limits (see Volume 1, Chapter 20, this handbook and Chapter 25, this volume). For example, on spatio-temporal grounds one can solve the following problem: At time 1, one sees object A (e.g., a ball) and object B (e.g., a toy duck) disappear behind a screen, then at time 2 object B reappears and disappears again, followed by the same sequence with object A. Here, because object A and object B move in separate continuous trajectories each as a solid and cohesive body, spatio-temporal tracking results in the subject's expectation that there must be two distinct bodies behind the screen. Confronted with either one object behind the screen (unexpected) or two (expected) in looking time studies, subjects should thus look longer at the former than at the latter. Many studies using looking time or simple search measures (e.g., box task; see Figure 26.2) have documented success in human infants early in the first year of life (for review, see Xu, 2007).

However, there are clear limits to the kinds of problems one can solve with such purely spatio-temporal

tracking: If object A and object B are never seen simultaneously, such that object B appears from behind the screen and disappears again, and then the same sequence is shown with object A, on purely spatio-temporal grounds there is no evidence for two distinct objects. In terms of bodies, the situation is ambiguous: At different times one could have seen the same Spelke object repeatedly, or different ones. What is required to keep track of the number of objects and thus to solve such a task is *sortal object individuation*—keeping track of which kinds of objects (duck, ball), and as a consequence, how many distinct ones (at least two).

Developmental work with human infants has shown that the capacity to solve these more complex individuation problems emerges later in ontogeny, only around one year of age (Xu, 2007). Interestingly, such individuation competence is related to language in infants: Individual performance in object individuation studies correlates with receptive language proficiency such that children mastering individuation tasks involving ducks and balls tend to be those who already understand the words *duck* and *ball* (Xu & Carey, 1996). Performance generally is also boosted when the objects are labeled linguistically in the experimental procedure (“Look, a duck/a ball”). Such findings have led to the psychological version of a claim long popular in philosophy (e.g., Quine, 1957)—that sortal object individuation is on the basis of language acquisition and should therefore be a uniquely human capacity.

Comparative research in recent years has explicitly addressed this claim by testing various species with analogous tasks as those developed for human infants. Experiments with rhesus macaques (Phillips & Santos, 2007; Santos, Sulkowski, Spaepen, & Hauser, 2002), apes (Mendes et al., 2008; Mendes, Rakoczy, & Call, 2011) and dogs (Bräuer & Call, 2011) used manual search methods developed in infancy research. Subjects at time 1 see an object of type A enter into a box and then at time 2 either find a qualitatively identical object of type A, or a different object of type B, after which they have the opportunity to continue searching in the box (see Figure 26.2). Searching time here serves as an indicator of numerical expectations as to whether there is still an object in the box, and longer searching in the A/B case compared to the A/A case is seen as an indicator

