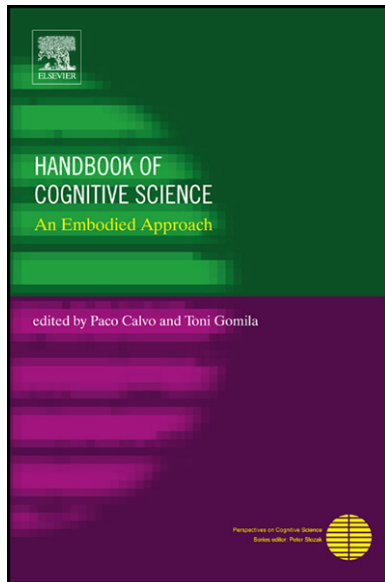


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SECTION

VI

SCALING UP

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HOW DID WE GET FROM THERE TO HERE? AN EVOLUTIONARY PERSPECTIVE ON EMBODIED COGNITION

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INTRODUCTION

Human cognition really is “something new under the sun.” Although research in animal cognition is rapidly piling up evidence that animals have abilities that were previously thought to be impossible, nevertheless there is no serious challenge to the apparent fact that human cognition is unique. The human capacities for language, long-term plans, manipulation of abstract concepts, and accretion of knowledge and skills across generations simply have no competitors in other animals. Yet to understand how human cognition works, investigators increasingly recognize, we must tell an evolutionarily plausible story about how we got from there to here. The embodied cognition perspective is fundamentally an evolutionary one, viewing cognition as a set of abilities that built upon, and still reflects, the structure of our physical bodies and how our brains evolved to manage those bodies. But the embodied cognition literature has sometimes taken a very strong stance that cognition is fundamentally and directly bound to the body in its immediate physical environment. Instead, I argue here, the value of the embodied cognition approach is not to deny the existence of abstract and de-contextualized thought, but to explain how it grew out of previously existing sensorimotor abilities.

This chapter will consider a cluster of possibly linked capacities that may have driven human embodied cognition, including the ability to exert flexible voluntary control over particular effectors, the ability to see analogies, and the ability to imitate. The story to be told is one of escape from situation-bound cognition to a more flexible, abstract, and “general purpose” form of cognition.

ANIMAL COGNITION: WHERE WE STARTED FROM

Humans and their ancestors, the hominids, are one branch of the great apes, having diverged from the ancestors of gorillas about 8 million years ago, and the ancestors of chimpanzees and bonobos about 6 million years ago. Humans evolved in the Great Rift Valley of eastern Africa, in a drier, more open environment than that of gorillas, chimpanzees and bonobos, with different ecological demands. Humans are the sole survivors of the hominid branch, but this branch was originally much “bushier,” with multiple species of genus *Australopithecus*, and later genus *Homo*.

The australopiths, although still possessing relatively small brains, developed the skeletal structure to walk upright and the ability to manufacture and use stone tools. The larger-brained genus *Homo* improved upon these abilities, creating tools according to a preconceived plan (rather than randomly chipping to create a sharp edge), and migrating from Africa to populate much of Europe and southern Asia (becoming, among others, the Neanderthals in Europe). Finally, a mere 200,000 years ago, *Homo sapiens* emerged from those hominids that had remained behind in Africa. They began to invent a much wider variety of tools, and to create decorative items. A small group left Africa to become the ancestors of all non-African modern humans, and out-competed their cousin species in Europe and Asia, leaving humans as the only surviving hominids on the planet. This new species, virtually identical to modern humans, apparently possessed the mental equipment that later made possible the “cultural explosion” of art and artifacts 50,000 years ago, and the discovery of agriculture and animal domestication 9000 years ago, leading to the first large population centers. Evolution has continued since the emergence of *Homo sapiens* 200,000 years ago, but in minor ways such as in skin tone to accommodate different amounts of sunlight, nose shape to accommodate different air temperatures, and the ability to digest different foodstuffs. (For a highly readable overview of hominid evolution for the non-specialist, see Zimmer, 2005.)

Today, we are left trying to reconstruct the cognitive past of the human lineage from a range of indirect sources, including dramatic increases in brain size, structural changes suggesting adaptation for vocal language production and manual manipulation, changes in the time course of infant and juvenile development, artifacts left behind, artifacts moved long distances from their manufacture sites, migration patterns, genetic divergence, and evidence of organized group activity such as hunting. Another important source of evidence, of course, is comparative study of other existing species, which allows us to make educated guesses about the cognitive abilities of our common ancestors, as well as the cognitive abilities demanded by various ecological niches and social structures.

