The Body in Space: Dimensions of Embodiment

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ABSTRACT

Recent research from a large number of fields has recently come together under the rubric of embodied cognitive science. Embodied cognitive science attempts to show specific ways in which the body shapes and constrains thought. I enumerate the standard variety of usages that the term "embodiment" currently receives in cognitive science and contrast notions of embodiment and experientialism at a variety of levels of investigation. The purpose is to develop a broad-based theoretic framework for embodiment which can serve as a bridge between different fields. I introduce the theoretic framework using examples that trace related research issues such as mental imagery, mental rotation, spatial language and conceptual metaphor across several levels of investigation. As a survey piece, this chapter covers numerous different conceptualizations of the body ranging from the physiological and developmental to the mental and philosophical; theoretically, it focuses on questions of whether and how all these different conceptualizations can form a cohesive research program.

Keywords: Embodiment; frames of reference; cognitive neuroscience; cognitive linguistics; mental rotation

1. Introduction: Embodiment and experientialism

1.1. *Embodiment: The return of the absent body to cognitive science*

HUMAN BEINGS HAVE BODIES. Academics of every variety, so often caught up in the life of the mind, find that simple truth altogether too easy to forget. Imagine working late into the night, hotly pursuing another bit of perfect prose. But now let there be a power outage and, in the absence of electric light or the pale glow of the computer screen, imagine how we grope and fumble to find our briefcase, locate the door, and exit the building. In such circumstances, the body returns. Whenever we are unexpectedly forced to move about in the dark, we are forcibly reacquainted with our bodily sense of space. Problems ordinarily solved beneath the level of our conscious awareness become dominant in our cognition; we find ourselves noticing subtle changes in the floor texture underfoot, carefully reaching out for the next step in the stairwell. It is a most peculiar experience, one that may well remind us of being young and just learning to walk down stairs.

Unfortunately for cognitive science, many academics of that particular variety haven't simply forgotten that human beings have bodies—cognitive scientists have deliberately theorized the body away. For most of its first fifty years, cognitive science was in the throes of a peculiarly devilish axis between information theory in computer science and functionalism in the philosophy of mind and psychology. Within computer science and information theory, the problem of building a thinking machine was identified with just one narrowly specified field of human cognition—computing mathematical functions (Turing 1950; Hodges 1983). Under the functionalist paradigm, the mind was treated as if it were a series of modular computer programs—or "black boxes"—whose inputs and outputs could be specified in symbolic terms. While no one would have argued that the physical architecture of vacuum tubes and transistors making up the early computers were identical to the physical architecture of the neural systems making up the brain, the functionalists did argue that the specific physical details of *how* such thinking systems computed was irrelevant to *what* they computed. In fact, they argued that as *computation* could take place not only in electrical and neural systems but also in mechanical systems such as a loom or Babbage's steam-powered analytical engine, *cognition* was independent of its physical medium. From this perspective, the only thing that mattered to simulating cognition was getting the inputs of these black boxes to compute the correct outputs (Cummins 1977). The physical body—whose architecture was seen as largely irrelevant to cognition—was redefined as a series of black boxes that computed mathematical functions. The disembodied computer was the analogical origin of the disembodied mind.

In recent years however, another strain of cognitive scientists have begun to take their inspiration from the contrarian vision—*embodied cognitive science*. Unlike the computationalist-functionalist hypothesis, embodiment theorists working in various disciplines argue that the specific details of how the brain and body embody the mind do matter to cognition. This broad theoretical approach has been the result of many parallel developments in diverse fields ranging from neurobiology and linguistics to robotics and philosophy. While there are undoubtedly many touchstones and origins of this approach, Johnson and I (Johnson & Rohrer *this volume)* have given a detailed account of some of the neurobiological and philosophical roots of the embodiment hypothesis in cognitive science with a particular emphasis on how the contributions of American Pragmatism anticipated modern cognitive neuroscience. By contrast, in this paper I intend only to survey the wide variety of manners in which embodied cognitive science is done, including these among others, in order to develop a general theoretic framework as a backdrop against which these research projects can be situated.

One of the most central examples of how embodied cognitive science has revolutionized the field lies in the details of how the mind, brain and body interact to construct our experience of space. Tracing this example across the different disciplines of cognitive science will require the whole of this article, but as a beginning recall the basic finding of the work on mental rotation (Shepard & Metzler 1971). In their renowned experiment wherein participants were asked to determine whether one two-dimensional drawing of a three-dimensional object was identical to or a mirror image of another, they found that subjects mentally rotated the object at a linear rate—about 60 degrees per second. In other words, participants were manipulating such images as wholes, preserving their topologies while rotating them through a series of intermediate depictions. At the time of its publication, their finding was surprising because the then prevailing computationalist and functionalist view held that the mind operated in a symbolic rather than depictive fashion, and therefore argued that any such mental imagery would be merely epiphenomenal (Pylyshyn 1973). Over the ensuing thirty years, a variety of convergent evidence has established not only the fact that mental images are rotated in the brain as perceptual wholes (Kosslyn et al. 1995), but have also specified how that fact impacts our understanding of exactly what our minds are "computing" (reviewed in Kosslyn 1994; Kosslyn, Ganis & Thompson 2002).

Consider, for example, how the body—and not just the brain—plays a role in modifying the rate at which mental rotations take place. Extend your left arm in front of you and hold your left hand straight out, palm upwards. Now try to rotate your hand 180 degrees to the left and then to the right. Notice that the rightward (inward) rotation is relatively easy, while the leftward is quite difficult, requiring additional shoulder and arm joint movements. A series of experiments by Parsons (1987ab, 1994; Parsons et al. 1995) showed that when subjects were asked to perform mental rotations of images which consisted of line drawings of human hands instead of Shepard-Metzler 2D/3D block diagrams, subjects were quicker and better at identifying those rotations of the hand that were easier to perform, given the kinds of bodily constraints on joint movements we have as humans. Furthermore, Parsons found that subjects were quicker and better at judging which hand—left or right—was pictured when imagining rotating that hand did not require difficult bodily movements. Given the details of the way the body works, the motor imagery system actively constrains how fast mental imagery is performed.[1]

Even more dramatically, consider how patients with chronic arm pain in one limb perform similar mental hand rotation tasks. For their affected arm as compared to their uninjured arm patients are much slower to perform the necessary mental rotations in those conditions where the bodily movements that would be required for the actual hand rotation involve large arm movements (Schwoebel et al. 2001). A group of non-patient controls also showed no such differences between their left and right arms. Not only does the body affect how our mind works, but the body in pain affects how the mind works. Of course, this last insight should come as no surprise to anyone except those cognitive scientists who believe that our minds work just like disembodied computers.

As a fallback position, a committed computationalist could simply jettison the functionalist claim that our cognition is independent of our neurophysiological architecture. One could argue that embodiment means only that "computations" of a particular kind—analog and iconic, not symbolic; physiologically embodied and perspectivally situated, not abstractly universal—are being performed as the body and brain pass topology-preserving structures forward and backward between the visual and motor systems. Admittedly, these topologies are not the "outputs" of the computations of a rigidly modular functionalist architecture, but rather dynamic activation patterns which imagistically map the perceptual contours of experience, rippling back and forth through multiple reentrant neuroanatomical connections within a web of functionally interrelated neural regions. These embodied neural "computations" compete to become the most salient and pragmatically useful mental constructs to address the current problem for the organism, whatever that is. While such revisions to our conception of what counts as cognitive "computations" are certainly warranted by the evidence and are important steps toward an embodied cognitive science, we might also inquire whether the focus on embodiment leads to additional constraints that are not purely physiological.

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[1] Interestingly, if one adds a cylindrical "head" to the Shepard-Metzler cube stimuli, one can produce similar embodied facilitation and inhibition to that produced by more naturallistically "embodied" stimuli such as Parsons' line drawings of hands (see Amorim, Isableu & Jarraya in press).

