Image Schemata in the Brain[*]

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ABSTRACT

A focus on the brain as an organic biological entity that grows and develops as the organism does is a prerequisite to a neurally-plausible theory of how image schemata structure language. Convergent evidence from the cognitive neurosciences has begun to establish the neural basis of image schemata as dynamic activation patterns that are shared across the neural maps of the sensorimotor cortex. First, I discuss the numerous experimental studies on normal subjects that, coupled with recent neurological studies of body-part language deficits in patients, have begun to establish that the sensorimotor cortices are crucial to the semantic comprehension of bodily action terms and sentences. Second, by tracing the cognitive and neural development of image schemata through both animal neuroanatomical studies and human neuroimaging studies, I review the neurobiologically plausible bases for image schemata. I propose that Edelman's theory of secondary neural repertoires is the likeliest process to account for how integrative areas of the sensorimotor cortex can develop both sensorimotor and image schematic functions. Third, I assess the evidence from recent fMRI and ERP experiments showing that literal and metaphoric language stimuli activate areas of sensorimotor cortex consonant with the image schemata hypothesis. I conclude that these emerging bodies of evidence show how the image schematic functions of the sensorimotor cortex structure linguistic expression and metaphor.

Keywords: Image schema, cognitive neuroscience, semantic comprehension, metaphor, neural development

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1.   Introduction

1.1   Dynamic patterns: image schemata as shared activation contours across perceptual modalities

Let me begin with a bold and preposterous claim. *I want to hand you an idea that at first may seem hard to grasp, but if you turn it over and over again in your head until you finally get a firm handle on it, it will feel completely right to you.* Now, if I could make a movie of what your brain was doing as you read that last sentence, it would most likely look very similar to a brain movie of you turning an unfamiliar object over and over again in your hand until you found a way to grip it well. Your primary motor and somatosensory cortices would be active in the areas mapping the hand and the wrist, and the premotor and secondary somatosensory hand cortices would also be active.

Until recently, these suggestions would have seemed to be more the stuff of idle speculation and science fiction than of scientific fact. However, over the past few years we have been able to paint just that kind of picture, given recent advances in brain imaging technology coupled with research findings by, e.g., Hauk et al. (2004); Coslett et al. (2002); Moore et al. (2000); Rizzolatti et al. (2002; 2001) and Rohrer (2001b). There have been substantial obstacles on the way, not the least of which was a long-standing misbelief that the language functions occur exclusively in areas of the inferior frontal lobe and superior temporal lobe—primarily in Broca's and Wernicke's areas.[1]

However, a new picture of a distributed model of semantic comprehension is now emerging. In the new model, brain areas formerly thought to be purely sensorimotoric are turning out to have important roles in the so-called 'higher' cognitive processes, e.g., language. In other words, language makes much more use of the brain's processes of spatial, visual and mental imagery than previously thought. Inspired by linguistic[2] and phi-

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[1] Such theories were driven by historical evidence from linguistic disorders such as aphasia and anomia, which showed that lesions to those areas in the left hemisphere of the brain were correlated with these disorders.

[2] This evidence mostly stems from the semantics of spatial-relation terms, which tend to be extremely polysemous (cf. Lakoff 1987: 416-61; Brugman 1983; Dodge and Lakoff, *this volume*; Talmy, *this volume*, 2000: 409-70, 1985: 293-337).

losophical[3] evidence, the philosopher Mark Johnson (1987) and the linguist George Lakoff (1987) theorized that linguistic expressions evidenced dynamic patterns of recurrent bodily experience which they called *image schemata,* and later hypothesized that these image schemata were such frequent and deeply held patterns of experience for human organisms that they were likely to be instantiated in our nervous system (Lakoff and Johnson 1999). For example Lakoff (1987: 416-61) observes that there are many linguistic senses of the English word 'over.' Consider two of them: 'the fly is over my head,' and 'I turned the log over.' In the first sentence 'over' is being used in what Lakoff calls a fairly canonical sense of an ABOVE image schema, where a small trajector (the fly) passes over a large landmark (my head). However, 'over' in the second sentence also utilizes a REFLEXIVE image schema transformation, in which the trajector and landmark become the same object (the log). Furthermore, he notes that such schematizations can be used metaphorically, as in the example of 'turning an idea over and over again.'

Johnson (1987) first defined an image schema as a recurrent pattern, shape or regularity in, or of, our actions, perceptions and conceptions. He argued that

> these patterns emerge primarily as meaningful structures for us chiefly at the level of our bodily movements through space, our manipulation of objects, and our perceptual interactions (Johnson 1987: 29).

His definition was illustrated by several examples of how linguistic and conceptual structure is underlain by image-schematic structure. For instance, the CONTAINMENT schema structures our regular recurring experiences of putting objects into and taking them out of a bounded area. We can experience this pattern in the tactile perceptual modality with physical containers, or we can experience this perceptual pattern visually as we track the movement of some object into or out of some bounded area or container. He argued that these patterns can then be metaphorically extended to structure non-tactile, non-physical, and non-visual experiences.

In a particularly striking sequence of examples, Johnson (1987: 30-32) traced many of the habitual notions of CONTAINMENT we might experience during the course of a typical morning routine: We wake up *out of* a deep sleep, drag ourselves *up out of* bed and *into* the bathroom, where we look *into* the mirror and pull a comb *out from inside* the cabinet. Later that same morning we might wander *into* the kitchen, sit *in* a chair at the breakfast

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[3] For extensive details, see Johnson (*this volume*, 1987: 18-193).

table and *open up* the newspaper and become lost *in* an article. Some of these experiences are spatial and physical but do not involve the prototypical CONTAINMENT image schema (as in the example of sitting *in* a chair) while some of these experiences draw on purely metaphorical extensions of CONTAINMENT (as in the example of getting lost *in* the newspaper article). Johnson proposed that the CONTAINMENT image schema, or some portion or variation of it, structures all of these experiences.