The last few years have seen a flood of studies that are eroding previous dogma on what non-human animals supposedly cannot do, and the game is no longer just to find precursors to human cognition in our own closest relatives the great apes (and by implication, our mutual ancestors). Surprising cognitive abilities are also being uncovered in more distantly related primates such as old-world and new-world monkeys (e.g. Frigaszy & Cummins-Sebree, 2005; Cheney & Seyfarth, 2007), and also in animals much further removed from us on the evolutionary tree, such as birds, marine mammals, dogs, and elephants (e.g. Emery & Clayton, 2004; Kuczaj & Walker, 2006; Miklósi et al., 2007; Hart et al., 2008).

At the present moment, there is much excitement about the emergence of social cognition abilities in particular, and how these might have been the driving force behind the evolution of sophisticated cognition in general (e.g. Hare, 2007). One set of abilities receiving a great deal of attention is the ability to understand what other individuals know, see, and think. Although the details are still in dispute, non-human primates are revealing surprisingly sophisticated abilities to understand eye gaze, to deceive, and to manipulate others based on their state of knowledge (e.g. Byrne & Corp, 2004; Scerif et al., 2004; Leavens et al., 2005; Hare et al., 2006; Melis et al., 2006; Braüer et al., 2007; Hattori et al., 2007; Wood et al., 2007). Similar findings are emerging for more distantly related species as well, such as scrub jays (Dally et al., 2006), and dolphins (Pack & Herman, 2007). These abilities may be interpreted as a rudimentary theory of mind, or as precursors to such a theory.

A second set of social cognition abilities receiving much attention revolves around fairness, reciprocity, morality, and justice. Evidence is increasingly showing that the human sense of fairness and the desire to punish violators (even at a cost to oneself, and even when the victim of the unfairness is someone else) have biological bases (for review see Fehr & Camerer, 2007). Research on non-human animals is investigating whether other species will choose options that benefit another individual, and other related empathic tendencies (Stevens & Hauser, 2004; Nowak & Sigmund, 2005; Silk, 2006; Warneken & Tomasello, 2006; Jensen et al., 2007). It has been argued that these kinds of social abilities and social awareness were a driving force behind modern human brain size, intelligence, and cognition, and made possible such important abilities as explicit teaching, cultural transmission, and complex communication leading to language and symbolic thought (e.g. Tomasello & Rakoczy, 2003; Seyfarth et al., 2005; Csibra, 2007).

But these social abilities do not constitute the whole story. Various animal species reveal additional cognitive abilities that were previously thought not to exist in non-humans, and many of these appear to be precursors or prerequisites for the kinds of cognitive abilities that humans display. Following is a brief menu of topics of current interest among researchers.

Planning and "mental time travel": To what extent are non-human animals able to disconnect their behavior from the present situation, in ways that cannot be reduced to simple learned associations (e.g., delaying a behavior will lead to a future reward) or innate predispositions (e.g., caching food or migrating), and

actually take into account future outcomes in choosing their behavior? A subset of this question is whether animals experience mental simulations of the future that are phenomenologically and neurologically similar to episodic memory of the past, an ability in humans that has been dubbed “mental time travel” (Suddendorf & Corballis, 1997, 2007). Although Suddendorf and Corballis (2007) argue that this latter ability has not been demonstrated in any non-human animal, nevertheless evidence of various non-simplistic planning abilities is beginning to emerge. For example, orangutans and bonobos save and transport tools for future use (Mulcahy & Call, 2008), and scrub jays preferentially cache food for the next morning in a location that they have previously learned will not have food at that time (Raby et al., 2007).

Numerosity and proto-mathematical abilities: Evidence is emerging that non-human primates are sensitive to the abstract concept of number, including both its ordinal (serial order) and its cardinal (quantity) properties (see Nieder, 2005; Cordes et al., 2007, for reviews). With respect to ordinal properties, rhesus macaques are able to correctly order displays of one to four items, but are unable to do so with an arbitrary order (Brannon & Terrace, 2000). These monkeys also generalize the ordering task to sets with greater numbers of items, without reinforcement. And with respect to quantity, macaques match number of seen monkey faces to number of heard monkey voices. That is, when they hear two monkey voices, they preferentially look at a display with two faces rather than a display with three (Jordan et al., 2005). Similarly, capuchin monkeys have shown sensitivity to quantity (Beran, 2008). It has even been shown that rhesus macaques can compute approximate addition of sets of items (Flombaum et al., 2005).