Suppose that the current problem for the organism is once again the mental rotation of images. Given the results concerning how the rate of the mental rotation varies when the stimulus is a hand, are there multiple strategies for rotating mental objects that could compete to solve such problems? As one obvious difference between the Parsons stimuli and the Shepard and Metzler stimuli is that the former are line drawings of body parts while the latter are line drawings of 3D blocks, it might be possible that the motor imagery effects Parsons observed are limited to body-part images. While Kosslyn et al. (1998) had initially argued that there was this sort of stimulus-determined choice between two separate neural systems that could perform mental rotations, namely the motor imagery (hand stimulus) and visual imagery (object stimulus) systems, Kosslyn et al. (2001) now argues that there are two possible perspectives—or spatial frames of reference—that influence which strategy for mental rotation is chosen. In one such frame of reference—a viewer-centred perspective—it is possible to imagine oneself physically grasping and rotating a 3D object; while in the other frame of reference—an object-centred frame—it is possible to imagine viewing something else rotating the 3D object. Kosslyn and colleagues built wooden 3D constructs of a Shepard-Metzler block figures, and just prior to the neuroimaging had the subjects either turn by hand the wooden blocks or observe the blocks rotating on a motor-driven spindle. Participants were then instructed to imagine rotating the visual stimuli presented during the neuroimaging task in precisely the same manner. The neuroimaging results showed that the differences in the strength of activation in the motor imagery (or visual imagery) brain regions correlated with which perspective was obtained on the model via the participant's socially instructed interaction with it. Their results show that participants could *voluntarily* choose to adopt a particular strategy based on the frame of reference in which they were told to interact with the object and not based solely on the type of stimulus image—i.e., body parts or blocks. In other words, it is not the case that *only* the details of our physiology matter, such as the constraints of our joints as we imagine rotating our hands. Instead, the socially instructed choice of perspective *also* matters to how the embodied mind works.

The Kosslyn group's experiments demonstrate why embodiment in cognitive science should never be construed as an exclusively physiological phenomenon. Even when researchers are measuring physiological changes such as changes in the blood flow or glucose uptake within the brain, both socially and environmentally induced factors can play a theoretically significant role as to what brain activity is being measured. Instructing a participant in a neuroimaging experiment to imagine using one spatial frame of reference or the other—that is, to imagine manipulating the blocks themselves as opposed to imagining the blocks spinning on their own—demonstrates how the social context influences the physiological response. Similarly, constructing a 3D physical version of a heretofore visually presented 2D stimulus predisposes the participant to interact with the stimulus using a slightly different mix of sensory modalities—resulting in a different physiological response. Note that it is not the case that the "body" enters into the measured response only in the condition where the participant physically manipulates the 3D object. In each case the body interacts with the stimuli in different ways (visually or motorically), and the resulting environmental predispositions to imagine using either the visual or the motor system are carried into the PET scanner. Unfortunately, the Kosslyn group has not yet investigated whether the social and environmental influences are separable, but it is reasonable to predict that they are. One could test this hypothesis using an experimental variation derived from semantic priming; if some participants were instructed to imagine operating in the opposite frame of reference during the scan than the one induced by their pre-scan bodily interaction with the stimulus, one would expect that their responses would be weaker in activation (inhibited) when compared to those participants for whom the social instructions coincided with the embodied environmental interaction.

1.2. Experientialism: "The body" of cognitive science expands

The Kosslyn et al. (2001) experiment is particularly revealing because it shows that even for those of us who use methodologies dedicated to measuring the body, embodiment means not just the physiological body—or worse yet, just the physiological brain—but the body-in-space, the body as it interacts with the physical and social environment. Many of the objects we interact with every day are in fact cognitive artifacts we have designed with our bodies in mind. Consider one last set of experiments on mental rotation, one which compares the mental rotation of hands with the mental rotation of tools. Vingerhoets et al. (2002) compared the fMRI activation patterns of right-handed male subjects who were asked to decide whether a pair of pictures were different or identical (except for being rotated) when presented with either two pictures of hands (either right or left) or two pictures of hand tools (a monkey wrench, a pencil sharpener, a can opener and a soup ladle). While they found pre-motor and motor activation in both experimental conditions, their key finding was that tools, unlike hands, activated only the left hemisphere premotor and motor hand cortices—contralateral to the subject's dominant hand. In other words, when we think about rotating tools—as opposed to Kosslyn's abstract shapes or Parsons' pictures of hands—we are mentally "grasping" those tools and rotating them with the same hand that we would ordinarily use to rotate them in the physical world. Thus, the body-in-the-brain is not just shaped by the body, but by the habitual interactions of the body with the environment.

The point is not just that the body shapes the embodied mind, but that the experiences of the body-in-the-world also shape the embodied mind. But the experiential worlds with which we interact are more than simply physical; we are born into social and cultural milieus which transcend our individual bodies in time. Tools are an excellent example of the elements of our physical world that come to us already shaped by socio-cultural forces which predate each individual's body, if not the human body in general—for there has certainly been a long process of cultural refinement in the design of hand tools. Like tools, language is another part of the socio-cultural milieu within which we exist. Can we investigate how socio-cultural factors (such as the language into which we are born) shape our cognition?

Let us begin by considering matters of prepositional structure, perspective and frames of reference in a linguistic context. In English we can speak metaphorically about features of the landscape in terms of the body, such as *the face of a mountain, the mouth of a river, the foothills,* and on. Peninsulas can be construed as *fingers* of land, or as *heads* (as in Hecata Head). In other words we understand features of the landscape metaphorically, using our bodies as the grounding frame of reference. Lakoff and Johnson (1999, 1980) have called such systematic patterns of metaphoric projection "conceptual metaphors", and have argued that they exhibit a general tendency to conceptualize more abstract entities in terms of the more bodily ones. We now know that both literal and metaphorical uses of body-part terms exhibit mental imagery effects similar to those described in the experimental lines already discussed. In an fMRI study which included instances of the LANDSCAPE IS A BODY metaphors, participants' primary and secondary hand sensorimotor cortices were active during the comprehension of both literal and metaphoric hand sentences (Rohrer 2005, 2001b). However, languages vary in how they construct space; is it possible that what is a metaphoric usage of in English is the basic frame of reference habitually used by members of another culture?

Linguists have documented a number of Mayan languages such as Mixtec, Tzeltal and Zapotec whose prepositional structure is entirely composed of body-part morphemes. For example, saying *the stone is under the table* requires saying the stone is proximal to the table's belly (*yuu wa hiyaa cii-mesa* / *stone the be-located table-belly*) (Lakoff 1987: 313). Within Cognitive Linguistics Brugman (1985) and Lakoff (1987; see also related work in MacLaury 1989) have claimed that such languages require projecting the names for body parts onto objects in the world. They argue that Mixtec speakers start off with a viewer-centred frame of reference[2] and then take up the perspective of the object. This change in perspective yields an object-centred frame of reference for Mixtec spatial relation terminology, where tables metaphorically acquire bellies located where a human belly would be. From a purely neurophysiological conception of the body—and one strongly influenced by an overly narrow conceptualization of the brain in terms of just the visual system (and not the sensorimotor system)—one could conclude that this order of events was inevitable, given that in the visual system we first construe the world in our visual system in viewer-centred neural maps, and only later in object-centred maps.[3] Given the cognitive neuroscience available at that time, Lakoff (1987) plausibly argued that speakers of such languages were metaphorically projecting the viewer-centred frame of reference to form another, object-centred frame of reference.