However, Johnson (1987: 19-27) proposed image schemata not only as a link between the linguistic evidence and the philosophical phenomenology, but explicitly intended them to be consonant with other research in the cognitive, developmental and brain sciences. Consider how experimental studies of infant cognition (Meltzoff and Borton 1979; Meltzoff 1993; cf. Stern 1985: 47-53) suggest a cross-modal perceptual basis for a SMOOTH-ROUGH schema: A blindfolded baby is given one of two pacifiers. One has a smooth nipple, the other a nubbed one covered with little bumps. The infant is allowed to suck on the nipple long enough to habituate to it, and then the pacifier and the blindfold are removed. When one smooth and one nubbed pacifier are placed on either side of the infant's head, the infant turns its head to stare at the pacifier just sucked about 75% of the time, suggesting that there is a cross-modal transfer between the tactile and visual modalities within the infant brain. It is as if the bumpy physical contours of the nipple are translated by the infant's tongue into bumpy activation contours in a tactile neural map of the object surface, which is then shared as (or activates a parallel set of) activation contours in a visual neural map of the object surface. Adults may not stare at such surfaces, but the experience of rough and smooth surfaces occurs myriads of times each day, as when we walk from a hardwood bedroom floor through a carpeted hall and onto the bathroom tile. As we do so, our eyes anticipate the change in surface and pass this on to our feet so that we can maintain our balance. If we perform the same bed-to-bath journey at night, we can utilize the surface underfoot in order to help us anticipate where to turn, visualize where the doorway is and so on. Whenever we accomplish such feats, we are relying on *our ability to share activation contours across perceptual modalities*.

Although the kind of abstractions evidenced in image schemata are perhaps most clearly introduced using examples of shared activation contours in cross-modal perception, there is no reason for image schemata to be construed as being *necessarily* cross-modal in every instance. Rather than an abstraction crossing perceptual modalities, an image schema might pick out

an abstraction "crossing" temporal boundaries. An image schema might be a particular pattern of neural activations in a neural map of pitch, say something corresponding to the musical scale in sequence (do-re-mi-fa-so-la …). From such an example we can see that image-schematic patterns are not temporally static, but take place in and through time. The musical scale is a sequence of activity in time; hearing an ascending pitch scale causes us to anticipate its next step. Given those first six notes, we sense its next step—ti—and expect the pattern to continue. The temporal character of image schemata creates the possibility of a 'normal' pattern completion, which in turn serves as the felt basis for their inferential capacity.[4] Image schemata are thus temporally dynamic in the sense that once they are triggered, we tend to complete the whole perceptual contour of the schema.

1.2   Image schemata and the body within the brain

In developing their notion of an *image schema*, both Johnson and Lakoff (Johnson 1987; Lakoff 1987; Lakoff and Johnson 1999) used the term 'image' in its broad neurocognitive sense of mental imagery and not as exclusively indicating visual imagery.[5] Mental imagery can also be kinesthetic, as in the felt sense of one's own body image. Take another thought experiment as an example. Imagine that I wish to sharpen my pencil. However, the pencil sharpener is located atop a tall four-drawer file cabinet next to my writing desk. Seated, I cannot reach the pencil sharpener by merely moving my arms. It is beyond my immediate grasp, and I will have to get up. What is more, if you were with me in my office, you would immediately grasp my predicament as well.

But how do we 'know' such things as what is within our reach? We know them because we have a coherent body image in our heads – soma-

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[4] While all humans normally develop neural maps for pitch, the musical scales do vary across cultures. Thus pattern-completion sequences such as the musical scale are good examples of how social and cultural forces can shape parts of image-schematic structure. Other image-schematic pattern completions, such as those for motor actions like grasping, are shared with other primates (Umiltá et al. 2001) and are likely to be universal across cultures.

[5] It is important to acknowledge, however, that the term "image schema" partly emerges from research on visual imagery and mental rotation (cf. Johnson and Rohrer in press; Johnson 1987: 25). The sentence, 'the fly walked all over the ceiling', for example, incurs a rotated covering schema (Lakoff 1987: 416-61).

totopic neurocortical maps of where our arms and hands are and how they can move, as well as neurocortical maps marking the location of objects in our visual field. We plan motor movements thousands of times each day, constantly re-evaluating the extent of our graspable space given our current bodily position. With a few discontinuities, the body image in the primary sensorimotor cortex is somatotopic, with adjacent neurons mapping largely contiguous sections of the body:[6] the ankle is next to the lower leg, and that to the knee and upper leg and so on. Similarly, the premotor cortical maps are also fairly somatotopic; e.g. neural arrays mapping hand motions are adjacent to those mapping wrist and arm motions. This topology is highly sensible, given that we need to use our hands and wrists in close co-ordination for tasks such as turning the pencil in the pencil sharpener.

Furthermore, in a series of recent studies on both macaque monkeys and humans, Rizzolatti, Buccino, Gallese and their colleagues have discovered that the sensorimotor cortices not only map 'peripersonal' space – i.e., what is within one's own grasp – but also contain 'mirror neurons' with which the premotor cortex simulates the actions being taken by another monkey, or another human (Rizzolatti and Craighero 2004; Fogassi et al. 2001; Buccino et al. 2001; Umiltá et al. 2001; Ferrari et al. 2003). When one monkey observes another monkey perform a grasping task with their hands, the mirror neurons will activate the motor-planning regions in the monkey's own hand cortex. The mirror neuron experiments of the Rizzolatti group (Rizzolatti and Craighero 2004) are cross-modal by design – experience in one modality must cross over into another. In this example, the visual perception of grasping crosses into the somatomotor cortices, activating the same sensorimotor schemata that would be activated by the monkey grasping something on its own. Moreover, other experiments (Umiltá et al. 2001) have also shown that the monkey needs only experience a small portion of the motor movement to complete the entire plan. Thus, their experiments also illustrate how the principle of the preservation of the bodily topology in the sensorimotor cortices affords the possibility of image-schematic pattern completion. Similarly, recent findings (Kohler et al. 2002) even suggest that such patterns can serve to integrate sensory input across modalities; a monkey's grasping mirror neurons can fire, for

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[6] The neural basis for the human body image was mapped by Wilder Penfield and colleagues at the Montreal Neurological Institute (Penfield and Rasmussen 1950), where neurosurgeons reported that patients under light anaesthesia either made movements or verbally reported feeling in the regions of their body when the cerebral cortex along the central sulcus was stimulated by the neurosurgeon.

instance, when the monkey hears a sound correlated with the grasping motion, such as tearing open a package. This suggests that even when triggered from another modality, the brain tends to complete the entire perceptual contour of an image schema.

1.3   Image schemata and language comprehension

Experimental studies on humans provide the additional avenue of investigating whether image schemata might arise in response to linguistic stimuli as well as to visual (or other sensory) stimuli. For instance we can use language to describe motor actions to participants in neuroimaging experiments, or we can ask brain-injured patients to name their body parts or to make simple pattern-completing inferences concerning their body parts (e.g. the wrist is connected to the ... hand).