Causal reasoning. Although evidence for inferences about cause-and-effect in non-humans is by and large either absent or negative (see Penn & Povinelli, 2007, for review), two recent results suggest that rats can engage in certain forms of causal reasoning. Rats who learned through observation that a light predicted both a tone and food unsurprisingly came to expect that food should accompany the tone. However, they did not exhibit this expectation when they themselves were allowed to cause the tone by pressing a lever, suggesting that they had developed a causal model of the relations among the events, and not just mere associations (Blaisdell et al., 2006). In a different study, Beckers et al. (2006) showed that whether rats show blocking in classical conditioning (a failure to develop a new conditioned stimulus when it is paired with another previously conditioned stimulus) is sensitive to the rat's knowledge of causal factors.

Imitation. Imitation, which humans do frequently and effortlessly, is a topic of hot debate in the animal literature (for reviews see Byrne, 2005; Zentall, 2006). Some authors have argued that non-human apes do not truly imitate at all, and that behaviors that appear to be imitation can instead be explained as instances of *emulation*, that is, learning about and then reproducing the affordances of objects that another individual has been seen manipulating (e.g. Call et al., 2005). The ape does not appear to be attending to and duplicating the actual actions of the individual. More recently though, it has been reported that chimpanzees learn to pull

a lever to deliver a reward when they see the apparatus used by another chimp, but not when the lever is activated by an invisible fishing line (Whiten, 2007). This appears to eliminate the emulation explanation for the learning. Furthermore, reports from observations of apes in the wild and in naturalistic captive settings support a richer view of imitation than what has been observed in laboratory experiments, although of course these observations are subject to the criticism that they do not involve strict controls (e.g. Russon & Galdikas, 1993; van Schaik et al., 2003; Byrne & Tanner, 2006; Whiten et al., 2007). In addition, vocal imitation of non-species-typical sounds has been reported in elephants (Poole et al., 2005), paralleling the well-known vocal imitation abilities of birds such as parrots; and there is a documented anecdote of a human-reared seal, Hoover, who produced imitations of the voice of the man who raised him. (A recording of Hoover saying "Get over here, come on, come on" can be found at: <http://www.neaq.org/scilearn/kids/hoveronly.html>.)

Tool use: Tool use is well documented in great apes, including the use of sticks to probe termite mounds, rocks to break open nuts, and broad leaves to serve as hats in the rain, as well as more sophisticated awareness of tool properties in human-enculturated chimps (Furlong et al., 2008). Tool use has also been demonstrated in capuchin monkeys for purposes of digging, cracking, and probing (Moura & Lee, 2004; Waga et al., 2006), and a recent study also documents probe-tool manufacture, transport, and use by crows (Kenward et al., 2005).

HUMAN COGNITION: WHERE WE ENDED UP

Given this impressive array of newly discovered animal abilities, with more likely to come, what makes human cognition unique? This is a case that is almost easier to make by mere looking around, rather than appeal to published data. Animals can make tools and can alter their environments through niche construction, but none has produced such a dizzying array of artifacts as even pre-agricultural humans, let alone electronic-age humans. Animals can recognize basic numerical relations, but none has discovered calculus. Animals can plan ahead, but none has conceived of a construction project like the medieval cathedrals that took longer than one person's lifetime to complete. And perhaps most obviously, animals can communicate, but none has developed language. Some of these abilities appear to slightly greater degrees in human-enculturated apes than wild apes (for review see Tomasello & Call, 2004), suggesting untapped cognitive potential, but still none comes even close to approximating participation in the human life of the mind.