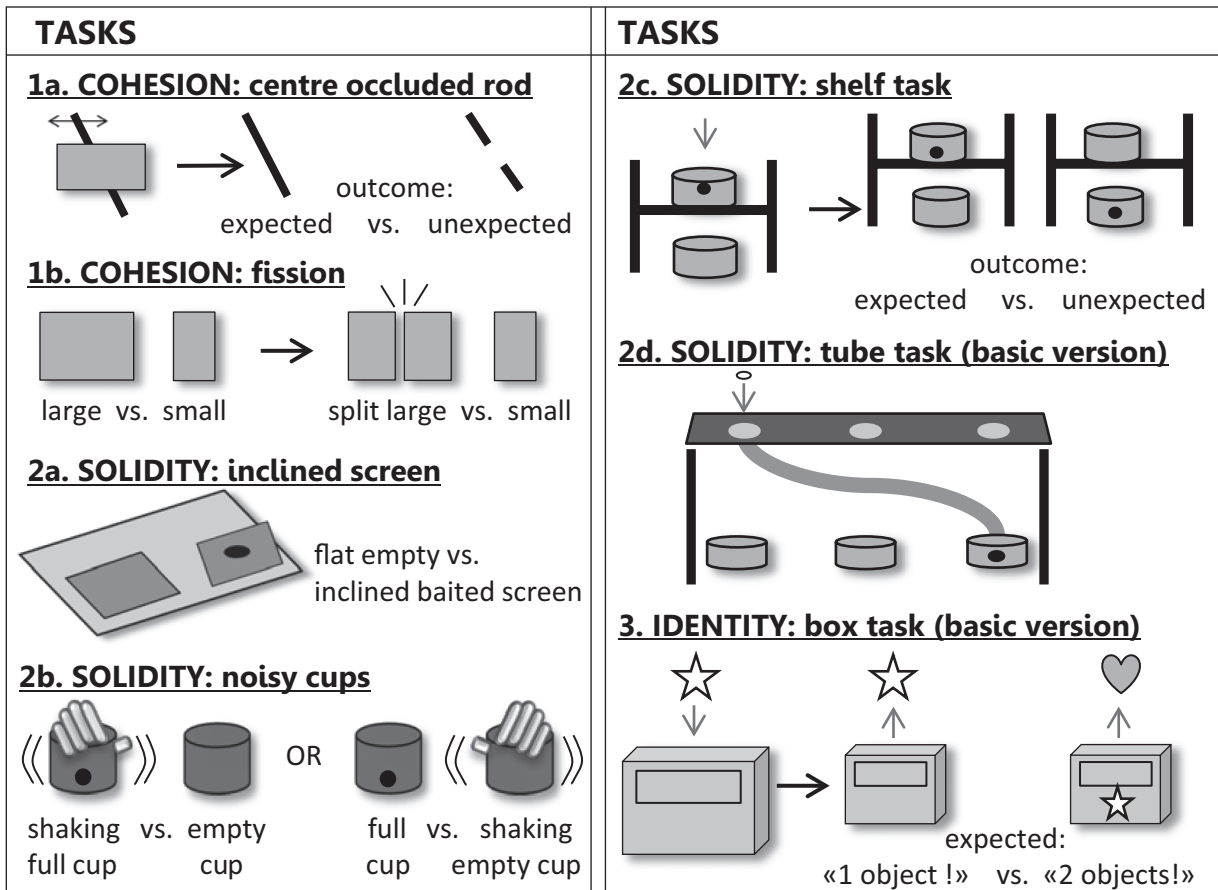


FIGURE 26.2. Illustrations of the tasks most commonly used to test (1) cohesion, (2) solidity and (3) identity. White figures indicate the initial (and intermediate) position of the objects, whereas black figures indicate their final position. Small gray arrows indicate that the object is visibly displaced, while black thicker arrows indicate that a manipulation occurs before subjects see the outcome.

of sortal (kind-based) object individuation. Studies with chicks had a slightly different methodological approach (Fontanari, Rugani, Regolin, & Vallortigara, 2011, 2014). An object of type A disappeared behind screen 1, then a qualitatively identical object of type A reappeared and disappeared again behind screen 1 (licensing the inferences that there is at least one object behind screen 1). In the same way, an object of type A first disappeared behind screen 2. Then, however, an object of type B appeared from behind the screen and disappeared again behind the screen (licensing the inference that there are at least two objects behind screen 2). Given that chicks have a known tendency to approach the bigger set of objects in such contexts, the dependent measure was differential approaching behavior toward the two screens.

The findings of these studies yield a largely consistent picture: They show that the same kinds of competencies (in the form of differential searching/approach behavior in A/A conditions compared to A/B conditions) that had been found to develop in human infants from around 1 year and to be correlated with language are well present in nonhuman animals in the absence of language (see Volume 1, Chapter 20, this handbook and Chapter 17, this volume).

A fundamental question, however, for animal and infant studies, is whether the tasks developed to tap sortal object individuation truly require subjects to apply sortal object concepts, or whether there might be ways to solve the tasks with simpler cognitive processes such as discriminating and tracking object features. The underlying problem is that in normal circumstances, object types and object features are

necessarily confounded—balls are different in type from ducks and banana slices are different from carrot slices, but they also differ in terms of superficial perceptible features (see Chapter 5, this volume). Perhaps, thus, subjects were not individuating objects in terms of their types, and thus searching for a missing object of a certain type (“there still must be this this banana slice around here”). Rather, they might have relied on simpler feature-based individuation, searching for some missing features (“there must still be some yellowness around here”). The only way to stringently address this concern is to