Recent research has begun to establish that the sensorimotor cortical regions play a much larger role in such semantic comprehension tasks than previously thought. In the patient-based neurological literature, Suzuki et al. (1997) have reported on a brain-damaged patient who has a selective category deficit in body-part knowledge, while Coslett et al. (2002) have reported on patients in whom the body-part knowledge has largely been spared. The locations of these lesions suggest that the involvement of premotor and secondary somatosensory regions is functionally critical to the semantic comprehension of body-part terms (cf. Schwoebel and Coslett 2005). Similarly, but within experimental cognitive neuroscience, Hauk et al. (2004) measured the brain's hemodynamic response to action words involving the face, arm, and leg (i.e. 'smile', 'punch' and 'kick') using functional magnetic resonance imaging (fMRI) techniques. Their results show differential responses in the somatomotor cortices, i.e. leg terms primarily activate premotor leg cortex, whereas hand terms activate premotor hand cortex and so on. Their research[7] shows that it is possible to drive the

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[7] In a related study by the same group, Pulvermüller et al. (2002) used excitatory transcranial magnetic stimulation (TMS), electromyography (EMG) and a lexical-decision task to examine the semantic contribution of the somatomotor cortices. After using EMG to determine exactly where to place the TMS electrode for optimal stimulation of the hand cortex and the optimal amplitude and duration of the TMS pulse, participants viewed linguistic stimuli which consisted of either arm and leg action words or nonsensical psuedowords. The results show that when the left hemispheric cortical region which matched the arm or leg word was excited by

somatomotor neural maps using linguistic – as opposed to perceptual – input. The notion of an image schema may have originated in linguistic and philosophical hypotheses about spatial language, but – given the recent evidence from cognitive neuroscience – is likely to have its neurobiological grounding in the neural maps performing somatomotor and multimodal imagery tasks.

Parallel experimental results on action sentences from cognitive psychology lend additional credence to the neurological and neuroimaging evidence showing that the mental imagery carried out in the premotor and multimodal somatosensory cortices is *functionally* critical to semantic comprehension. Numerous experiments assessing the relationship between embodied cognition and language have shown that that there is a facilitatory/inhibitory effect on accuracy and/or response speed that holds for a diverse set of language comprehension tasks.[8] Such experiments suggest that the sensorimotor and somatosensory neural regions implicated by the neuroimaging and the selective-deficits studies are functionally related to language comprehension. The perceptual and motor imagery performed by certain regions of the brain subserve at least some processes of language comprehension: we understand an action sentence because we are subconsciously imagining performing the action.[9] Moreover, cognitive psychologists have shown that the sentence stimuli do not even need to be about

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TMS, the response time was significantly quicker than in the control condition without TMS. Similar results were obtained using TMS on both hemispheres, but not in the right hemisphere-only condition—as would be expected for right-hand dominant participants. The facilitation in the cortical excitation condition suggests that these somatosensory regions are not only active but functionally implicated in semantic comprehension.

[8] For example, Zwaan et al. (2004) found facilitatory effects when the direction of an object's motion implied by a sentence matched a change in the size of the object in two successive visual depictions of a scene; mismatches produced inhibition. Glenberg and Kaschak (2002) found similar effects for participants who listened to sentences describing bodily motions either toward or away from the body (e.g. "pull/push") and then responded via a sequence of button presses in a congruent or incongruent direction of movement (toward or away from the body).

[9] For example, Matlock et al. (in press) compared the effect of metaphoric motion and no-motion sentences on participants' reasoning in response to an ambiguous temporal question. The motion-sentence group were more likely to choose the response which reflected reasoning using a spatial metaphor for time that was congruent with the spatial metaphor introduced in the motion sentences.

literal actions to show the facilitation effects of image-schematic simulations (cf. Gibbs *this volume*).

1.4   Summary: Goals of this article and preview of remaining sections

By now it should be how clear how richly cross-disciplinary the concept of an image schema is. As image schema have phenomenological, linguistic, developmental, and neural purchase in explicating the preconceptual and preverbal structures of human experience, they can only be defined precisely in terms of a cross-disciplinary set of factors (cf. Johnson and Rohrer *in press*). Image schemata:

  (a)   are recurrent patterns of bodily experience;
  (b)   are 'image'-like in that they preserve the topological structure of the whole perceptual experience;
  (c)   operate dynamically in and across time;
  (d)   are structures which link sensorimotor experience to conceptualization and language;
  (e)   are likely instantiated as activation patterns (or 'contours') in topologic neural maps;
  (f)   afford 'normal' pattern completions that can serve as a basis for inference.

Throughout the remainder of this chapter my major objective is to pursue how image schemata might be neurobiologically grounded.

To deepen our understanding of what image schemata are, I first consider some of the developmental evidence concerning whether image schemata are innate for humans. This leads into a brief discussion of the neural development of image schemata in non-humans, where I explain how current research on the plasticity of neural maps provides candidate neurobiological mechanisms for image schemata and then offer an admittedly speculative account of how image schemata might work at the neuronal level. In section 3, I return to the recent neuroimaging and neurological evidence of image schemata in humans, discussing how these neural areas are recruited in the comprehension of both literal and metaphoric language in a number of experiments carried out by my colleagues and myself at the University of California in San Diego.

2.   The cognitive and neural development of image schemata

When considering the definition of image schemata from the vantage points of cognitive and neural development, two important sets of interrelated questions arise. First, are image schemata innate or learned (as in a Piagetian account) from the co-occurrence of sensorimotor experiences in different modalities? Are they genetically programmed or do they require appropriate environmental stimuli? Given that image schemata supposedly link species-specific behaviors like language to sensorimotor experience, to what extent are they unique to humans? Are there relevant analogues in animals? Second, exactly how might such image schemata be neurobiologically grounded? Does the fact that they often integrate perceptual imagery from multiple perceptual modalities imply that they are coordinated activation patterns linking small neural assemblies within two or more primary sensorimotor cortical maps, are they instead specialized cross-modal maps which integrate multiple perceptual images in the sensorimotor cortices, or are they some combination of these? Can animal research on neural development also help in answering this second set of questions?