Given that many of the precursors to human intelligence are present in other animals—some in virtue of related lineage, others by convergent evolution—one might ask why various unique human abilities have not arisen in other species. It is difficult to see how these kinds of abilities could *not* contribute to adaptive fitness. Why, then, are humans the oddballs? One possible reason is that the "engineering solutions" required to build such a cognitive system may not

be easy for evolution to construct out of previous genetic resources (cf. Wilson, 2002, p. 627). If this is true, then humans are the beneficiaries of a lucky and unlikely evolutionary accident. An alternative explanation, and one that is gaining some empirical support, is that the caloric needs of brain tissue offset the survival advantages of smarter brains. According to this view, hominids broke through the brain-size barrier by learning to extract additional calories from their environment, through the discovery of roots and tubers (“underground storage organs”) as a food source during times when other food sources were unreliable (Laden & Wrangham, 2005; Yeakel et al., 2007), or the discovery of cooking, which releases additional calories (Lucas et al., 2006; Gibbons, 2007).

But however it came about, humans undeniably possess startling cognitive abilities, with no precedent in the previous life of the planet. How did we get from there to here, and, particularly if one takes seriously the embodied view of the cognition of our ancestors, how do we explain human cognition in embodied terms?

EMBODIED COGNITION: CAN IT EXPLAIN WHERE WE ARE NOW?

Underlying most of the embodied cognition literature is an implicit evolutionary argument. Traditional abstract-symbol-processing views of cognition that were typical in the 1950s–1980s are now considered implausible precisely because there is no continuity with the cognitive skills that would have been demanded of the ancestors of the human species. Thus, the embodied cognition approach attempts to provide continuity between cognitively simpler creatures that lived in the moment, and modern humans.

This has led to interesting new perspectives on human cognition, including the study of “situated cognition,” cognition that is about, entwined with, and time locked to unfolding events in the immediate physical environment. However, I have argued previously that human cognition cannot, in principle, be entirely or even largely reduced to situated cognition (Wilson, 2002). This fundamental error, resulting from an over-application of the evolutionary argument, has riddled the field of embodied cognition since its inception: the assumption that, because human cognition is *for* survival in immediate real-world situations, therefore human cognition must be entirely *about* those immediate real-world situations. Instead, an essential feature of human cognition is the ability to decouple from the present environment and represent situations and ideas that are of the past, the future, the physically distant, the imaginary, the generalized, or the abstract.

A productive science of embodied cognition, if it takes seriously the claim that much or all of human cognition has its roots in embodiment, must consider how embodied cognition can go “off-line”—decouple from situation-bound reactivity and use body-based resources for other purposes.

How do we embody abstract thought? In the early years of embodied cognition theorizing, this was a large unmet promissory note. It was assumed that progress

would be made in this area, and plausible examples were proposed, but empirical data were lacking. Instead, studies tended to focus on embodying “thoughts” that were themselves very close to external activities, such as mental rotation (Kosslyn et al., 1998), playing video games (Kirsh & Maglio, 1994), and understanding mechanical diagrams (Hegarty, 1992). Recently, however, considerable progress has been made in identifying the embodied underpinnings of various cognitive domains. These include representation of language and of abstract concepts (Barsalou, 2005; Gallese & Lakoff, 2005; Zwaan & Taylor, 2006), spatializing of abstract quantities such as numbers and time (Stoianov et al., 2008), gesturing to support cognition (Broaders et al., 2007; Goldin-Meadow, 2006), and offloading information onto body-based resources in working memory (Wilson, 2001b; Wilson & Fox, 2007). The striking feature that these have in common is the way in which we expand the domain of what is “embodyable” by creative use of body resources, decoupled from immediate action on the environment. In this chapter, I advance a proposal of a related cluster of abilities that allowed this transformation to take place.

FLEXIBILITY AND RESEMBLANCE: KEYS TO OFF-LINE EMBODIMENT?

VOLUNTARY CONTROL

One important prerequisite for a flexible, general purpose, off-line embodied cognition is voluntary control over important articulators, if not the whole body. Species differ as to how much control they have, and over which muscle groups. Non-human primates appear to lack any great degree of voluntary control over their vocal apparatus, both in the sense that they possess a limited and fixed repertoire of calls, and that the calls are predictably elicited by certain situations and are not deployed flexibly or creatively. For this reason, it has been suggested that manual dexterity (Arbib & Rizzolatti, 1996; Gentilucci & Corballis, 2006; Pollick & de Waal, 2007), or non-vocal facial movements such as lip-smacking and chewing (MacNeilage, 1998), rather than vocal calls, may have been the evolutionary precursor to human speech, because these are domains in which our closest relatives (and therefore presumably our common ancestor) show greater flexibility and control.