However, related evidence gathered in cross-cultural language acquisition studies reveals that the embodied mind is being shaped here not simply by the neurophysiology but by the particular socio-cultural practices that accompany language acquisition. The metaphoric projection hypothesis predicts that such terms would be learned first as names for the body parts, and only later extended to spatial relations terms. In a cross-cultural study of Danish- and English-speaking children on one hand and Zapotec-speaking children on the other, Jensen de López and Sinha (1998; Sinha & Jensen de López 2000; Jensen de López 2002) investigated whether each culture's children acquire body-part morphemes first as body-part terms and then only later metaphorically project them as spatial relations terms. Their results show that Zapotec-speaking children acquire the body-part morphemes first as spatial relations terms and only later—and seemingly independently—as names for the body parts, while Danish and English children acquire them first as body-part names and only later use them to indicate spatial relations. Furthermore, Jensen de López and Sinha hypothesize that the difference derives from differing cultural practices of child-rearing. They note that Zapotec infants spend most of their first two years in a sling on the mother's back, sharing her spatial perspective, while Danish and English infants are placed in cribs and encouraged more to move about on their own. Consequently, joint attentional episodes during which the child's body parts are named may be less frequent in Zapotec child-rearing practices than in Danish or English child-rearing practices. In short, Jensen de López and Sinha suggest that what might have looked like a projection of viewer-centred body-part terms in order to form an object-centred frame of reference is instead simply the acquisition of an object-centred frame of reference through joint attentional episodes focused on

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[2]Even though the topic has somewhat shifted to language, I am still using the term "frame of reference" primarily in its spatial sense, as would be found in cognitive psychology and cognitive neuroscience. I discuss the complex relation between linguistic and non-linguistic frames of reference in Section 3 and 4.

[3] Current studies of the sensorimotor system reveal that there are separable frame of reference maps for body-centred (i.e., viewer-centred) mental rotation and object-centred mental rotation (see review in Parsons 2003).

the spatial characteristics of such objects. The work of Jensen de López and Sinha, along with cross-cultural language acquisition work (Bowerman & Choi 2003), is an example of why embodied cognitive science must include the socio-cultural milieu as one dimension of variability.

Note how similar the findings of Jensen de López and Sinha are to the Kosslyn et al. (2001) finding concerning how the actions that directly precede the mental rotation experiment influence which neural system is chosen to perform the task. In both cases, the social context of joint attentional episodes, whether between caregiver and child or experimenter and participant, influences what frame of reference is chosen. To be embodied as a human being means in part that we are born into a socio-cultural milieu within which we have particular problem-solving strategies reinforced through experience. Deeply habitual experiences or an immediately prior attentional experience can alter which strategy we choose to employ. The body of embodied cognitive science is not limited to physiological and neurophysiological influences on mind, nor to that plus the physical body's interactions with the physical world, but also incorporates the experiences of the social and cultural body as well. In other words, it has to take account of the socio-cultural context within which a particular body is situated.

At this point it is clear that there are a number of different, if interrelated, senses of the term "embodiment" at play in the literature. I began this chapter with the image of how the phenomenological body intrudes upon the mind when the lights unexpectedly go out and one must fumble to find the way out of a building, and then traced some examples of how such experiential considerations motivate experiments that investigate the physiological and neurophysiological responses to the experienced body (as in imagining rotating the hand for both normal participants and participants with chronic arm pain). Continuing to examine the literature on imagination and mental rotation, I showed how even a focus on measuring the neurophysiology leads to the realization that both the physical environment and the socio-cultural context are factors which impact the embodied mind. Now it is time to begin addressing the meta-theoretic picture explicitly. How can all these senses of the term hang together as a framework for research on embodied cognition? What are the dimensions of embodiment that different theorists think it is important to measure and address? How many dimensions are there, and how do they interact to form different research clusters?

2. Surveying the dimensions of embodiment

Like most scientists, linguists usually acknowledge that it is a difficult but admirable goal to begin as descriptively as possible before proceeding prescriptively. By my latest count the term "embodiment" can be used in at least twelve different important senses with respect to our cognition. Because theorists often (and sometimes appropriately, given their specific purposes) conflate two or more of these dimensions, it is important to get a clear picture of as many of the different dimensions of variability as possible. This list is not intended to be entirely exhaustive of the term's current usage, nor are the dimensions necessarily entirely independent of each other nor even entirely distinct from one another. Thus it is important to note that, and unlike the argumentative analyses given in Anderson (2003) or Wilson (2002), *this initial survey is not intended to be a prescriptive definition of the term*, but instead is intended only to catalogue some of the contemporary usage of the term in a way that reveals the most relevant dimensions to which one must be responsive in order to develop a general theoretic framework for embodiment theory in cognitive science. However, I do note where some theorists have used the term in several of these senses simultaneously, and in several cases I argue for making finer distinctions and recognizing more dimensions than do the original theorists themselves.

2.1. Dimension 1: Philosophy

First—and perhaps most broadly—"embodiment" is used as a shorthand term for a counter-Cartesian *philosophical* account of mind, cognition and language. Descartes took problems within geometric and mathematical reasoning (such as the meaning of the term "triangle") as model problems for study, and concluded that knowledge *par excellance* is "disembodied"—that is, fundamentally independent of any particular bodily sensation, experience, or perspective—all of which are roots of uncertainty. In arguing that the meaning of the term "triangle" consists in the reference relationship between the word and an object that exists not in the physical, embodied world but in thought alone, Descartes' thought experiments set the stage for many thinkers within analytic philosophy, formal semantics, and early cognitive science. Broadly speaking, such philosophers of language typically construe the two central problems of meaning to be (i) mapping the reference relations between idealised objects of knowledge, their counterpart symbolic expressions in language and the objects or "states of affairs" in the real world (as in Fregean semantics), and (ii) explaining the internal logical structure of the relations which hold between these idealised objects or their corresponding linguistic symbols (as in theories of "autonomous syntax"). While Descartes was by no means unique nor alone within Western philosophy in claiming this position, his extraordinary clarity has garnered him the laurel of becoming metonymic for this package of philosophical assumptions (Lakoff & Johnson 1980, 1999; Geeraerts 1985; Johnson 1987; Rohrer 1998). Most such embodiment theorists, while perhaps somewhat favouring the empiricist side of the rationalist-empiricist split, generally try to dissolve such philosophical problems as hangovers from a bad metaphysics by recasting the problems in a different metaphysical basis. Many, although not all, of the theorists objecting to such Cartesian treatments of language, meaning and representation use "embodiment" in this broadly philosophical sense even as they work explicitly in one or more of the somewhat narrower dimensions of the term that follow.

2.2. Dimension 2: The socio-cultural situation

"Embodiment" is also used to refer to the *social* and *cultural* practices within which the body, cognition and language are perpetually *situated*. In this sense, "embodiment" is often used to emphasize the particularistic, rather than the universalistic, tendencies of human cognition; e.g., how a particular mind in a particular body is shaped by the particular culture within which it is embedded. One example of a cognitive cross-cultural language acquisition study would be the previously discussed research by Sinha and Jensen de López (2000). The cultural variations in child-rearing practices might well account for differing acquisition sequences of spatial language terms in English-, Danish-, and Zapotec-speaking children.