2.1.   The developmental course of image schemata in infancy

The evidence from developmental cognition offers some intriguing – if also ambiguous – insights into whether image schemata are innate or learned. Mandler (*this volume*, section **X.x**) summarizes much of the infant development research supporting the idea that at least some image schemata are present from very early ages. She argues that "infants come equipped with a concept-creating mechanism that analyzes perceptual information and redescribes it into simpler form," and furthermore that this simpler form is image-schematic in character. Infants show early tendencies to attend to events which lead to the formation of highly general preverbal concepts, such as making distinctions between animate/inanimate motion and self versus caused motion. For example, infants are likely to have an innate PATH image schema as from birth as they are particularly attentive to the path and manner of motion of objects in their visual field. At just 3 months infants can differentiate between a point-light display affixed at the joints of people or animals from a biologically incoherent point-light display; similarly they can differentiate point-light displays depicting animal motion from those depicting moving vehicles (Arterberry and Bornstein 2001; Bertenthal 1993).

However, while some of the most basic image schemata are present from an early age, it is equally certain that infants clearly learn increasingly complex versions of them throughout the first two years of infancy. For example, the SOURCE-PATH-GOAL image schema shows a developmental timeline of increasing complexity throughout the first year. At five months infants are able to attend to the goal of the path traced out by a human hand reaching toward an object (Woodward 1998); then, at nine months they can distinguish between a hand grasping an object and a hand resting upon it (Woodward 1999); while at twelve months infants are able to selectively attend to objects by following changes in the direction that a caregiver points or looks (Woodward and Guajardo 2002).

An infant's ability to perform cross-modal experimental tasks is thus both present in early infancy and increases with age. In the Meltzoff and Borton study (1979) mentioned above, infants appear to be able to perform the pacifier-selection task from a very early age (1 month). Although there is some doubt about whether this experiment is replicable at such an early age (Maurer et al. 1998), other studies have shown that infants clearly get better at the task with age (Rose et al. 1972; Rose 1987). Other cross-modal image schemata are also present in early infancy. For example, Lewcowitz and Turkewitz (1981) show that at about three weeks infants can determine what levels of light intensity correspond to what levels of sound intensity (i.e. volume of white noise), suggesting that there is a cross-modal INTENSITY image schema already present in early stages of infant development. Finally, infants can imitate facial expressions from just minutes after birth, suggesting that some capacity for cross-modal coordination from the visual to the propioceptive motor modality is innate (Meltzoff and Moore 1977; Meltzoff 1993).

2.2   The neural development of image schemata

2.2.1.   *Neural maps and image schemata as developmental processes*

One might well pause to ask, however, why we continue to define 'innateness' in terms of the moment of birth. In a traditional Piagetian account the sensorimotoric schemata would emerge first after birth, and only then would the co-occurrence of sensory experiences in multiple modalities (or

sensory experience in conjunction with temporally extended experiences) interact and produce the 'reciprocal assimilation' necessary for more abstract schemata to form (Stern 1985: 45-68). From the perspective of neuroembryology however, sensory stimuli in general (with the obvious large exception of the visual) do not commence at birth. We know from recent prenatal studies that foetuses hear maternal speech while still in the womb and this influences their postnatal linguistic development, presumably by influencing the initial development of their auditory neural maps (DeCasper et al. 1994). Birth simply is not a determinative point after which some image schemata are fixed, or before which they do not exist. Although image schemata may ultimately require the consolidation of postnatal sensorimotor experience, their origins stretch back into prenatal experiences. Innate *and* learned is a more accurate way to characterize image schemata.

The innate/learned dichotomy is now often rephrased as a question about whether something is genetically determined or environmentally acquired. Once again, considering this version of the innateness question from the vantage of neuroembryology gives the insight that the question may be poorly formed, given that it is mathematically improbable that the mechanisms underlying such schemata are entirely genetically specified (Edelman 1987: 121-126). Assuming that image schemata do take place in and/or between the sensorimotor neural maps, the initial development of them would begin during the development of those maps late in the formation of the neural tube. While cell differentiation is clearly genetically instructed, the developmental forerunners of the neural maps are what Edelman calls neuronal groups. He argues that their number, shape, connectivity and final locations are too numerous to be genetically determined.

Instead, Edelman argues that neuroembryonic development is best understood as a competitive process known as 'neural Darwinism.' As organic living things, neurons in the embryo seek to flourish, find nourishment and reinforcement. As a result the developing neurons begin to form Hebbian associations between one cell's axons and another's dendrites, clustering together in neuronal groups. These neuronal groups act like organisms that seek out stimulation as nourishment, and the neuronal groups compete with each other as they migrate along the neural tube toward the emerging sense organs. Some unfortunate groups perish at all stages of the process, while others hang on in intermediate states of success, creating overlapping neural arbors exhibiting a specific kind of redundancy called 'neural degeneracy' (Edelman 1987: 46-57).

Over time, the population-growth dynamics and migration of the neuronal groups creates yet another emergent property: neurons array themselves into physical patterns which 'map' the sensory modalities. This use of physical space within the brain to re-represent environmental stimuli yields the incipient primary topographic spatial neural maps of the various sensory modalities. Auditory areas develop maps indicating increasing pitch and volume; later, tactile areas develop somatic maps for pain and touch along the limbs; still later yet, somatomotor maps develop for muscles distributed across the limbs. These formative neural maps are probably enough to sustain some rudimentary cross-modal image-schematic patterns, particularly between the tactile and auditory modalities. But the competition between neuronal groups does not end there. As different 'neurally degenerate' neuronal groups are crowded out by the more successful groups mapping primary 'topographic' stimuli, the intermediately successful groups hang on by mapping different, more abstractly 'topological' aspects of the sensory stimuli. Although all this activity begins before birth, much of the ongoing development and refinement of these maps awaits the much stronger reinforcement of the increase in environmental stimuli that comes with the infant's first movements, cries and sights.

From this brief consideration of innateness and the neuroembryological underpinnings of image schemata, we see that the neural maps are dynamic developmental processes that rely on these underlying principles of neural Darwinism and redundant neural degeneracy. To understand how such organismic forces shape the postnatal development of image schemata, we now turn to detailed neuroanatomical studies of how animals develop cross-modal spatial schemata in and between their neural maps. This will yield the candidate neurobiological mechanisms for image schemata.

2.2.2   The plasticity of the neural maps in juvenile and adult animals

A series of experiments by Knudsen and colleagues (Knudsen 2002; 1998) address the question whether a barn owl can still successfully hunt if it were given prismatic glasses with lenses that distort the owl's perception 23 degrees to the right or left. Normally, a circling barn owl hears a mouse stirring in the fields below and locates it using the tiny difference in time that it takes for the sound to travel from one ear to the other along a path defined by the angle of its head and the origin of the sound. However, during the final dive of a strike the owl normally uses its eyes to pinpoint the

exact location of its prey. Would the optical distortion from the glasses cause the owl miss its prey? If so, would it eventually learn to compensate?