Species more distantly related to us can also possess a remarkable degree of voluntary control over articulators that they use to manipulate their environments. Walruses, to take one example, forage for food on the bottom of the ocean by way of extremely sensitive and sophisticated movements of the mouth and snout, and also use their highly mobile mouth and throat structures to produce a large repertoire of social calls. Walruses in captivity have been observed to use these abilities for other purposes, including manipulating toys and generating novel vocalizations (Schusterman & Reichmuth, 2008). Thus, voluntary control of

particular articulators appears to be an ability that evolves specifically when and where it is needed for the animal's particular survival strategy.

What is remarkable about humans is that we have managed to achieve an unprecedented degree of control over our bodies. Of notable importance to humans are the hands and the vocal apparatus, but to a great degree our entire bodies are under voluntary control. Even large and cumbersome muscle groups, such as those of the abdomen, can with practice be brought under voluntary control. Thus, we can not only choose at will from among pre-existing skills, but we can also develop a virtually unlimited range of new ones, as demonstrated by different dance styles from belly dance to ballet to hula to classical Indian dance.

How does this relate to cognition? In order to take embodied cognition off-line, it is necessary to decouple our bodily actions (or mental representation of those actions) from the demands of the immediate situation. We need to be able not only to walk, jump, turn, point, move objects, smile at people, and speak words, but also to perform or think about performing those actions at will when they are not necessarily appropriate to the situation but can assist us in our cogitations. Escaping stimulus-driven activation of our motor skills is a necessity for off-line embodied cognition.

Furthermore, it is plausibly of great importance to a broad, general cognitive system to be able to learn or invent new bodily actions at will, expanding the array of tools available for embodied thinking. A gymnast, for example, familiar with rotating the entire body not only around the vertical axis (remaining upright) but also around both horizontal axes (consider a cartwheel and a back handspring, respectively), may possess spatial imagery skills that differ from those of a ballet dancer. A person who is mathematically inclined can learn to count on their fingers in binary (a finger up is a 1, down is a 0), enabling representation of the integers up to 512 by hand configuration alone. A pianist, whose musical skill involves chords, may have greater cognitive flexibility in thinking about music than a vocalist of equal musical training, whose instrument can only produce one note at a time. According to Yale musician Joel Wizansky, "it's more or less a truism that any composer, regardless of his main instrument, must have some level of keyboard skill, so as to be able to 'think polyphonically' at the piano" (J. Wizansky, personal communication, February 19, 2008). And to take a far more mundane example, whose astounding cognitive usefulness gets overlooked in its sheer familiarity, we learn the fine motor skills of handwriting and typing in order to be able to put our thoughts on paper. For purposes of embodied cognition, this last example is perhaps most interesting not so much in terms of its archival functions (writing down information for later reference or to be read by other people) but for its functions in serving as an external memory device during ongoing cognitive processing—polishing a line of poetry, for example, or trying to remember all the names of the seven dwarfs. All of these examples can be considered instances of what has been termed "cognitive technologies" (Frank et al., in press; see also O'Connor, 1996). Rather than being universal tools of human cognition, they are inventions, made possible by creative uses of the body.

A broad degree of voluntary control over the body, then, is arguably a bonanza for the expansion of the capabilities of embodied cognition. In the next section we turn to how this voluntary elicitation of movement can be harnessed to be able to do cognitive work.

ANALOGY

The ability to exploit analogies is ubiquitous in human cognition and perception. Humans excel at recognizing and capitalizing on structural isomorphisms between different objects or different conceptual domains. When an analogy is not obvious or made explicit by others (as in the well-known tumor/fortress problem), we do not always immediately recognize the parallelism between domains; but once we are aware of the parallelism we exploit it effortlessly (Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987; Pedone et al., 2001; Didierjean & Nogry, 2004).