Such socio-cultural practices can be given material form in the *material artifacts* that aid and manifest cognition—many of which are extensions of the body (Hutchins 1995, 1999; Fauconnier & Turner 2002). In assessing the differences between Micronesian and Western traditions of navigation, Hutchins observes that the

> […] physical artifacts became repositories of knowledge, and they were constructed in durable media so that a single artifact might come to represent more than any individual could know. Furthermore, through the combination and superimposition of task-relevant structure, artifacts came to embody kinds of knowledge that would be extremely difficult to represent mentally. (1995: 96)

Hutchins cites the example of the medieval astrolabe, a set of rotating disks that embody the spatial relationships of the celestial bodies at different latitudes with much greater precision than would be possible from only the individual navigator's memory. These are set into a frame that represents the horizon, which is itself inset with a scale marking out the 24 hour day and/or the 360 degrees of the compass. He notes that the astrolabe embodies socio-cultural practices in two important ways. First, the astrolabe is an extension of the body in that a skilled navigator *physically* manipulates it by rotating its disks in order to predict celestial movements. Second, in its design the astrolabe is "a physical residuum of *generations of astronomical practice*" (Hutchins 1995: 96-97). Any particular navigator using the astrolabe is the intellectual heir of a wide set of social practices which have been designed into the instrument. In contrast, a Micronesian navigator eschews such material artifacts, relying successfully instead on cultural artifacts such as chants that encode the relevant celestial relations for voyages between particular islands (Hutchins 1995: 65-92, 111). However, such cultural artifacts perform a similar function in that they also embody generations of knowledge gleaned from navigational practices.

2.3. Dimension 3: Phenomenology

"Embodiment" has a *phenomenological* sense in which it can refer to the things we consciously notice about the role of our bodies in shaping our self-identities and our culture through acts of conscious introspection and deliberate reflection on the lived structures of our experience (Brandt 2000, 1999). The conscious phenomenology of cognitive semiotics can be profitably contrasted with the cognitive unconscious of cognitive psychology (see dimension 7). For example, Gallagher (*this volume*) traces how the work of phenomenological philosophers such as Husserl and Merleau-Ponty has contributed to the distinction between the conscious body image and the largely automatic body schema now emerging in cognitive neuroscience. For Husserl and Merleau-Ponty, embodiment refers not only to the lived experience of our own bodies but also to the ways in which our experience of other animate bodies moving differs from our experience of other moving objects in the physical world. This has found theoretic support from cognitive neuroscience in the discovery of the "mirror neuron" system in the premotor cortex (Rizzolatti & Craighero 2004; Gallese et al. 1996), in which primates have been shown to have neural systems which are activated not only by their own motor actions but also by witnessing another's motor action. Gallagher suggests that the emergent sense of "intercorporeality" from mirror neuron activity could be a basis of human intersubjectivity.

2.4 Dimension 4: Perspective

"Embodiment" can also refer to the particular subjective vantage point from which a particular *perspective* is taken, as opposed to the tradition of the all-seeing, all-knowing, objective and panoptic vantage point. While this sense of the term can be seen as at least partly philosophical (as in Nagel 1979: 196-213; Geeraerts 1985; Johnson 1987; Rohrer 1998), the idea of considering the embodied viewpoint of the speaker has linguistic implications in the role of perspective in subjective construal (Langacker 1990; MacWhinney 2003), as well as a myriad number of psychological implications (e.g., Kosslyn et al. 2002; Carlson-Radvansky & Irwin 1993).

For example, consider how the embodied perspective of the subject can interact with the canonical orientations implicit to construing spatial situations. When we give directions, we ordinarily assume that one is facing in the direction of the travel. However, in many subway trains the seats face in both directions. Should we give directions such as "after the subway goes above ground, look to your left. When you pass the automobile dealership, exit at the next stop...", imagine the confusion if the addressee should choose a seat facing opposite in the direction of travel and not make the adjustment to look to the right. Similarly, not only our bodies but also many of the objects of our world have canonical orientations that our determined by the ways in which we—that is our bodies—interact with them. Cups and trash cans stand upright, while mattresses lie flat. When we say "the fly is over the trash can", but the trash can is lying on its side, is the fly above the side of the trash can or adjacent to its mouth? Buildings such as cathedrals or ski lodges also have canonical orientations as to their fronts and backs; one can say "I'll meet you in the restaurant to the right of the cathedral at noon", and inadvertently fail to specify if that is the perspective of the tourist facing the cathedral or the perspective of the cathedral as it faces the city square. We routinely project the canonical orientation of our embodiment onto the objects in the world; sometimes we take up the perspective of inanimate objects, sometimes we take up the perspective of animate bodies. Of course, problems of co-aligning frames of reference are of practical import in areas such as ship navigation practices and the internal maps built up by robots; as such this dimension frequently interacts with the other practical senses of the term as well as the meta-theoretic ones.

2.5 Dimension 5: Development

In yet another important sense "embodiment" is used to refer to the *developmental* changes that the organism goes through as it transforms from zygote to fetus, or from infant to adult. There are at least three ways in which the developmental sense interacts with the other dimensions of "embodiment". First, certain events in the development of an organism open windows for the acquisition of a particular skill. Babies are not born speaking, nor can they handle objects or self-locomote at birth. As the infant acquires additional sensorimotor skills, additional patterns become available to be incorporated into its cognitive functioning. Second, and perhaps counterintuitively, such events may not expand but instead *constrain* the mappings between the possible patterns of embodied perceptual structures and the resulting conceptual structures of later developmental stages. For example, Bowerman and Choi (2003) have shown that while nine-month old Korean and English speaking infants can make the same spatial discriminations, at eighteen months their acquisition of language has solidified their spatial categories enough so that they are no longer able to make the discriminations which their language does not. Note that such developmental changes are not purely physiological, but take place within the relevant socio-cultural and linguistic contexts.

2.6. Dimension 6: Evolution

An equally important temporal sense of the term "embodiment" refers to the *evolutionary* course the species of organism has undergone throughout the course of its genetic history. For example, an account of the gradual differentiation of the cortex into separate neural maps each representing a different frame of reference in the visual and tactile systems of mammals might provide an evolutionary explanation for which multiple frames for spatial reference were universally found by the typological studies of spatial language and cognition (Majid et al 2004). Or on an even grander scale: humans have not always had the capacity for language and so evidence from studies on the evolutionary dimension of embodiment may often prove crucial to understanding why, for example, language processing in the brain does not appear to be exclusively concentrated as an autonomous module but instead draws on numerous subsystems from the perceptual modalities (see for treatments Deacon 1997; Edelman 1992; Donald 1991; MacWhinney 1999).

2.7. Dimension 7: The cognitive unconscious

Additionally "embodiment" can mean those routine cognitive activities that ordinarily operate too quickly and too automatically for the conscious mind to focus on them. Lakoff and Johnson (1999: 9-15) have recently called these the *cognitive unconscious*. In this sense "embodiment" refers to the ways in which our conceptual thought is shaped by many processes below the threshold of our ordinary conscious awareness. As such they are generally inaccessible to introspection, though they may be measured indirectly using methods from cognitive and social psychology. Lakoff and Johnson cite examples ranging from mental imagery to semantic processing to processing sound into phonemes. They intend that this sense of the term "describes all unconscious mental operations concerned with conceptual systems, meaning, inference and language" (1999: 12). While their primary source of evidence for the cognitive unconscious is cognitive psychology, Lakoff and Johnson also intend for this sense of embodiment to include the neural modelling at least some aspects of our neurophysiological embodiment, noting that these "are obviously not independent of one another" (1999: 104). However, I would argue that these two aspects can be profitably separated out from the cognitive unconscious of experimental cognitive and social psychology as two additional dimensions of embodiment.

2.8. Dimension 8: Neurophysiology

In a *neurophysiological* sense, the term "embodiment" can refer to measuring the activity of the particular neural structures and cortical regions that accomplish feats like object-centred versus viewer-centred frames of reference in the visual system, metaphoric projection, and so on (Rohrer 2005, 2001b; Coulson & Van Petten 2002). Such methods would include single-neuron recording, electroencephalography (EEG) and derivative measures (EMG and ERP), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magneto-encephalography (MEG), as well as the neuroanatomical organization of the brain and nervous system. This dimension would comprise a portion of, but not be synonymous with Lakoff and Johnson's use of their term "neural embodiment" (1999: 102-103), in which they lump neurophysiologically-based methods together with the neurocomputational modelling of both high-level cognitive tasks (such as temporal aspect in language) and low-level cognitive tasks (spatial perception). Together with observations on human physiology, the relevant neurophysiology is sometimes advanced as explaining certain constraints on the patterns exhibited in linguistic systems, such as in the regularities in the cross-cultural typology of color words (Lakoff 1987).