systematically deconfound *deep properties* of an object (that define its kind and thus cannot be changed without altering the nature of the object), and merely superficial features (that can be transformed without changing the object as such). Such contrasts have long been used in verbal studies with older children and adults to probe their intuitions of psychological essentialism (e.g., Keil, 1989). In some classical vignettes, an animal was superficially transformed to look like another one (e.g., a squirrel was shaved and painted like a raccoon), and subjects were asked to judge what kind of animal it would turn out to be. Adults and older children in such studies based their explicit identity judgments exclusively on the original kind of the animal and disregarded superficial property transformations. Recent infant and comparative research therefore has tried to combine such transformation scenarios from experiments on psychological essentialism with established object individuation methods. Although this work has just begun, it has produced first evidence that, in infants and nonhuman primates, early object individuation builds on representations of objects’ kinds and not just on tracking superficial properties (Cacchione, Hrubesch, Call, & Rakoczy, 2016; Cacchione, Schaub, & Rakoczy, 2013; Phillips & Santos, 2007).

CONCLUSION

In this chapter, we focused on the roots of object thought in comparative psychology, that is, on the way different species think about objects that exist independently from them and persist over time. The most basic form of such object cognition is object permanence, or the capacity to keep track of the

histories of solid and cohesive bodies moving continuously in space and time. This capacity is widespread in the animal kingdom and thus seems to have deep evolutionary roots. Object permanence in its simplest form (searching for objects not currently perceived) has been found in numerous mammal and bird species. Even more complex forms of thinking about objects (e.g., rudimentary logical and hypothetical reasoning and kind-based object individuation) are not confined to humans. In contrast to long-standing assumptions, therefore, more complex forms of reasoning about kinds and objects seem to be evolutionarily older than and independent from language. Similar capacities as those emerging in human ontogeny around age one have recently been documented in nonhuman primates, other mammals (dogs), and some birds (chicks). Some of the most exciting open questions in this field currently are how far the cognitive commonalities go between humans and other species, and whether sortal object individuation may constitute the evolutionary roots of psychological essentialism (Rakoczy & Cacchione, 2014).