One example, where the analogy between two domains is very clear and nearly perfect, is the use of maps, scale models, and drawings to understand their real world counterparts. This is an ability that emerges in children around 2 years of age, when they begin to recognize the relation between, for example, “feeding” a doll with a toy spoon and feeding a person (Johnson et al., 2005). By the age of three, children master the more complex analogical skill of using a scale model of a room to find a hidden object in the real room (Troseth et al., 2007). Interestingly, the power of the analogy is so compelling that children go through a stage of making scale errors, attempting to treat smaller model objects as if they were their larger counterparts (DeLoache et al., 2004; Ware et al., 2006). The ability to understand and use scale models appears to be shared with chimpanzees, although only some individuals use the information spontaneously whereas others need to be taught (Kuhlmeier et al., 1999; Kuhlmeier & Boysen, 2002).

A second example of our ability to see analogies is our ability to recognize structural parallels between objects that differ in their superficial characteristics, such as a penguin and a canary, or a truck and a sports car. This ability to “see” structural or functional similarities is crucial to the formation of concepts and categories. Bar (2007) goes further, suggesting that it also underlies our ability to generalize from our memories of past experiences in order to successfully anticipate new situations. As such, this tendency may have precursors in other animals (e.g. Murai et al., 2005), who must also generalize beyond the particular stimulus in order for past learning to be useful in new situations. Such an ability may arise from our perceptual systems, which likewise face the problem of needing to generalize in order to do pattern recognition, which cannot be reduced to mere template matching. Around the age of 2 years, children begin to recognize and creatively invent analogies that are based on only a partial match between domains. This can be seen in pretend play, in which one object stands in for another to which it may bear only gross featural similarity (e.g., pretending that a banana is a telephone).

A special case of seeing and exploiting imperfect analogies involves recognizing isomorphisms between different parts of the human body, and using one

set of body parts to represent another set of body parts, as in gesturing with the two hands to show an action with the feet, or gesturing with two fingers to show walking. More sophisticated versions of these last examples can be found in signed languages, in the form of iconic signs and classifier constructions that refer to bodies or body parts (Taub, 2001; Emmorey, 2002). These are various even within a single signed language, and also differ across signed languages. For example, in American Sign Language the action of walking can be represented by a single upright index finger indicating the whole body, by the index and middle fingers of the dominant hand representing legs, by the two index fingers of the two hands representing legs, or by the two whole hands held in a flat position to represent feet. Each of these is used systematically in different situations to convey different shades of meaning. Other examples abound: fluttering eyelashes can be represented by the fingers, closing eyes by two flat hands coming together as the upper and lower lids, widened eyes by fists opening into semi-circles, and so on.

Certain body-to-body analogies may actually have a biological basis. There is evidence that a connection between opening and closing of the mouth and opening and closing of the hands is hardwired. Gentilucci et al. (2004) have shown that grasping or observing someone else grasp a small object (a cherry) or a large object (an apple) actually alters the way that people simultaneously pronounce a syllable, resulting in a more closed or open vowel sound. This hand–mouth connection may be an exception though, with its basis in the specific brain circuits that govern these two important manipulators and which appear to overlap in Broca's area (e.g. Rizzolatti & Arbib, 1998; Gentilucci & Dalla Volta, 2007; Skipper et al., 2007). In contrast to this hardwired case, though, humans are also able to productively employ analogies between any variety of body parts, provided the analogy is apt, as seen in the wide variety of body representations by the hands in signed languages.

Further examples of the ability to recognize isomorphism become progressively more abstract. When they reach school age, children are capable of mapping an abstract domain onto a concrete, spatial one, such as a clock face to represent time, or the number line to represent sequence or quantity. This ability becomes increasingly complex as children mature into adults, and forms the basis for many of our most sophisticated cognitive abilities, including higher math, computer programming, literary symbolism, and musical composition.

This strategy of using a concrete domain to represent an abstract one also underlies much of our use of analogical mappings in everyday life. This has been extensively explored in the context of conceptual metaphor (Johnson & Lakoff, 2002), in which an extensive network of part-by-part correspondences between domains is systematically exploited. Well-known examples include conceptual metaphors such as *communication is transferring an object between containers*, which can be broken down to a fine grain of detail (minds are containers, ideas are objects, difficulties in communication are physical barriers, communicative acts are bodily actions of handing, placing, or throwing, and so on). These