2.9. Dimension 9: Neurocomputational modelling

"Embodiment" can sometimes also refer to research using *neurocomputational* models. Such neural networks may be said to be "embodied" in at least four different ways. First, they may more or less closely model the actual *neurophysiology* of the neural circuitry whose function they seek to emulate. Second, some kinds of neural networks build on better-understood neurocomputational models of the actual neurophysiology to provide "existence proofs" that a series of neural nets could in principle account some kind of cognitive behaviour—as in "structured connectionism". Neurocomputational models such as those in Lakoff and collaborators' "neural theory of language" thus are not explicit models of the underlying neurophysiology, but instead (and by using as their input structures the output from better understood perceptual neural structures) they seek to demonstrate how the known computational facts about the neurophysiology *could* produce certain kinds of observable linguistic behaviours (such as the metaphoric structuring of more abstract experience in terms of perceptual experience) (Lakoff & Johnson 1999: 569-83; see also Regier 1992, 1995; Feldman & Narayanan 2003). Third, and most often without any explicit reference to any intermediate structures in the underlying neuroanatomy, connectionist neural networks are taken to be models of *experiential* activity at the conceptual and/or psychological levels of processing, as in the stochastically-based arguments that there is no "poverty of stimulus" but instead plenty of experience to account for the acquisition of syntax by children—(Elman et al. 1996; MacWhinney 2003). Fourth, neural networks can be seen as models of how socio-cultural norms can be internalized within a specific "mind" (Zlatev 1997, 2003; Howard 2001). For example, by developing neural models of how the age/gender contrasts are marked in English and Spanish, Howard argues that biased socio-cultural norms of age and gender are partly the result of predispositions of how the human brain and nervous system learn.

It is important to note that the neurocomputational use of this sense of "embodiment" is partly motivated by the fact that some other physiological, experiential and/or socio-cultural dimension of that term is explicitly being modeled by the neural network. Yet such models seek to ground their models not only in what they seek to model, but also in the fact that "neurocomputational embodiment" is explicitly anti-functionalist. All neural networks are anti-functionalist in that the particular shape of the neural model is at least partly determined by analogizing some of its computational properties to the underlying neurophysiology, rather than presuming that the cognition or behavior to be modeled is computationally independent of any such bodily constraints (as in functionalist models).

2.10. Dimension 10: Morphology

The terms "embodiment" and "embodied cognition" are now also widely used in robotics (Chrisley & Ziemke 2002) where any computational modelling necessarily requires a body of some type for interaction with the world. While in robotics it is perhaps most saliently associated there with humanoid robot projects (Brooks & Stein 1994), it can also refer to cases where the work done by the robot depends on the particular *morphological* characteristics of the robot body (Pfeifer & Scheier 1999). For example, Cornell University's Passive Dynamic Walker uses no motors and no centralized computation but instead relies on gravity, mechanical springs and cleverly designed limb morphology to "walk". By exploiting the capacities of the morphology, cognition is offloaded onto the body—a design principle that is consonant with both evolutionary theory and embodied cognitive science (Collins, Wisse & Ruina 2001; Bertram & Ruina 2001).

The morphology of the physiological body also yields important constraints for measuring cognition in cognitive psychology or cognitive neurophysiology, as in the already discussed studies by Parsons (1987ab, 1994; Parsons et al. 1995) on the mental rotation of line drawings of the hand and in the Vingerhoets et al. (2002) fMRI study of the activation courses in response to images of tools.

2.11. Dimension 11: Directionality of metaphor

Within Cognitive Linguistics, the term "embodiment" has two often conflated senses that stem from Lakoff and Johnson's (1980: 112) initial formulation of the embodiment hypothesis as a constraint on the directionality of metaphoric structuring. More accurately, this sense of "embodiment" could be termed the *directionality of metaphor mappings*. In this strong directionality constraint Lakoff and Johnson claim that we normally project image-schematic patterns of knowledge unidirectionally from a more embodied source domain to understand a less well-understood target domain. In other words, they claim that each and every mapping between the elements of the source and the elements of the target is unidirectional; the logic of the image-schema is projected from the source to the target, and not from target to source. For example, in their analysis of the metaphors shaping various theories of visual attention in cognitive psychology, Fernandez-Duque and Johnson claim that:

> […] each submapping is directional, going from source to target. We understand aspects of the target domain via the source domain structures and not the reverse. Such unidirectionality shows itself clearly in the reasoning we do based upon conceptual metaphors. (Fernandez-Duque & Johnson 1999: 85)

This constraint has been the source of much controversy within cognitive linguistics. Faucounier and Turner (1995, 2002) and others have argued that there is a much greater role for feedback between target and source to the extent that they have proposed an alternate theory in cognitive semantics, conceptual blending, which is in part a response to the unidirectionality constraint. Non-unidirectional and blending-like phenomena can be observed with respect to the same theories of visual attention analyzed by Fernandez-Duque and Johnson. For example, they correctly argue that a VISUAL ATTENTION IS A SPOTLIGHT metaphor shapes research questions in cognitive psychology, such as for experiments designed to measure the speed at which the attentional spotlight moves across the visuo-spatial field when experimental participants shift the focus of their attention (Shulman, Remington & McLean 1979) and whether the subject would attend to intermediary objects in the path of the attentional spotlight (Tsal 1983). However, the cognitive psychologist Müsseler (1994) observed that although relatively proximal shifts in the focus of visual attention seemed to behave as if the attentional spotlight did follow an analog path across the visual field illuminating everything in its path, larger shifts in the focus of visual attention did not follow an analog path. This observation about the target domain (visual attention) initiated a re-examination of the source domain. Müsseler initially proposed that the attentional spotlight was "reset" during large attentional shifts. However, convergent evidence from both other psychological studies of attention and from cognitive neuropsychology on colour, motion, shape and other visual subsystems caused an even more radical shift in the source domain of the metaphor—visual attention began to be understood as an array of multiple spotlights, as would be found in a theatre (Rohrer 1998). In no case was this process of feedback, revision, and accommodation strictly unidirectional; it was always motivated by observed changes in the target domain of visual attention that required making changes to the source domain of spotlight(s).

2.12. Dimension 12: Grounding

Finally, "embodiment" can be used to refer to a particular hypothesis as to how we might explain how abstract symbolic behaviour is grounded in experience. Within Cognitive Linguistics even Lakoff and Johnson's original formulation (1980: 112) of the embodiment hypothesis contained the germ of a broad generalisation about the kinds of basic conceptual domains which were typically serving as source domains for conceptual metaphors, rather than as explicitly referring to the directionality of projection for each and every element mapped within a particular metaphor. We might call this additional sense of embodiment *the directionality of explanation* in order to distinguish it from the directionality of metaphor mappings. Lakoff and Turner specifically acknowledge this sense of embodiment in their *"grounding hypothesis"*, in which they argued that meaning is grounded in that we must choose from a finite number of semantically autonomous source domains to understand more abstract experiences (Lakoff & Turner 1990: 113-120). This sense of the term is related to the *symbol-grounding problem* in cognitive science generally (Harnad 1990), though it is important to note that many embodiment theorists would want to address that issue without conceding any sort of Cartesian-like split between words, thoughts or symbols and the worldly things to which they refer.