Their results show that it depends on exactly *when* the experimenters put the prismatic glasses on the owl. Adult barn owls will reliably miss the target, but juvenile owls (~60 days) were able to learn to hunt accurately. Furthermore, juvenile owls raised with the prisms were able to learn as adults to hunt accurately either with or without their prisms. However, the prism-reared owls were not able to adapt to new prisms which distorted the visual field in the opposite direction of the prisms they wore as juveniles.

The barn owl experiments are of central importance to giving a neuro-biological account of image schemata for a number of reasons. First, the barn owl locates its prey in space using cross-modal coordination between the auditory and visual perceptual modalities, making it a good animal ana-logue of image schemata. Second, the work on cross-modal schemata in barn owls addresses 'neural plasticity,' or the biological mechanisms by which experience-dependent learning takes place at the neuronal level. By understanding how an unnatural intervention into the juvenile owl's visual experience results in the abnormal neuroanatomical development of the owl's neural maps for space, we can better understand the normal neuro-anatomical mechanisms by which human infants learn to make the sort of spatial distinctions picked out by image schemata. Related research on learning and neural plasticity in other animals, including frogs and mon-keys, will introduce other important insights into how spatial information is re-organized, re-learned and abstracted at the neuronal level. Finally, for obvious ethical reasons we cannot normally obtain analogous human data at the same neuroanatomical level of investigation using these methods. However, after seeing these principles at work in animals we can ask whether homologous areas of the human cortex are active using less inva-sive methodologies such as lesion studies and neuroimaging.

From the owl research, we know that a series of at least three neural maps are involved in this cross-modal schemata within the owl brain: a primarily auditory map of space in the central nucleus of the inferior col-liculus (ICC), a multimodal auditory spatial map in the external nucleus of the inferior colliculus (ICX), and a primarily visual yet still multimodal spatial map in the optic tectum (also called the superior colliculus). When Knudsen and colleagues injected the ICX of their owls with an anatomical tracing dye, they were able to see significant differences in both the pat-terns of axonal growth and of the synaptic 'boutons' (clusters). In compar-ing prism-reared owls compared to normal owls, they found an increased

density of bouton-laden axon branches within the colliculus *only in the direction predicted* given the direction of the prismatic distortion. This suggests that reentrant connections from the visual map in the optic tectum of prism-reared owls changes the developmental course of the spatial map in the ICX. Furthermore, the unidirectional shift in the neuroanatomy of the map explains why adult prism-reared owls were unable to adapt to prisms which distorted the visual field in the opposite direction of their juvenile prisms (Knudsen 2002; DeBello et al. 2001; Knudsen and Brainerd 1991; Knudsen and Konishi 1978). These experiments reveal that epigenetic developmental experience can shape axonal structure in cross-modal neural maps, "showing that alternative learned and normal circuits can coexist in this network" (Knudsen 2002: 325).[10]

   The retention of overlapping and branched neural arbors in neural maps is crucial to the adaptive learning behavior exhibited by higher primates. Working on adult squirrel and owl monkeys, Merzenich and colleagues (Buonomano and Merzenich 1998; Merzenich et al. 1984, 1987; Allard et al. 1991; Jenkins et al. 1990; Wall et al. 1986) have shown that adult primates are able to dynamically reorganize the somatosensory cortical maps within certain constraints. Similar to the dual neural arborizations found in owls, these monkeys exhibited a plasticity based on their ability to select which parts of their neural arbors to use given different kinds of sensory activity. In a series of studies, the experimenters altered the monkey's normal hand sensory activity by such interventions as (1) cutting a peripheral nerve such as the medial or radial nerve and (1a) allowing it to regenerate naturally or (1b) tying it off to prevent regeneration; (2) amputating a single digit; and (3) taping together two digits so that they could not be moved independently. The results show that the somatomotor cortical areas now lacking their previous sensory connections (or independent sensory activity in the third condition) were 'colonized' in a couple of weeks by

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[10] By comparison, these dual neural circuits do not persist in a visual map of the frog's optic tectum. Neuroembryological experiments on frogs with surgically-rotated eyes has shown that after five weeks, the visual map in frog's optic tectum has neural arbors that initially exhibit a pattern of axonal growth similar to the juvenile owls called the 'two-headed axons.' However, after ten weeks the older axonal connections are starting to decay and disappear, while after sixteen weeks no two-headed axons could be traced (Guo and Udin 2000). Apparently, the frog's unimodal tectal maps do not receive enough reentrant neural connections from other sensory modalities to retain the overlapping and highly-branched neural arbors found in the cross-modal map of the owl inferior colliculus.

adjacent neural maps with active sensory connections. In other words, the degree of existing but somewhat dormant neural arbor overlap was large enough that the cortex was able to reorganize to meet the demands of the new experiences. And in the case of (1a), where the nerve was allowed to regenerate, the somatosensory map gradually returned to re-occupy a similar-sized stretch of cortex, albeit with slightly different boundaries. This research suggests that adaptive learning behaviors in adult animals is accomplished in part by neural switching between overlapping and 'degenerate' neural arbors. The competition for stimulation between neuronal groups is severe enough that, when deprived of their 'normal' sensory stimulation, neurons will fall back on lesser-used axon branches to reorganize. Edelman (1987: 43-47) calls these latent reorganizations of these neuronal groups based on their branching arborizations *secondary repertoires*, as distinguished from their normal organization as *primary repertoires.*

   At this point most of the elements for the probable neurobiological grounding of image schemata have been introduced. In the case of the owl we have examined how an experience-dependent, cross-modal map of space arises from the coordinated activity of primary visual and auditory maps. Because of the dual arborizations present in the cross-modal spatial map of the prism-reared owls, the prism-reared adult owl can switch between multiple degenerate neural arbors and 'learn' a sensorimotor schema to hunt effectively with and without glasses.[11] The monkey evidence demonstrates how a more unimodal sensorimotoric schemata can be adaptively learned; in response to radical interventions the tactile and proprioceptive motor maps of the primary sensorimotor cortex reorganize. Once again this is accomplished by calling upon degenerate neural arbors to perform a new, slightly different mapping. Confronted with the new stimuli, the monkey cortex has reorganized to take advantage of latent secondary repertoires – but in this case, the interventions took place on adult monkeys and hence likely borrowed latent pre-extant, degenerate neural arborizations left over from unrelated developmental experiences. Unlike in the study of juvenile owls, the experimental interventions were not the precise cause of the degenerate and overlapping neural circuits which were then re-learned by the adult organism – the new learning required simply took advantage of latent organizational possibilities.