Piaget set the stage for investigating the roots of the fundamentals of our worldviews in developmental metaphysics, and by this, indirectly prepared the field for comparative metaphysics. Although many of the kinds of questions he asked were and still are at the center of this kind of inquiry, novel methodological and theoretical approaches have led to findings that deviate fundamentally from his assumptions. In particular, when measured with alternative methods, cognitive competence has been shown to be present much earlier, and to be more domain-specific than assumed by Piaget. However, what is potentially interesting for research on comparative metaphysics, and for comparative psychology more generally, is a partial revival of the central Piagetian emphasis on domain-general cognitive integration in recent developmental theories (e.g., Carey, 2009; Gopnik & Schulz, 2004; Karmiloff-Smith, 1992; Spelke, 2003). Though differing widely in specific theoretical leanings and commitments, these recent accounts stress that crucial steps in cognitive development beyond human infancy consist in the integration of information across initially separated domains.

The main reason such theories are interesting for comparative research is that they might allow us to

describe cognitive commonalities and differences between humans and other species. More precisely, recent findings show more and more commonalities in domain-specific capacities, for example, concerning numerical, spatial, or social cognition (e.g., Carey, 2009; see also Volume 1, Chapter 20, this handbook). Key differences between humans and other species might then be found not in any given domain per se, but in the integration across domains. In the particular case of object cognition, that was our focus here: Although capacities for tracking and individuating objects might be largely comparable in humans and other species, what is special about human object cognition might be the way such capacities are integrated widely with other cognitive faculties and domain-general reasoning. For example, when tracking and searching for objects, human children make use of general logical reasoning capacities, e.g., reasoning from negated disjuncts (p or q; not q, therefore p). When they see an object being hidden in one of three locations A, B or C, without knowing in which, they start searching at one location, say C, then move on to location B and finally to location A (Watson et al., 2001). Crucially, with each step the latencies decrease—indicating that the degree of certainty increases, which in turn suggests that subjects reason from negated disjuncts (“It must be in A, B, or C. It is not in C, therefore it must be in A or B. It is not in B, therefore, it must be in A”). In a comparative study with the same methodology, dogs also searched sequentially, but did not show the pattern of decreasing latencies—a finding compatible with the possibility that dogs might have engaged in less complex forms of reasoning (Watson et al., 2001).

Whether such integration of domain-specific object tracking and domain-general reasoning capacities is in fact something peculiar about humans, or if not, how far it extends into the primate lineage or beyond, is one of the most exciting questions for future research in this area.

References

- Albiach-Serrano, A., Bräuer, J., Cacchione, T., Zickert, N., & Amici, F. (2012). The effect of domestication and ontogeny in swine cognition (*Sus scrofa scrofa* and *S. s. domestica*). *Applied Animal Behaviour Science*, *141*, 25–35. <http://dx.doi.org/10.1016/j.applanim.2012.07.005>
- Amici, F., Aureli, F., & Call, J. (2008). Fission-fusion dynamics, behavioral flexibility, and inhibitory control in primates. *Current Biology*, *18*, 1415–1419. <http://dx.doi.org/10.1016/j.cub.2008.08.020>
- Amici, F., Aureli, F., & Call, J. (2010). Monkeys and apes: Are their cognitive skills really so different? *American Journal of Physical Anthropology*, *143*, 188–197. <http://dx.doi.org/10.1002/ajpa.21305>
- Ashton, R. L., & De Lillo, C. (2011). Association, inhibition, and object permanence in dogs' (*Canis familiaris*) spatial search. *Journal of Comparative Psychology*, *125*, 194–206. <http://dx.doi.org/10.1037/a0022584>
- Auersperg, A. M. I., Szabo, B., von Bayern, A. M. P., & Bugnyar, T. (2014). Object permanence in the Goffin cockatoo (*Cacatua goffini*). *Journal of Comparative Psychology*, *128*, 88–98. <http://dx.doi.org/10.1037/a0033272>
- Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child Development*, *62*, 1227–1246. <http://dx.doi.org/10.2307/1130803>
- Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition*, *20*, 191–208. [http://dx.doi.org/10.1016/0010-0277\(85\)90008-3](http://dx.doi.org/10.1016/0010-0277(85)90008-3)
- Barth, J., & Call, J. (2006). Tracking the displacement of objects: A series of tasks with great apes (*Pan troglodytes*, *Pan paniscus*, *Gorilla gorilla*, and *Pongo pygmaeus*) and young children (*Homo sapiens*). *Journal of Experimental Psychology: Animal Behavior Processes*, *32*, 239–252. <http://dx.doi.org/10.1037/0097-7403.32.3.239>
- Beran, M. J., Beran, M. M., & Menzel, C. R. (2005). Spatial memory and monitoring of hidden items through spatial displacements by chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology*, *119*, 14–22. <http://dx.doi.org/10.1037/0735-7036.119.1.14>
- Bräuer, J., & Call, J. (2011). The magic cup: Great apes and domestic dogs (*Canis familiaris*) individuate objects according to their properties. *Journal of Comparative Psychology*, *125*, 353–361. <http://dx.doi.org/10.1037/a0023009>
- Bugnyar, T., Stöwe, M., & Heinrich, B. (2007). The ontogeny of caching in ravens, *Corvus corax*. *Animal Behaviour*, *74*, 757–767. <http://dx.doi.org/10.1016/j.anbehav.2006.08.019>
- Cacchione, T. (2013). The foundations of object permanence: Does perceived cohesion determine infants' appreciation of the continuous existence of material objects? *Cognition*, *128*, 397–406. <http://dx.doi.org/10.1016/j.cognition.2013.05.006>
- Cacchione, T., & Call, J. (2010). Do gorillas (*Gorilla gorilla*) and orangutans (*Pongo pygmaeus*) fail