extended metaphors tend to be culturally shared, as shown by their systematic use in language, but can vary from culture to culture. One striking example is the observation that, unlike most cultures, which talk about the future as ahead and the past behind, the Aymaras of the Andes do the reverse, metaphorically placing the future behind the body (since it is unknown) and the past in front (Núñez & Sweetser, 2006). The grounding of abstract conceptual knowledge in concrete domains has also been explored by Barsalou and colleagues, proposing that abstract concepts are grounded in schemata based on the sensory, motor, and introspective qualities of specific experiences (e.g. Barsalou, 1999). Although less extensively explored in the empirical literature, this same principle of abstract-to-concrete is clearly at work in activities such as mathematics (cf. Lakoff & Núñez, 2000). The insight that abstract quantities and relationships could be represented graphically underlay much of ancient Greek mathematics; led to the recognition in Persia in the 11th century and Europe in the 17th century that algebra and geometry are fundamentally related, which spawned the field of analytic geometry; and contributed to the development of calculus in the 17th century. One recent study that investigates this principle in the laboratory showed that formally irrelevant aspects of how elements are physically grouped can affect accuracy of mathematical judgements (Landy & Goldstone, 2007).

In short, recognizing and exploiting analogies, particularly physical and spatial analogies, seem to be a general feature of human cognition, ranging from the perceptual to the abstractly cognitive (cf. Wharton et al., 2000).

IMITATION

How does the ability to see analogies further the cause of embodied cognition? One special case of analogizing is the ability to recognize the isomorphism between one's own body and something else. This includes recognizing the isomorphism between one's own body and another person's body, and using this for imitation and social learning (Wilson, 2001a).

Imitation is ubiquitous in human activity, and in many cases appears to be unconscious and automatic (see Wilson, 2001a; Wilson & Knoblich, 2005, for reviews). Examples that have been studied experimentally include the chameleon effect (unconscious copying of another's posture and movements); speeded reaction times when the stimulus is a human body movement that matches the required response; rudimentary imitation in neonates and the subsequent development of imitation in children; disinhibition of imitation in frontal lobe patients; activation of motor brain areas and even muscles themselves in response to perceived action; and, expanding on the remarks above about sign language, the use of "iconic" (i.e., imitative) handshapes and movements to represent a wide variety of objects and events, which occurs in all documented signed languages of the world.

In addition there is the discovery of the "mirror system," involving regions in pre-frontal and parietal cortex (for reviews see Fadiga et al., 2005; Lepage & Théoret, 2007). The mirror system is so called because it is involved both in the

perception and the production of body movements. This system is sometimes incorrectly referred to in the literature on humans as *mirror neurons*. However, only with single-cell recording in monkeys have specific neurons been observed that serve both perceptual and motor functions. In humans, at most we know that certain brain *regions* are involved in both. A second difference from the animal literature on mirror neurons is that monkey mirror neurons seem to be quite limited in the range of actions to which they respond. So far, mirror neurons have been found that respond to specific movements of the hand and mouth, such as grasping, placing, and tearing of objects, communicative and ingestive mouth movements, and reaching with a tool (Gallese et al., 1996; Kohler et al., 2002; Ferrari et al., 2003; Ferrari et al., 2005). In contrast, the human mirror system has been observed to respond to a wide variety of activities, including learned skills that can in no way be considered part of the “natural” repertoire of human movement (the way that walking might), for example, playing the piano (Haueisen & Knösche, 2001). In a parallel to the previous remarks about recent research on animal cognition, research on mirror neurons has tended to focus on the social functions of such a system, with speculative links being drawn to empathy and theory of mind (Meltzoff & Decety, 2003; Iacoboni & Dapretto, 2006; Agnew et al., 2007; Braten, 2007; Kilner et al., 2007). However, there are also several ways in which the mirror system may have contributed more generally to the development of human cognition. One obvious and direct way is that the mirror system plausibly gave rise to the ability to imitate.

As noted earlier, the existence of true imitation in non-humans is a subject of intense debate. If we concede that our closest relatives do not imitate with the same ease and flexibility as humans, it becomes worthwhile to ask what role imitation has played in the emergence of uniquely human cognition. What benefits did it confer? As noted earlier, it may have played a role in developing social cognition, but it may have played other roles as well. I have argued elsewhere that, in addition to the perceptual system driving the motor system, the information may flow back the other direction (Wilson & Knoblich, 2005). Unconscious activation of the motor system in response to perceived human body action may feed back again into the perceptual system, and provide more robust processing of the perceptual signal.