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[11] By contrast, the example of the frog in the previous footnote shows that in the absence of such two-branched dual arborizations, adaptive learning does not occur.

2.2.3 The neurobiological grounding of image schemata in humans

Though gathered using less invasive methodologies, similar findings hold for the human sensorimotor cortex. Analogous human studies show that similar cortical changes take place for the development of image schemata in the human sensorimotor cortices.

For example, the size and boundaries of neural maps can be changed from experience-dependent learning. Pascual-Leone and Torres (1993) studied differences in the hand somatosensory cortex of subjects who had learned to read Braille as adults. Using magnetoencephalography (MEG), they showed that compared to non-Braille reading adults the Braille-readers had a significantly larger scalp area over which potentials could be recorded for the right index finger. Further, the parts of the hand which were not used to read Braille were smaller in their somatosensory areas than in non-Braille readers. In another study, the somatosensory areas for the digits of the left hand of stringed-instrument players were larger than for their right hand or than for the left hand of control subjects who did not play a stringed instrument (Elbert et al. 1995). As in the case of the monkeys, the change in sensory experience causes a competitive reorganization of adjacent cortical areas so that the neural map of the fingers enlarges.

It is my contention that, similar to what was found for animals, the image schemata evidenced in human language and development are grounded in the sensorimotor cortices. While it is theoretically possible that every image schema is in fact simply physiologically encoded in an integrative secondary sensory cortical area (as in the owl's cross-modal map), I rather suspect this is not the case.[12] Instead, suppose that image schemata rely on *functional* secondary repertoires which exist in the sensorimotor cortices, either in the primary sensorimotor cortex, the more secondary integrative somatosensory cortex, the premotor cortex, or in some combination of these. In other words, when we read about grasping an object (or idea) rather than actually grasping an object, we use a functioning secondary repertoire to mentally *simulate* – to imagine – performing the action using many of the same cortical areas that we would use to perform the action. As the monkey mirror neurons have been divided into a number of sub-categories, there is some support for this hypothesis in the mirror-neuron

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[12] It is possible that some particularly important image-schematic elements might have dedicated neural circuitry rather than a network of secondary repertoires.

literature (see Rizzolatti and Craighero 2004). Of the grasping neurons in area F5, approximately one third were classified as 'strictly congruent' neurons that code for precise hand shapes, while two thirds are 'broadly congruent' mirror neurons that did not require observation of exactly the same action (Gallese et al. 1996). Some of these broadly congruent neurons appear to be responding to more abstractly general components of the hand shape or movement, such as being directed toward an end-goal. Thus one plausible proposal is that image schemata are the coordinated activation of secondary repertoires within the sensorimotor cortex consisting of some 'broadly congruent' mirror neurons.

However, and whatever the exact neuronal mechanism might be, the theory of image schemata predicts that we understand language concerning the body and bodily actions using the same cortical areas that map the sensorimotor activity for performing such actions. We would also expect that the activation course for language stimuli would be somewhat different – as understanding the sentence 'I grabbed my knee' does not require my actually grabbing my knee, though pathological cases who do something similar have been reported (Schwoebel et al. 2002). Presumably, in the case of first-person action sentences, it is possible that there is either simultaneous inhibitory activation in the same cortical areas or, and more likely, an inhibitory firing in the spinal cord (as reported in Baldissera et al. 2001).

If this proposal for the neurobiological grounding of image schemata is correct, we should expect to see some areas within the primary sensorimotor, premotor and the more secondary 'integrative' somatosensory cortices, activated in fMRI studies by a range of linguistic tasks related to the body and bodily actions. Moreover, metaphoric versions of such language tasks ought to cause similar activation even when not literally describing bodily actions.

3. Metaphor in maps: convergent neuroimaging, electrophysiological and neurological studies of meaning

Recall first that the opening sentence of this chapter takes an abstract idea and gives it a concrete basis using the bodily metaphor of manipulating the idea-objects with the hands. As Lakoff and Johnson (1980) have shown, the conceptual metaphor IDEAS ARE OBJECTS is a commonplace way of speaking about intellectual matters. In English, there is a system of meta-

phoric expressions such as: *he handed me the project*, *the ideas slipped through my fingers*, *I found Lobachevskian geometry hard to grasp*, and so forth. Such expressions are instances of a related metaphor system, in which the image schemata of the source domain of object manipulation are systematically projected onto the target domain of mental activity. The inference patterns of the source can then be used to reason about the target. For example, if an idea slips through one's fingers, it means that we do not understand it; whereas, if we have a firm grasp on the idea, it means we do understand it. We understand what it means to grasp an idea much like we understand what it means to grasp an object.

In order to measure whether the same brain areas known to be involved in sensorimotor activity in monkeys and humans would also be activated by literal and metaphoric language about object manipulation, I compared the fMRI results from a hand stroking/grasping task to those from a semantic comprehension task involving literal and metaphoric hand sentences, as well as to a set of non-hand control sentences (Rohrer 2001b).[13] The sensorimotor areas active in the tactile task were congruent with previous studies of the somatotopy of the hand cortex (Moore et al. 2000), and were used to identify regions of interest for the two semantic conditions. As hypothesized, the results in the semantic conditions show that the participants exhibited several overlaps between the somatotopy found for a tactile hand stroking/grasping task and that found for both the literal hand sentence comprehension task and the metaphoric hand sentence comprehension task. These overlaps were concentrated particularly in the hand premotor cortex and in hand sensorimotor regions along both sides of the central sulcus, as well as in a small region of the superior parietal cortex (see figure 1). As expected, the overlaps were larger and more significant for literal than metaphoric sentences, though in most participants these same areas of overlap were observed. Furthermore, many of the cortical areas in which these overlaps were found are similar to those areas active in the hand/arm portion of the action-word experiments by Hauk et al. (2004). To provide a

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[13] Twelve right-hand dominant subjects participated in a block-design fMRI experiment on a 1.5T Siemens scanner at Thornton Hospital on the UCSD campus, using a small surface coil centered above the sensorimotor cortex with a TR of 4. Participants viewed eight alternating 32-second blocks of hand sentences and control sentences. Three such blocks were averaged together in each semantic comprehension condition. After the semantic data were obtained, one tactile right-hand stimulation block was performed. All data were analyzed using the FreeSurfer fMRI analysis package available from UCSD (Fischl et al. 1999).

cross-methodological corroboration of these results, I also conducted related experiments with body-part word tasks in which I measured brain wave activity using event-related potential (ERP) methodologies (Rohrer 2001b). In short, I found that reading both metaphoric and literal hand sentences activated many of the same sensorimotor areas as tactile stimulation of the hand did, as would be predicted by the image schemata hypothesis.