- to represent objects in the context of cohesion violations? *Cognition*, 116, 193–203. <http://dx.doi.org/10.1016/j.cognition.2010.05.002>
- Cacchione, T., Call, J., & Zingg, R. (2009). Gravity and solidity in four great ape species (*Gorilla gorilla*, *Pongo pygmaeus*, *Pan troglodytes*, *Pan paniscus*): Vertical and horizontal variations of the table task. *Journal of Comparative Psychology*, 123, 168–180. <http://dx.doi.org/10.1037/a0013580>
- Cacchione, T., Hrubesch, C., & Call, J. (2013). Chimpanzees (*Pan troglodytes*) and bonobos (*Pan paniscus*) quantify split solid objects. *Animal Cognition*, 16, 1–10. <http://dx.doi.org/10.1007/s10071-012-0545-3>
- Cacchione, T., Hrubesch, C., Call, J., & Rakoczy, H. (2016). Are apes essentialists? Scope and limits of psychological essentialism in great apes. *Animal Cognition*. Advance online publication. <http://dx.doi.org/10.1007/s10071-016-0991-4>
- Cacchione, T., Schaub, S., & Rakoczy, H. (2013). Fourteen-month-old infants infer the continuous identity of objects on the basis of nonvisible causal properties. *Developmental Psychology*, 49, 1325–1329. <http://dx.doi.org/10.1037/a0029746>
- Call, J. (2001). Object permanence in orangutans (*Pongo pygmaeus*), chimpanzees (*Pan troglodytes*), and children (*Homo sapiens*). *Journal of Comparative Psychology*, 115, 159–171. <http://dx.doi.org/10.1037/0735-7036.115.2.159>
- Call, J. (2004). Inferences about the location of food in the great apes (*Pan paniscus*, *Pan troglodytes*, *Gorilla gorilla*, and *Pongo pygmaeus*). *Journal of Comparative Psychology*, 118, 232–241. <http://dx.doi.org/10.1037/0735-7036.118.2.232>
- Call, J. (2007). Apes know that hidden objects can affect the orientation of other objects. *Cognition*, 105, 1–25. <http://dx.doi.org/10.1016/j.cognition.2006.08.004>
- Carey, S. (2009). *The origin of concepts*. <http://dx.doi.org/10.1093/acprof:oso/9780195367638.001.0001>
- Cheries, E. W., Mitroff, S. R., Wynn, K., & Scholl, B. J. (2008). Cohesion as a constraint on object persistence in infancy. *Developmental Science*, 11, 427–432. <http://dx.doi.org/10.1111/j.1467-7687.2008.00687.x>
- Chiandetti, C., & Vallortigara, G. (2011). Intuitive physical reasoning about occluded objects by inexperienced chicks. *Proceedings of the Royal Society B. Biological Sciences*, 278, 2621–2627. <http://dx.doi.org/10.1098/rspb.2010.2381>
- Collier-Baker, E., Davis, J. M., Nielsen, M., & Suddendorf, T. (2006). Do chimpanzees (*Pan troglodytes*) understand single invisible displacement? *Animal Cognition*, 9, 55–61. <http://dx.doi.org/10.1007/s10071-005-0004-5>
- Collier-Baker, E., Davis, J. M., & Suddendorf, T. (2004). Do dogs (*Canis familiaris*) understand invisible displacement? *Journal of Comparative Psychology*, 118, 421–433. <http://dx.doi.org/10.1037/0735-7036.118.4.421>
- de Blois, S. T., & Novak, M. A. (1994). Object permanence in rhesus monkeys (*Macaca mulatta*). *Journal of Comparative Psychology*, 108, 318–327. <http://dx.doi.org/10.1037/0735-7036.108.4.318>
- de Blois, S. T., Novak, M. A., & Bond, M. (1998). Object permanence in orangutans (*Pongo pygmaeus*) and squirrel monkeys (*Saimiri sciureus*). *Journal of Comparative Psychology*, 112, 137–152. <http://dx.doi.org/10.1037/0735-7036.112.2.137>
- Deppe, A. M., Wright, P. C., & Szelistowski, W. A. (2009). Object permanence in lemurs. *Animal Cognition*, 12, 381–388. <http://dx.doi.org/10.1007/s10071-008-0197-5>
- Diamond, A. (1990). The development and neural bases of memory functions as indexed by the A-not-B and delayed response tasks in human infants and infant monkeys. In A. Diamond (Ed.), *The development and neural bases of higher cognitive functions* (pp. 267–317). <http://dx.doi.org/10.1111/j.1749-6632.1990.tb48900.x>
- Doré, F. Y., Fiset, S., Goulet, S., Dumas, M. C., & Gagnon, S. (1996). Search behavior in cats and dogs: Interspecific differences in working memory and spatial cognition. *Animal Learning and Behavior*, 24, 142–149. <http://dx.doi.org/10.3758/BF03198962>
- Dumas, C., & Doré, F. Y. (1989). Cognitive development in kittens (*Felis catus*): A cross-sectional study of object permanence. *Journal of Comparative Psychology*, 103, 191–200. <http://dx.doi.org/10.1037/0735-7036.103.2.191>
- Fedor, A., Skollár, G., Szerencsy, N., & Ujhelyi, M. (2008). Object permanence tests on gibbons (*Hylobatidae*). *Journal of Comparative Psychology*, 122, 403–417. <http://dx.doi.org/10.1037/0735-7036.122.4.403>
- Fiset, S., Beaulieu, C., & Landry, F. (2003). Duration of dogs' (*Canis familiaris*) working memory in search for disappearing objects. *Animal Cognition*, 6, 1–10. <http://dx.doi.org/10.1007/s10071-002-0157-4>
- Fiset, S., & Doré, F. Y. (2006). Duration of cats' (*Felis catus*) working memory for disappearing objects. *Animal Cognition*, 9, 62–70. <http://dx.doi.org/10.1007/s10071-005-0005-4>
- Fiset, S., & Plourde, V. (2013). Object permanence in domestic dogs (*Canis lupus familiaris*) and gray wolves (*Canis lupus*). *Journal of Comparative Psychology*, 127, 115–127. <http://dx.doi.org/10.1037/a0030595>
- Fontanari, L., Rugani, R., Regolin, L., & Vallortigara, G. (2011). Object individuation in 3-day-old chicks: Use of property and spatiotemporal information. *Developmental Science*, 14, 1235–1244. <http://dx.doi.org/10.1111/j.1467-7687.2011.01074.x>