I have also argued that the human capacity for imitation, that is, easy automatic translation between perceptual and motor codes of body action, may be a key factor in working memory performance (Wilson, 2001b; Wilson & Fox, 2007). Rehearsal in working memory involves repeated covert articulation of the stimuli to be remembered, closely coupled to a quasi-perceptual representation of those stimuli. As a result, stimuli that can be imitated, which is to say stimuli that can be rehearsed in this articulatory way, yield much more robust working memory performance than stimuli that cannot.

These two cases, perception and working memory, can be seen as specific examples of a more general principle, which is that imitation is crucial to embodied cognition. To represent something with the body, we need to be able

to shape the body to match the thing to be represented. This takes us beyond an embodied cognition of actions we might perform to operate on the world (as in the video game and mechanical diagram examples), and allows us to represent, using bodily resources, a much wider variety of events. That is, we can represent *what someone or something else is doing*, and not just *what we ourselves might do*.

In this connection, it is important to note that the ability to imitate can go beyond imitating other people, and can give us the ability to use the body to represent other objects. This includes anthropomorphizing jointed, multi-part entities, such as machinery and animals; and also includes using body movements such as hand trajectories, rotations, and pointing to represent object motion and location. These types of uses have been documented in a variety of cognitive tasks, such as mental rotation of non-human objects (Amorim et al., 2006), memory retrieval (Dijkstra et al., 2007), simple algebra (Broaders et al., 2007), and working memory (Chieffi et al., 1999).

In sum, in order to develop an embodied cognition that is about more than just the immediate situation (or, at most, planning future actions using representations of the same actions one would use in the actual situation), requires two things: the first is the ability to exert flexible control over one's body to recruit existing motor skills at will and to take on new and diverse body shapes and actions; and the second is the ability to use that control and flexibility to represent, by resemblance, a wide variety of things in the world.

FUTURE DIRECTIONS

In this chapter, I have argued that core properties of human cognition that are radically new in the scope of evolutionary history can nevertheless still be accommodated within an embodied cognition framework. It is not necessary either to insist that we are still situation-bound, or on the other hand to abandon embodiment for an ungrounded symbol-processing view of cognition. What is needed, though, is an evolutionarily plausible account of how we broke the limits of a situation-bound sensorimotor cognition, further limited by a small repertoire of species-typical behaviors. Two well-documented human abilities—our broad flexibility in control of our bodies, and our capacity to imitate and otherwise see and exploit analogies—can explain this shift.

This account still leaves several important questions unanswered. One, of course, is how voluntary control and imitation themselves arose. Were they driven directly by the advantages conferred by taking embodied cognition off-line? Or did they emerge for other reasons (perhaps socially based reasons), to then be exploited by an increasingly sophisticated off-line cognition?

Another important question that has not been addressed here is how language fits into an off-line embodied cognition theory. In the rush to get away from traditional views of cognition as abstract, symbolic, and disembodied, there has

been a tendency to discount the unavoidable fact that humans *do* use symbols. As Barsalou (2005, p. 389) puts it, "Although abstraction has gone out of fashion, it will not go away." One of the most obvious ways that we use symbols, of course, is language. Does this mean that language has allowed us to escape embodiment, that aspects of cognition related to language are in fact disembodied in the tradition of old-fashioned cognitive psychology? Not necessarily. One important piece of this puzzle is being addressed by sensorimotor accounts of meaning (e.g. Barsalou, 1999, 2005; Johnson & Lakoff, 2002; Zwaan & Taylor, 2006). Another piece may reside in the fact that language is a bodily activity, expressed with the vocal tract or, more rarely, with the hands. This allows a meaning to be offloaded into mere motor activity, from which it can be retrieved and re-converted into meaning. In this respect, it is not an exaggeration to say that the emergence of human language revolutionized working memory. Nevertheless, the scope of the problem of understanding the evolution of language, and how it drove or was driven by off-line cognition, should not be underestimated.

In spite of these unanswered questions, though, the ideas put forward in this chapter may help to explain how embodied cognition theory can account for many of the important features of human cognition that appear on the surface to be disconnected from our immediate sensorimotor experience and behavior. Further, these ideas may help to bridge the apparent gulf between human and animal cognition, and help to explain how we got from there to here. As with all of evolution, spectacular new characteristics are possible, even though, in the words of Darwin (1862, p. 348), they "use old wheels, springs, and pulleys."

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