Of course, one standard objection to this interpretation of the fMRI evidence is that the neural activation might be merely an after-effect of 'spreading activation'—that is, when we read the body-part term, we first understand it using some other region of the brain, and only after we understand it does the activation spread to the primary sensorimotor, premotor and secondary sensory cortices. Such an objection would thus suggest that the sensorimotor activation observed would not be functionally involved in semantic comprehension, but instead would be indicative of a preparatory response occurring after semantic comprehension has taken place elsewhere.

Fortunately much of the evidence already presented suggests that the after-effect proposal is likely not true. In the neurological literature, the dissociation of body-part knowledge observed in selective-deficit studies (Schwoebel and Coslett 2005; Suzuki et al. 1997; Shelton et al. 1998; Coslett et. al. 2002) suggests that that the comprehension of body-part terms requires the undamaged and active participation of at least *some* of the somatotopic maps located in the sensorimotor cortices and the egocentric spatial neural maps located in the parietal cortices.[14] From experimental cognitive neuroscience, we know that the stimulation of the sensorimotor cortex (via TMS) can facilitate or inhibit the real-time comprehension of body-part action terms (Pulvermüller et al. 2002). Together with the other convergent psychological evidence for dynamic perceptual simulations also discussed in the introduction, these lines of evidence all suggest that these cortical areas are *functionally* involved in the semantic processing of body-part and bodily action terms and not a mere after-effect of it.

Finally, the spreading-activation objection to the fMRI overlap results is also explicitly addressed in my cross-methodological experiments using event-related potentials (ERPs). Using a single-word body-part task similar to that of Hauk et al. (2004), I examined the temporal dynamics and scalp

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[14] Lesions can cause difficulties in tasks such as naming pictures of body parts, understanding body-part terms versus control terms, pointing to or naming contiguous sections of the body, naming the part of the body upon which a particular piece of clothing or jewellery is worn, etc.

distribution of the electrical signals from the sensorimotor cortices to measure first whether the ERPs are distributed across the sensorimotor cortices, and second whether the ERP response distributed across the sensorimotoric cortex occurs concurrently with (or after) the ERP response to a list of control words (Rohrer 2001a). Thirteen right-handed participants read a list of single-word body-part terms such as 'foot,' 'ankle,' 'calf,' 'knee,' and so on. These language stimuli were grouped into four subcategories based on the somatotopic order as represented on the central sulcus and adjoining gyri: face, hand, torso, and legs/feet.[15] Each word was presented for 500 ms followed by a 500 ms blank interval. In the temporal window during which semantic comprehension most likely takes place (~400-600 ms after the presentation of the word), current source density (CSD) maps of the scalp distribution showed a only slightly lateralized bilateral distribution pattern ranging along the arc of the scalp above the central sulcus (figure 2a). This pattern was in direct contrast to a control condition of car-part terms (figure 2b), which showed the classic left-lateralized pattern of scalp distribution typically expected with single-word reading tasks. The response to body-part terms was closer to a second control condition in which participants were asked to imagine a movement in response to each body-part term read. Figure 2c shows a uniformly bilateral pattern in response to the movement visualization task.

Though the CSD maps in which all the body-part terms were averaged together may seem rather flat in amplitude compared to the control stimuli, this is an artifact of averaging the responses to all body-part terms. When the analysis of the ERPs to body-part terms is broken down into the four somatotopic subcategories (figures 2d-2g), the resulting CSD maps show a sharply divergent pattern of somatotopic distribution measured across the electrode sites that cover the sensorimotor cortical areas; face at both edges near the temples, followed by hands, torso and feet as we move toward the midline.[16] Finally, note that the peak amplitudes to these four stimuli sub-

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[15] The genitals were omitted because reading genital terms can cause an emotional response (blinking) that would likely create oculomuscular artifacts in the ERPs. Each word was presented for 500 ms followed by a 500 ms blank interval.

[16] Note that in comparing torso and foot scalp distribution maps (figures 2f and 2g) there is also an inversion of polarity in the CSD map. This is likely a direct result of a sharp curvature in the primary sensorimotor cortex. As ERPs presumably record the summed firing of large pyramidal neurons lying perpendicular to the cortical surface, the polarity of the signal is likely to invert as the cortex curves where it descends along the medial wall of the brain.

groups are concurrent with those of the control stimuli, suggesting that the sensorimotoric activation is not an after-effect of semantic comprehension but crucial to it. Together with the fMRI results, these CSD maps show not only where the response to body-part language occurs but also that it occurs during the appropriate time window for semantic comprehension. In short, the ERP evidence once again suggests that the activation in the sensorimotor cortices is functionally involved in the semantic comprehension of body-part terms.

5.   Conclusion

Taken together, the converging results of these studies show that we now have an emerging body of compelling evidence that supports that the hypothesis that our semantic understanding takes place via *image schemata* located in the same cortical areas which are already known to map sensorimotor activity. The theory is robust enough to make a number of predictions about what we might expect to see in future studies.

Firstly, we can, with appropriately designed linguistic stimuli, expect to drive primary and secondary sensorimotor cortical maps. More specifically, we can predict that motion terms should activate motion maps, color terms should activate color map areas, object-centered versus egocentric sentences to activate the object-centered or ego-centered frame of reference maps in the parietal lobe, and so on. It is an open empirical question if such activation in relation to linguistic stimuli can be observed in other primary sensory cortices, or whether it will only be seen in more integrative secondary cortical areas (as might be expected in the visual modality).

Secondly, it remains to be seen whether one can ask similar questions about whether neural maps might also underlie a cognitive grammar. Langacker has argued that grammatical relations are derived from spatial relations (Langacker 1987); indeed he originally called his theory of cognitive grammar a 'space' grammar, and so we might design fMRI experiments to determine whether his proposals are reflected in the brain regions known to be involved in the neural mapping of spatial movement. For example, one could examine tense and aspect by examining the response in motion map areas to many paired constructions such as "Harry is walking to the store" versus "Harry walked to the store." Similarly, it may be possible that many of the current fMRI studies of syntax designed from outside cognitive linguistics may eventually be reinterpreted in terms of the embodied functions

(mostly object recognition and manipulation) that the brain regions supposedly responsible for syntax primarily perform. For instance, Rizzolatti and colleagues (Rizzolatti and Buccino *in press*; Rizzolatti and Craighero 2004) have recently suggested that the evidence for hand and mouth mirror neurons in and near Broca's area (inferior frontal gyrus) suggests that the disruption in the syntax of Broca's aphasiacs may result from the disruption of the ability to imitate actions and gestures.