This descriptive list is meant to illustrate that the embodied cognitive science requires thinking through evidence drawn from a multiplicity of perspectives on embodiment, and therefore drawn from multiple methodologies. Of course almost no researcher or research project can attend to all these different senses of the term at once and still produce scientific findings, but research projects that build bridges or perform parallel experiments across these differing dimensions are of particular interest. However, once the descriptive work has been done it can be seen that many of these senses cluster about at least two poles of attraction. Critiques of the embodied cognitive science from within have often given voice to two broad senses in which the term "embodiment" is used. These two could be well described as "embodiment as broadly experiential" and "embodiment as the physical substrate". In one cluster the term refers to dimensions that focus on the specifically subjective, contextual, social, cultural and historical experiences of language speakers. Dimensions (2) through (4) of my enumeration of the term's usage would typically cluster in this realm, while dimensions (7) through (10) would often cluster about the pole which emphasizes the physiological and neurophysiological bodily substrate that is typically associated with supposedly more "objective" methodologies.

Such a division is at best rough and provisional however. Clearly not all the dimensions of the term can be so clustered, given that the attention to temporal character which characterizes the developmental (5) and evolutionary (6) dimensions can place them about either pole. Similarly, there are many interesting studies which bridge the gap between the experiential and the physiological poles even while largely measuring a dimension typically construed as mostly one or the other, such as the Kosslyn group's neuroimaging research into alternate strategies of mental rotation (2001). Depending on the behaviour modelled, embodiment as neurocomputational modelling (9) can also cross the line from the physical substrate to more experiential matters. Finally, the more explicitly meta-theoretical dimensions of the term, (1), (11) and (12), have much traffic with both the experiential and physical substrate poles and also do not lend themselves easily to such a rough and ready distinction. Given such considerations, at least two more poles of attraction emerge—temporal and metatheoretical studies. In the end, an adequate theoretic framework for embodiment theory in cognitive science will have to acknowledge all of the wide variety of senses in which the term "embodiment" is being used and provide a non-reductionistic framework for reconciling research across all these different dimensions.

3. The levels of investigation theoretic framework

The rough and ready distinction between experiential and physiological embodiment does have the virtue, however, of illuminating how we might assess the utility of different approaches to embodied cognition. Two other recent attempts to clarify the uses of the term "embodiment" have come to diametrically opposed conclusions as to how embodiment theory can contribute to future work. On one tack, the computer scientist Anderson (2003) proposes evaluating embodiment theory in terms of its practical utility in reconceiving how our work and our lives can be enhanced. His objectives are fundamentally technological, inquiring whether embodiment theory has any import for efforts to offload difficult cognitive tasks onto the social and cultural environment, such as teamwork or the design of intelligent material artifacts such as embedded computers. On another tack, theorists such as the psychologist Wilson (2002) propose an experimentally-based evaluation of embodiment theory, arguing that we need more investigations of how offline, subconscious bodily processes structure real-time cognition while explicitly rejecting efforts to explain cognition as being situated in and distributed across socio-cultural practices. Clearly, these approaches differ not only as to what direction future research should take but also in terms of the physical scale of their research scope. Wilson's concerns are primarily with how the individual physiological organism interacts with its environment, arguing that distributed social and cultural patterns of cognition are too impermanent to constitute a unit of analysis having explanatory force (2002: 630-631). While Anderson also agrees that insights from how the embodied individual organism interacts with the physical world are relevant, he argues that embodied cognition has "social significance, for the construction of meaning, of the terms through which we encounter the world, is not generally private, but is rather a shared and social practice" (2003: 125). In considering whether and how a material artifact such as patient's medical chart might be extended by embedded computers, he notes that such efforts should not seek to obliterate important facets of how the material artifact encodes the fact that cognition is distributed across the social group caring for the patient, such as how the handwriting indicates what member of the group made a particular observation or where the chart is kept indicates what member of the medical team has responsibility for the patient. On Wilson's argument the scope of the research would be limited to the size of space within which the individual interacts with the artifact, but for those cognitive scientists interested in improving the functioning of such social groups, the scope of the physical scale expands to encompass the entire cultural and communicative space of the team.

However, from my own vantage as a cognitive scientist originally trained in the philosophical tradition of American Pragmatism, both of these theorists are sailing in the right direction—given that the relevant operational scale of the phenomena they are studying has changed. The first challenge for developing a theoretical framework in which we can address such differing approaches is to propose the adoption of a simple and well-understood organising criterion. Unfortunately, most previous proposals have generally accorded an ontological status, rather than an epistemological or methodological status, to the organisation of their theoretic framework. Thus most such frameworks postulate "higher" and "lower" levels of cognition in ways which imply that the higher levels may be reduced to operations at the lower levels, ultimately arguing for the elimination of higher-levels of description in favour of lower levels of description (Churchland 1981, 1989). One exception is Posner and Raichle's (1994) schematisation of the levels of investigation in cognitive neuroscience, in which the primary emphasis is given to the methodologies used to investigate the phenomena rather than their ontological status. Similarly, Edelman (1992) points out that in the physical sciences, the phenomena are operationally grouped in levels according to the physical scale of the methodology with which the phenomena are being studied. Thus the most basic organising criterion of this theoretic framework is the scale of the relative physical sizes of the embodied phenomena which produce the different kinds of socio-cultural, cognitive or neural events to be studied.

In Figure 1, physical size is mapped on the y-axis, providing a relative distribution of the "higher to lower" methodological levels of cognitive processes. A general name for each level is indicated by boldface type in the first column. To provide clarification, the next column provides examples of what the relevant physiological structures are at a given physical scale. For example, at the communicative, cultural and social level we study spatial language as it used between people, and hence multiple central nervous systems; alternatively, it is possible to measure one individual's (and hence one central nervous system's) performance on a similar set of linguistic tasks. Similarly we can examine, with even more granularity, relative changes in cerebral blood flow to regions of the brain in response to spatial linguistic tasks; or we can construct neurocomputational models of those brain regions. However, Posner and Raichle's key insight is that it is important to consider how the basic inquiry change changes given the different tasks and methods at various levels of investigation. All methodologies have constraints and freedoms which limit or enhance their scope of investigation and define the theoretical constructs that they develop, and these are a product of the physical scale at which the measurement is taking place. The final two columns acknowledge this by specifying some of the relevant theoretic constructs and the various methodologies operative at each level of investigation.

Size	Physiological Structures	Level of Investigation	*Typical Cognitive Science Tasks*	*Sample Operative Theoretic Constructs*	*Sample Methods of Study and Measurement*
1 m and up	Multiple Central Nervous Systems	**Communicative and cultural systems** in anthropology, language, science and philosophy	Cross-cultural investigations of mental rotation and frames of reference; language acquisition; conceptual metaphor; gesture	Viewer-centred, object-centred, geo-centred frames of reference in language; child-rearing practices; norms as to which spatial frame used	Linguistic analysis, cross-linguistic typology, videotaped interview, cognitive ethnography, discourse analysis
.5 m to 2 m	Central Nervous Systems	**Performance domain;** Cognitive, conceptual, gestural and linguistic systems as performed by individual subjects	Individual performance on frames of reference and mental rotation tasks; measuring ability to gesture in direction-giving situations contrived to inhibit it	Spatial frames of reference, speed of mental rotation; morphological constraints	Verbal report, observational neurology, cognitive and developmental studies examining reaction time (RT)
10^{-1} m to 10^{-2} m	Gross to medium size neural regions (anterior cingulate, parietal lobe, etc.)	**Neural systems**	Activation course in somatosensory, auditory, and visual processing areas when processing spatial frames of reference tasks or mental rotation tasks	Body-image, motor and visual cortices, what-where pathway;	Lesion analysis, neurological dissociations, neuroimaging using fMRI and PET, ERP methods, neurocomputational simulations
10^{-2} m to 10^{-4} m	Neural networks, maps and pathways	**Neuroanatomy;** Neural circuitry in maps, pathways, sheets	Neuroanatomical connections from visual, auditory, somatosensory regions to language areas	Motor and visual cortices, parietal topographic neural maps	Electrocellular recording, anatomical dyes, neurocomputational simulations
10^{-3} m to 10^{-6} m	Individual neurons, cortical columns	**Neurocellular systems;** Cellular and very small intercellular structures	Fine neuroanatomical organisation of particular structures recruited in language processing	Orientation-tuning cells; ocular dominance columns	Electrocellular recording, anatomical dyes, neurocomputational simulations
Less Than 10^{-6} m	Neuro-transmitters, ion channels, synapses	**Subcellular systems;** subcellular, molecular and electrophysical	None—beyond theoretical scope	Neurotransmitter, synapse, ion channels	Neuro-pharmacological, neurochemical, and neurophysical methods

Figure 1. Theoretic framework for embodied cognitive science

This framework can be used to structure studies of various topics of interest to cognitive scientists, such as mental imagery, frames of reference, metaphor and so on. While this type of theoretic framework is becoming commoner within much of cognitive neuroscience, most embodiment theorists have been slow to give explicit attention to the problem of how we are to theoretically situate and reconcile these different levels of investigation, perhaps due to a fear of appearing to favour reductionism.