- Fontanari, L., Rugani, R., Regolin, L., & Vallortigara, G. (2014). Use of kind information for object individuation in young domestic chicks. *Animal Cognition*, *17*, 925–935. <http://dx.doi.org/10.1007/s10071-013-0725-9>
- Fujita, K. (2001). Perceptual completion in rhesus monkeys (*Macaca mulatta*) and pigeons (*Columbia livia*). *Perception and Psychophysics*, *63*, 115–125. <http://dx.doi.org/10.3758/BF03200507>
- Fujita, K., & Giersch, A. (2005). What perceptual rules do capuchin monkeys (*Cebus apella*) follow in completing partly occluded figures? *Journal of Experimental Psychology: Animal Behavior Processes*, *31*, 387–398. <http://dx.doi.org/10.1037/0097-7403.31.4.387>
- Funk, M. S. (1996). Development of object permanence in the New Zealand parakeet (*Cyanoramphus auriceps*). *Animal Learning and Behavior*, *24*, 375–383. <http://dx.doi.org/10.3758/BF03199009>
- Gagnon, S., & Doré, F. Y. (1992). Search behavior in various breeds of adult dogs (*Canis familiaris*): Object permanence and olfactory cues. *Journal of Comparative Psychology*, *106*, 58–68. <http://dx.doi.org/10.1037/0735-7036.106.1.58>
- Gagnon, S., & Doré, F. Y. (1993). Search behavior of dogs (*Canis familiaris*) in invisible displacement problems. *Animal Learning and Behavior*, *21*, 246–254. <http://dx.doi.org/10.3758/BF03197989>
- Gagnon, S., & Doré, F. Y. (1994). Cross-sectional study of object permanence in domestic puppies (*Canis familiaris*). *Journal of Comparative Psychology*, *108*, 220–232. <http://dx.doi.org/10.1037/0735-7036.108.3.220>
- Gómez, J. C. (2005). Species comparative studies and cognitive development. *Trends in Cognitive Sciences*, *9*, 118–125. <http://dx.doi.org/10.1016/j.tics.2005.01.004>
- Gopnik, A., & Schulz, L. (2004). Mechanisms of theory formation in young children. *Trends in Cognitive Sciences*, *8*, 371–377. <http://dx.doi.org/10.1016/j.tics.2004.06.005>
- Goulet, S., Doré, F. Y., & Rousseau, R. (1994). Object permanence and working memory in cats (*Felis catus*). *Journal of Experimental Psychology: Animal Behavior Processes*, *20*, 347–365. <http://dx.doi.org/10.1037/0097-7403.20.4.347>
- Hanus, D., & Call, J. (2008). Chimpanzees infer the location of a reward based on the effect of its weight. *Current Biology*, *18*, 370–372. <http://dx.doi.org/10.1016/j.cub.2008.02.039>
- Hauser, M. D. (2001). Searching for food in the wild: A nonhuman primate's expectations about invisible displacement. *Developmental Science*, *4*, 84–93. <http://dx.doi.org/10.1111/1467-7687.00152>
- Hauser, M. D. (2003). Knowing about knowing: Dissociations between perception and action systems over evolution and during development. *Annals of the New York Academy of Sciences*, *1001*, 79–103. <http://dx.doi.org/10.1196/annals.1279.006>
- Hoffmann, A., Rüttler, V., & Nieder, A. (2011). Ontogeny of object permanence and object tracking in the carrion crow (*Corvus corone*). *Animal Behaviour*, *82*, 359–367. <http://dx.doi.org/10.1016/j.anbehav.2011.05.012>
- Hood, B., Carey, S., & Prasada, S. (2000). Predicting the outcomes of physical events: Two-year-olds fail to reveal knowledge of solidity and support. *Child Development*, *71*, 1540–1554. <http://dx.doi.org/10.1111/1467-8624.00247>
- Hribar, A., & Call, J. (2011). Great apes use landmark cues over spatial relations to find hidden food. *Animal Cognition*, *14*, 623–635. <http://dx.doi.org/10.1007/s10071-011-0397-2>
- Hughes, K. D., & Santos, L. R. (2012). Rotational displacement skills in rhesus macaques (*Macaca mulatta*). *Journal of Comparative Psychology*, *126*, 421–432. <http://dx.doi.org/10.1037/a0028757>
- Huntley-Fenner, G., Carey, S., & Solimando, A. (2002). Objects are individuals but stuff doesn't count: Perceived rigidity and cohesiveness influence infants' representations of small groups of discrete entities. *Cognition*, *85*, 203–221. [http://dx.doi.org/10.1016/S0010-0277\(02\)00088-4](http://dx.doi.org/10.1016/S0010-0277(02)00088-4)
- Jaakkola, K. (2014). Do animals understand invisible displacement? A critical review. *Journal of Comparative Psychology*, *128*, 225–239. <http://dx.doi.org/10.1037/a0035675>
- Jaakkola, K., Guarino, E., Rodriguez, M., Erb, L., & Trone, M. (2010). What do dolphins (*Tursiops truncatus*) understand about hidden objects? *Animal Cognition*, *13*, 103–120. <http://dx.doi.org/10.1007/s10071-009-0250-z>
- Johnson, S. P. (2004). Development of perceptual completion in infancy. *Psychological Science*, *15*, 769–775. <http://dx.doi.org/10.1111/j.0956-7976.2004.00754.x>
- Kant, I. (1997). *Critique of pure reason*. Cambridge, England: Cambridge University Press. (Original work published 1781)
- Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.
- Keil, F. (1989). *Concepts, kinds and cognitive development*. Cambridge, MA: MIT Press.
- Kellman, P. J., Spelke, E. S., & Short, K. R. (1986). Infant perception of object unity from translatory motion in depth and vertical translation. *Child Development*, *57*, 72–86. <http://dx.doi.org/10.2307/1130639>
- Kundey, S. M., De Los Reyes, A., Taglang, C., Baruch, A., & German, R. (2010). Domesticated dogs' (*Canis*