I have included just a single level of cultural and communicative analysis, but by no means should this be taken as indicative of its importance relative to other the other levels. Of course, one could argue for a multiplicity of levels embedded within this one, though they might not be clearly differentiated from one another in terms of physical scale. In choosing to include a general level situated at a meter and up on the physical size axis I mean to emphasize only that human beings should be considered not simply in terms of physiological size, but also in terms of the standard scale of their interactional distance in speaking and interacting with one another.

At this level of the chart the "physiological structures" column reads "Multiple Central Nervous Systems", but that awkward term is intentionally inadequate so as to emphasize that the physiology is less relevant here—what primarily matters on this level are the social and cultural interactions *between* human beings. Investigations at the cultural level are occasionally given short shrift by some versions of embodied cognitive science, but generally this has been and should remain a strong thrust of future research in the field. Note also that difficult phenomena such as cultural and linguistic norms, or individual consciousness and awareness, are situated at the physical scale at which they are measured and observed, rather than attempting to place them on (or reduce them to) a lower level of investigation. Nonetheless, it is certainly possible and sometimes useful to ask, for example, how long the neural processing of a visual experience takes before impacting conscious decision-making, or how the linguistic norm of forming the English past tense might be performed in a neurocomputational model. However, research in embodied cognitive science should not seek to reduce such phenomena to another level but should instead bridge across these levels in important ways—for example, the linguistic corpora used to train the neurocomputational model should be based on naturalistic recordings of an actual child's utterances rather than text harvested from internet newsgroups, and so on.

While the chart depicting the theoretic framework is designed to give an overview of the relationship between body, brain and culture, this representation is not as illustrative for issues pertaining to evolutionary and developmental time scales, which may be considered at any of these levels. However, this failing is more a limitation of the imagery of a two-dimensional chart than of the theoretic framework itself. If we were to add another axis for time perpendicular to the surface plane of the chart, we could imagine this framework as a rectangular solid. I have omitted representing this dimension because such an illustration would make it difficult to label the levels, but I make the point explicit here because both the developmental and evolutionary time courses of these phenomena are a central dimension to understanding them, and their bearing on the embodied mind.

4. Applications of the theoretic framework

This theoretic framework can help link related research from one level of investigation to another, providing opportunities to test similar hypotheses and incorporate insights originally developed at one level of investigation at another. As in the introduction I have already given several examples of embodied cognition linking physiological and neurophysiological experiments on cognition, consider three examples from the cultural and performative levels of investigation involving mental rotation and frames of reference.

First, in a series of cross-cultural and cross-linguistic typological studies on spatial cognition, Pederson et al. (1998) have found that the linguistic frame of reference[4] which predominates in a language strongly influences the spatial cognition problem-solving strategy chosen. In one of several tasks they use, experimenters place three animal figurines in a row on a table and ask

[4] As I summarize their typological work I use Levinson's (2003) terminology for linguistic frames of reference, though I try to indicate a rough alternative term from the broader literature on spatial frames of reference in the cognitive sciences where their nomenclature may be uninformative to the naïve reader. However, such indications are intended only as clarifying approximations, and readers should refer to Levinson's own work for detailed definitions of his terms for the linguistic frames of reference.

participants to memorize the scene. The participants are then rotated 180 degrees and asked to reconstruct the scene on a second table. Speakers of languages which predominately use a relative frame of reference normally recreate the scene relative to their own body position—i.e., the animal to their left in the original rotation remains the animal on their left in the new 180-degree rotation. However, speakers of languages in which an absolute (geo-centric) frame of reference predominates recreate the same scene relative to the position of the animals with respect to invariant features of the landscape—i.e., the animal to the north is still placed on the north side even though the participant's body position has been rotated 180 degrees from the original scene. Despite numerous challenges, they have successfully replicated their findings in a variety of experimental environments and across a wide variety of languages (Majid et al. 2004). A typological finding, gathered at the cultural level of investigation, has been transposed onto the performative level of investigation.

Their experimental research has been extended by a second source of evidence concerning spatial frames of reference which is of substantial interest to researchers working on embodiment—studies of gesture. By cleverly manipulating the body position of his experimental subjects relative to the directions the experimenter requests, Kita (2003) has shown that in giving directions speakers of languages in which the relative frame of reference predominates will often make difficult, torso-twisting gestures across their bodies in an attempt to co-align their current bodily perspective with the perspective that they would need to have in order to tell if a landmark at that point in the directions will be on the right or left. Just as with the work on mental rotation and mental imagery, in direction-giving the embodied mind simulates following the path of the directions being given. This process of mental imagery—the *mental* gymnastics done by the speaker's mind as one visualizes how the hearer will need to follow the directions—surfaces in the form of *physical* gymnastics—that is, the gestures involving the rotation of the torso. Once again, these experiments link the cultural and performative levels of investigation.

Third, evidence of the ways in which language and culture embody spatial frames of reference has also been found in studies linking gesture and conceptual metaphor. In Indo-European languages such as English and Spanish, time is typically conceptualized using two basic TIME IS SPACE metaphors—one in which the observer stands still while times pass by (e.g., "The end of the year is *coming up* on us soon"; and another in which the observer is moving through a landscape of times (e.g., "We're *coming up* on the end of the year") (Lakoff & Johnson 1980, 1999). However, in both metaphor systems the observer faces the future, while the past is behind the observer. Núñez and Sweetser (in preparation) have shown that for speakers of Aymara, who almost exclusively use a stationary version of the TIME IS SPACE metaphor, the past is in front and the future comes from behind. In Aymara, the orientation of the spatial frame of reference is reversed. Using videotaped interviews with bilingual Spanish and Aymara speakers both recounting Aymara legends and talking about their own communities' immediate future, they demonstrate how speakers gesture to areas in front of them when referring to the past, while gesturing to future events with over the shoulder motions. Furthermore, the gestures reveal that more recent past events are closer to the speaker's point of view than events in the more distant past. For example, as he contrasts ancient times with current events, an informant gestures by pointing outward and upward as opposed to pointing four times closer to his body. Together with their linguistic research on the Aymara conceptual metaphors for time, the Núñez and Sweetser research shows that the Aymara map the temporal frame of reference onto a viewer-centred frame of reference in an inverse direction to that found in English or Spanish.

These three studies, largely situated at the “top” levels of the theoretic framework, are excellent examples of how the cultural level of embodiment is expressed in the performances of individual experimental participants. Not only that, but they also provide clues of what researchers might ask next at other levels of investigation. For example, one might ask what sorts of analogous linguistic stimuli would show neural responses similar to spatial stimuli. One could design neuroimaging experiments investigating whether navigating directions on a visual display required mental imagery rotation in either the visual or motor imagery system. Analogously, one could also investigate whether or not *sentence* stimuli concerning a similar navigational task requiring either a viewer-centred, object-centred, or geo-centred set of coordinates would activate distinct brain regions.

There are several convergent neural studies which indicate that this is a hypothesis worth pursuing. In a recent review article, Parsons (2003) argues that we can already distinguish between superior parietal cortical regions active when mentally rotating objects about their own axis (i.e., in an object-centred frame) and superior parietal regions active when mentally rotating one’s own body (a viewer-centred frame). Several neuroimaging studies using spatial relations terms as linguistic stimuli also show activation of either left (Damasio et al. 2001) or both (Emmorey et al. 2005; Carpenter et al. 1999) superior parietal cortical areas, though none of those tasks were designed to elicit distinctions between the frames of reference. Similarly, there is also convergent evidence from the literature on attention in visual hemi-neglect (a syndrome typically resulting from damage to the right superior parietal cortex) suggesting that viewer-centred and object-centred neglect are dissociable phenomena in experimental and observational neurology (Behrmann & Tipper 1999; see Rohrer 2001a for discussion). Halligan et al. (2003) reviews the neurological evidence that neglect of near and far space occurs independently, suggesting that they are likely to be mapped in separable parietal areas—evidence which suggests that the geocentric frame of reference in language could be correlated with the map of far space. Furthermore, while most studies of neglect do not report language deficits on standard naming or visuo-auditory picture matching tasks, a recent study by Eden et al. (2003) shows that when dyslexic children were asked to draw a clock face they neglected to fill in the numbers on the left side of the clock face in much the same manner as observed for the standard clock drawing task given visual neglect patients. Their results suggest that there may be a common underpinning for spatial representation and language in right superior parietal cortical areas. Yet more evidence of parietal involvement in spatial language can be found in Coslett and Lie (2000), who have reported on parietal patients who exhibit spoken language and comprehension deficits correlated with the spatial orientation of their body (see also Chatterjee 2001). In sum, while there are not yet any definitive studies showing that linguistic stimuli can drive distinct regions of the parietal cortex thought to be responsible for maintaining viewer-centred, object-centred and geo-centred frame of reference maps, studies of both parietal involvement in language and the parietal processing of different spatial frames of reference provide good reason to investigate the possibility. Although the mapping between the frames of reference observed in linguistic typologies (Majid et al. 2004) and the frames of reference used in neural processing is not likely to be isomorphic, experiments bridging the two lines of investigation could prove fruitful.

One could also ask about the role of the parietal regions in understanding metaphoric expressions of spatial relations. If linguistic stimuli can drive the brain regions demonstrably involved in tasks involving the different spatial frames of reference, then would metaphoric linguistic stimuli drive those same brain areas given in tasks involving a temporal frame of reference? Similar to the Aymara gestural results, other studies of how temporal reasoning and spatial reasoning interact (see Matlock, Ramscar & Boroditsky 2005) have shown that temporal problem-solving uses the resources of spatial problem-solving. One could design linguistic comprehension and linguistic problem-solving tasks using the TIME IS SPACE metaphor that might differentially activate those parietal areas.

It is also important to see that the dialogue between the levels of investigation in this theoretic framework is not a one-way street. Similar questions can also be taken to the cultural and communicative level from the neurophysiological level. For example, and with respect to multimodal user interface design, as we know that altering the viewer-centred versus the object-centred perspective influences which neural system performs mental rotations (Kosslyn et al. 2001), can we take advantage of that fact to design better hand controls and visual displays for real-world tasks that involve real-time mental rotation, such as airplane piloting or air traffic control? The appropriate display and control interface should prompt for the appropriate frame of reference. How might such controls help mitigate errors in frames of reference problems that result from the finding that people find it more difficult to rotate object-centred frames than ego-centred frames (Wraga, Creem & Proffitt 1999)? If the speakers of some languages prefer to use a certain frame of reference, how does that alter how one might teach technical skills (such as navigation) that involve mental rotations in a cross-cultural setting? The list of such questions is endless, for the details of embodiment play an enormous role in every cognitive activity.

5. Conclusions

Human beings have bodies, and those bodies shape and constrain how we think. At the outset of this chapter, I asked the reader to imagine how an event as mundane as a power outage can reawaken an awareness of the body. However, and as I have argued throughout this chapter, the body is not some other thing to which the mind returns when thinking is interrupted—thinking itself is shot through and through with the body. In the words of the early American Pragmatist philosopher-psychologist William James:

> […] our own bodily position, attitude, condition, is one of the things of which *some* awareness, however inattentive, invariably accompanies the knowledge of whatever else we know. We think; and as we think we feel our bodily selves as the seat of the thinking. If the thinking be *our* thinking, it must be suffused through all of its parts with that peculiar warmth and intimacy that make it come as ours. (James 1900, 1: 241-242, emphases original)

When we think about rotating a hand in space, we *feel* that it is more difficult to rotate in ways which conflict with the natural motions of our joints; when we have pain in the appropriate joints, we rotate it slower. As James notes, we often may be inattentive to this sort of awareness, especially when we are physically fit and habitually lost in thought; at such times we may need experiments to reacquaint ourselves with the body. But for those of us who feel pain in their wrists as they imagine gripping and rotating a hammer, no argumentative reintroduction is necessary—for them, the awareness that our own thinking is embodied is inescapable.

James' felt sense of the experienced body, or what I have called the phenomenological dimension of embodiment, is only one prominent dimension among the many dimensions of the term discussed in this article. Over the first fifty or so years of cognitive science the field deliberately theorized away the many contributions of the body to thinking, a theoretical failing that is only now beginning to be corrected. Interdisciplinary research, ranging from linguistics and neuroscience to philosophy and psychology, using methods ranging from the experimental and physiological to the phenomenological and sociological, has begun to show that there are multiple dimensions along which the human body shapes human thought. For example, in classical cognitive science our mental representations were assumed to be logical and symbolic; however, cognitive neuroscience has shown them to be embodied and image-like. Like the Pragmatist philosophers, the new approaches see human cognition as action situated within a practical context, and mental representation as instrumental rather than absolute. Our ordinary experience of space is not one in which we seek to discover some absolute external frame of reference, but one in which we are obsessed with co-ordinating multiple frames of reference—body-, head-, or other-centred—in order to solve the practical problem at hand. That practical problem may be getting directions to an unfamiliar place, helping a patient recover from and cope with visual neglect, a team of navigators piloting a ship, file management within a computer's graphical user interface, or tracking a lost child through the forest; but all of these examples share a common thread of understanding how the body establishes frames of reference and moves in space. As the neuroscientist Antonio Damasio puts it:

> The body, as represented in the brain, may constitute the indispensable frame of reference for neural processes that we experience as the mind; that our very organism rather than some absolute external reality is used as the ground reference for the constructions we make of the world around us and for the construction of the ever-present sense of subjectivity that is part and parcel of experiences; that our most refined thoughts and best actions, our greatest joys and deepest sorrows, use the body as a yardstick. (Damasio 1994: xvi.)

Embodied cognitive science begins with the realization that the body, along all of the dimensions I have outlined in this chapter, grounds and shapes human cognition.

Wakened from its long dormant slumber, the body has returned to cognitive science. In this survey chapter I have traced how our physiological, neurophysiological, interactional and sociocultural embodiment impinges on how we think. The embodied mind is not something which should be narrowly identified with any one of these levels of investigation, nor with any one of the dimensions of variability that I have noted. The embodied mind cannot be reduced only to the brain any more than it can be reduced to culture. Nor is the embodied mind merely a computer, in any traditional sense of that term; it can be said to perform "computations", but the substance and structure of these computations are imagistic due to the particular kind of bodies we have and the environments we inhabit. We are just at the beginning phase of understanding the myriad ways in which the body is in the mind.

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