- familiaris*) use of the solidity principle. *Animal Cognition*, 13, 497–505. <http://dx.doi.org/10.1007/s10071-009-0300-6>
- Lourenço, O., & Machado, A. (1996). In defense of Piaget's theory: A reply to 10 common criticisms. *Psychological Review*, 103, 143–164. <http://dx.doi.org/10.1037/0033-295X.103.1.143>
- Luo, Y., & Baillargeon, R. (2005). Can a self-propelled box have a goal? Psychological reasoning in 5-month-old infants. *Psychological Science*, 16, 601–608. <http://dx.doi.org/10.1111/j.1467-9280.2005.01582.x>
- Mallavarapu, S., Perdue, B. M., Stoinski, T. S., & Maple, T. L. (2013). Can black-and-white ruffed lemurs (*Varecia variegata*) solve object permanence tasks? *American Journal of Primatology*, 75, 376–386. <http://dx.doi.org/10.1002/ajp.22118>
- Marcovitch, S., & Zelazo, P. D. (1999). The A-not-B error: Results from a logistic meta-analysis. *Child Development*, 70, 1297–1313. <http://dx.doi.org/10.1111/1467-8624.00095>
- Marcovitch, S., Zelazo, P. D., & Schmuckler, M. A. (2002). The effect of number of A trials on performance on the A-not-B task. *Infancy*, 3, 519–529. http://dx.doi.org/10.1207/S15327078IN0304_06
- Mendes, N., & Huber, L. (2004). Object permanence in common marmosets (*Callithrix jacchus*). *Journal of Comparative Psychology*, 118, 103–112. <http://dx.doi.org/10.1037/0735-7036.118.1.103>
- Mendes, N., Rakoczy, H., & Call, J. (2008). Ape metaphysics: Object individuation without language. *Cognition*, 106, 730–749. <http://dx.doi.org/10.1016/j.cognition.2007.04.007>
- Mendes, N., Rakoczy, H., & Call, J. (2011). Primates do not spontaneously use shape properties for object individuation: A competence or a performance problem? *Animal Cognition*, 14, 407–414. <http://dx.doi.org/10.1007/s10071-010-0375-0>
- Miller, H. C., Gipson, C. D., Vaughan, A., Rayburn-Reeves, R., & Zentall, T. R. (2009). Object permanence in dogs: Invisible displacement in a rotation task. *Psychonomic Bulletin and Review*, 16, 150–155. <http://dx.doi.org/10.3758/PBR.16.1.150>
- Miller, H. C., Rayburn-Reeves, R., & Zentall, T. R. (2009). What do dogs know about hidden objects? *Behavioural Processes*, 81, 439–446. <http://dx.doi.org/10.1016/j.beproc.2009.03.018>
- Müller, C. A., Riemer, S., Range, F., & Huber, L. (2014a). Dogs' use of the solidity principle: Revisited. *Animal Cognition*, 17, 821–825. <http://dx.doi.org/10.1007/s10071-013-0709-9>
- Müller, C. A., Riemer, S., Range, F., & Huber, L. (2014b). The use of a displacement device negatively affects the performance of dogs (*Canis familiaris*) in visible object displacement tasks. *Journal of Comparative Psychology*, 128, 240–250. <http://dx.doi.org/10.1037/a0036032>
- Munakata, Y., McClelland, J. L., Johnson, M. H., & Siegler, R. S. (1997). Rethinking infant knowledge: Toward an adaptive process account of successes and failures in object permanence tasks. *Psychological Review*, 104, 686–713. <http://dx.doi.org/10.1037/0033-295X.104.4.686>
- Neiwirth, J. J., Steinmark, E., Basile, B. M., Wonders, R., Steely, F., & DeHart, C. (2003). A test of object permanence in a new-world monkey species, cotton top tamarins (*Saguinus oedipus*). *Animal Cognition*, 6, 27–37. <http://dx.doi.org/10.1007/s10071-003-0162-2>
- Nekovarova, T., Nedvidek, J., Klement, D., Rokyta, R., & Bures, J. (2013). Mental transformations of spatial stimuli in humans and in monkeys: Rotation vs. translocation. *Behavioral Brain Research*, 240, 182–191.
- Okamoto-Barth, S., & Call, J. (2008). Tracking and inferring spatial rotation by children and great apes. *Developmental Psychology*, 44, 1396–1408. <http://dx.doi.org/10.1037/a0012594>
- Osthaus, B., Slater, A. M., & Lea, S. E. G. (2003). Can dogs defy gravity? A comparison with the human infant and a non-human primate. *Developmental Science*, 6, 489–497. <http://dx.doi.org/10.1111/1467-7687.00306>
- Pattison, K. F., Miller, H. C., Rayburn-Reeves, R., & Zentall, T. (2010). The case of the disappearing bone: Dogs' understanding of the physical properties of objects. *Behavioural Processes*, 85, 278–282. <http://dx.doi.org/10.1016/j.beproc.2010.06.016>
- Pepperberg, I. M., & Funk, M. S. (1990). Object permanence in four species of psittacine birds: An African Grey parrot (*Psittacus erithacus*), an Illiger mini macaw (*Ara maracana*), a parakeet (*Melopsittacus undulatus*) and a cockatiel (*Nymphicus hollandicus*). *Animal Learning and Behavior*, 18, 97–108. <http://dx.doi.org/10.3758/BF03205244>
- Pepperberg, I. M., Willner, M. R., & Gravit, L. B. (1997). Development of Piagetian object permanence in a grey parrot (*Psittacus erithacus*). *Journal of Comparative Psychology*, 111, 63–75. <http://dx.doi.org/10.1037/0735-7036.111.1.63>
- Perner, J. (1991). *Understanding the representational mind*. Cambridge, MA: MIT Press.
- Phillips, W., & Santos, L. R. (2007). Evidence for kind representations in the absence of language: Experiments with rhesus monkeys (*Macaca mulatta*). *Cognition*, 102, 455–463. <http://dx.doi.org/10.1016/j.cognition.2006.01.009>
- Piaget, J. (1952). *The origins of intelligence*. <http://dx.doi.org/10.1037/11494-000>
- Piaget, J. (1954). *The construction of reality in the child*. <http://dx.doi.org/10.1037/11168-000>

- Pinker, S. (1997). *How the mind works*. New York, NY: Norton.
- Pollok, B., Prior, H., & Güntürkün, O. (2000). Development of object permanence in food-storing magpies (*Pica pica*). *Journal of Comparative Psychology*, *114*, 148–157. <http://dx.doi.org/10.1037/0735-7036.114.2.148>
- Quine, W. V. O. (1957). Speaking of objects. *Proceedings and Addresses of the American Philosophical Association*, *31*, 5–22. <http://dx.doi.org/10.2307/3129242>
- Rakoczy, H. (2014). Comparative metaphysics: The development of representing natural and normative regularities in humans and non-human primates. *Phenomenology and the Cognitive Sciences*. Advance online publication.
- Rakoczy, H., & Cacchione, T. (2014). The developmental and evolutionary origins of psychological essentialism lie in sortal object individuation. *Behavioral and Brain Sciences*, *37*, 500–501. <http://dx.doi.org/10.1017/S0140525X13003865>
- Rooijakkers, E. F., Kaminski, J., & Call, J. (2009). Comparing dogs and great apes in their ability to visually track object transpositions. *Animal Cognition*, *12*, 789–796. <http://dx.doi.org/10.1007/s10071-009-0238-8>
- Santos, L. R., & Hauser, M. D. (2002). A non-human primate's understanding of solidity: Dissociations between seeing and acting. *Developmental Science*, *5*, 1–7. <http://dx.doi.org/10.1111/1467-7687.t01-1-00216>
- Santos, L. R., Sulkowski, G. M., Spaepen, G. M., & Hauser, M. D. (2002). Object individuation using property/kind information in rhesus macaques (*Macaca mulatta*). *Cognition*, *83*, 241–264. [http://dx.doi.org/10.1016/S0010-0277\(02\)00006-9](http://dx.doi.org/10.1016/S0010-0277(02)00006-9)
- Sato, A., Kanazawa, S., & Fujita, K. (1997). Perception of object unity in a chimpanzee (*Pan troglodytes*). *Japanese Psychological Research*, *39*, 191–199. <http://dx.doi.org/10.1111/1468-5884.00053>
- Schloegl, C., Waldmann, M. R., & Fischer, J. (2013). Understanding of and reasoning about object-object relationships in long-tailed macaques? *Animal Cognition*, *16*, 493–507. <http://dx.doi.org/10.1007/s10071-012-0591-x>
- Schrauf, C., & Call, J. (2011). Great apes use weight as a cue to find hidden food. *American Journal of Primatology*, *73*, 323–334. <http://dx.doi.org/10.1002/ajp.20899>
- Spelke, E. (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 thought* (pp. 277–311). Cambridge, MA: MIT Press.
- Spelke, E. S. (1990). Principles of object perception. *Cognitive Science*, *14*, 29–56. http://dx.doi.org/10.1207/s15516709cog1401_3
- Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*, 605–632. <http://dx.doi.org/10.1037/0033-295X.99.4.605>
- Suddendorf, T., & Whiten, A. (2001). Mental evolution and development: Evidence for secondary representation in children, great apes, and other animals. *Psychological Bulletin*, *127*, 629–650.
- Sümeği, Z., Kis, A., Miklósi, Á., & Topál, J. (2014). Why do adult dogs (*Canis familiaris*) commit the A-not-B search error? *Journal of Comparative Psychology*, *128*, 21–30. <http://dx.doi.org/10.1037/a0033084>
- Thelen, E., Schöner, G., Scheier, C., & Smith, L. B. (2001). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences*, *24*, 1–34. <http://dx.doi.org/10.1017/S0140525X01003910>
- Topál, J., Gergely, G., Erdohegyi, A., Csibra, G., & Miklósi, A. (2009). Differential sensitivity to human communication in dogs, wolves, and human infants. *Science*, *325*, 1269–1272. <http://dx.doi.org/10.1126/science.1176960>
- Triana, E., & Pasnak, R. (1981). Object permanence in cats and dogs. *Animal Learning and Behavior*, *9*, 135–139. <http://dx.doi.org/10.3758/BF03212035>
- Ujfalussy, D. J., Miklósi, Á., & Bugnyar, T. (2013). Ontogeny of object permanence in a non-storing corvid species, the jackdaw (*Corvus monedula*). *Animal Cognition*, *16*, 405–416. <http://dx.doi.org/10.1007/s10071-012-0581-z>
- Uzgiris, I. C., & Hunt, J. M. (1975). *Assessment in infancy: Ordinal scales of psychological development*. Champaign–Urbana: University of Illinois Press.
- Watson, J. S., Gergely, G., Csanyi, V., Topal, J., Gacsi, M., & Sarkozi, Z. (2001). Distinguishing logic from association in the solution of an invisible displacement task by children (*Homo sapiens*) and dogs (*Canis familiaris*): Using negation of disjunction. *Journal of Comparative Psychology*, *115*, 219–226. <http://dx.doi.org/10.1037/0735-7036.115.3.219>
- Xu, F. (2007). Sortal concepts, object individuation, and language. *Trends in Cognitive Sciences*, *11*, 400–406. <http://dx.doi.org/10.1016/j.tics.2007.08.002>
- Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology*, *30*, 111–153. <http://dx.doi.org/10.1006/cogp.1996.0005>
- Zosh, J. M., & Feigenson, L. (2009). Beyond “what” and “how many”: Capacity, complexity, and resolution of infants' object representations. In L. Santos & B. Hood (Eds.), *The origins of object knowledge* (pp. 25–52). <http://dx.doi.org/10.1093/acprof:oso/9780199216895.003.0002>
- Zucca, P., Milos, N., & Vallortigara, G. (2007). Piagetian object permanence and its development in Eurasian jays (*Garrulus glandarius*). *Animal Cognition*, *10*, 243–258. <http://dx.doi.org/10.1007/s10071-006-0063-2>