Although it remains an open question how many of these related hypotheses will bear out, the converging evidence thus far for the participation of the sensorimotor cortices in language processing is undeniable. The ideas presented in this chapter may at first have seemed hard to handle, but my hope is that you no longer find my opening claim preposterous, though I will accept that it is bold. The most recent neurocognitive evidence shows that whenever you turn ideas over in your head, you are performing image-schematic simulations that take place in the hand sensorimotor cortices. Furthermore, converging recent research shows that semantic meaning is embodied and widely distributed throughout the brain, not localized to the classic 'language areas.'

Still, we are just at the beginning of explaining how semantic comprehension works, and our hypotheses are overly simplistic and gross in their scope. Future hypotheses in this field will undoubtedly become more abstract and refined as neuroimaging technology improves to the point where we can describe just the beginning of an action and measure its consequents – such abstractions, however, will not lead us away from the role of perception in language and cognition, but to it. Our theories of language and cognition will become more refined because our senses – and the image schemata which emerge from them – are even more refined than we yet know.

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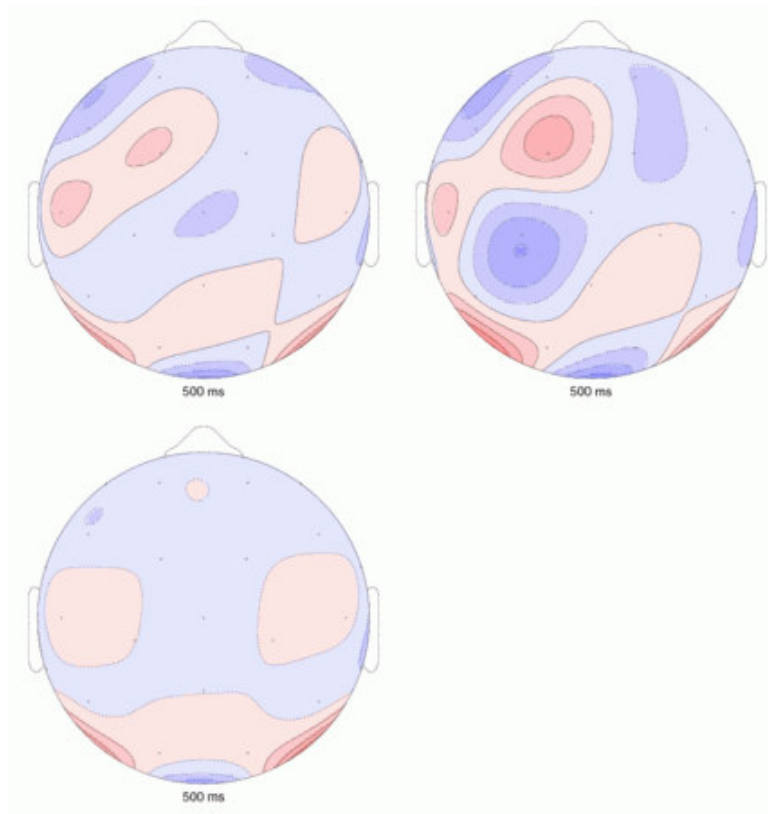   2004   Moving words: Dynamic representations in language comprehension. *Cognitive Science* 28: 611-619.

Figure 1. Overlap of fMRI activation in the primary and secondary sensorimotor cortices between a sensorimotor task and two linguistic hand sentence tasks (literal and metaphoric). Areas active in the sensorimotor task are delimited by the white line. Only those areas that overlapped between the sensorimotor and particular language condition were traced (literal on top, metaphoric below). These are lateral views with the right hemisphere presented on the left side of the figure and the right hemisphere on the left side of the figure. The cortical surface has been inflated so that no data will be hidden in the cortical folds. Sulci are represented in the darker areas, while gyri are represented by the lighter areas. This figure represents individual data from one of the 12 subjects in the experiment. All data were analyzed using the FreeSurfer fMRI brain analysis package available from UCSD (Fischl, Sereno et al. 1999).
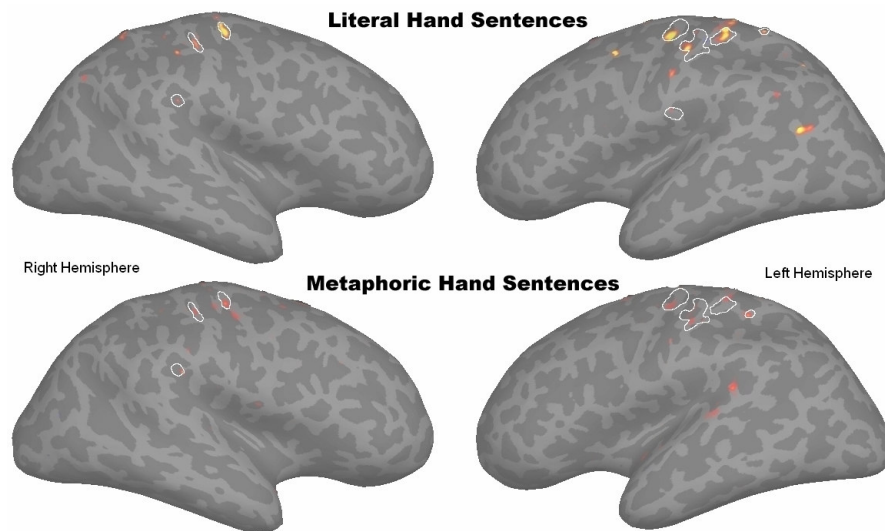
Figures 2a-c. Current source density (CSD) maps of the scalp electrophysiological response to single word body-part and control (car-part) stimuli. The leftmost figure shows the response to all body-part terms averaged together, the middle figure shows the response to a list of car-part terms and the rightmost figure shows the response of participants as they imagined moving the body part as they read each body-part term in sequence. The middle figure shows a classic left-hemisphere lateralized response to language stimuli, while the rightmost figure shows a decentralized pattern of response which stretches across the sensorimotor cortices (an arc extending from each temple through a point roughly halfway between the nose and the top of the head). The response to a passive reading of a body-part word (leftmost figure) shows a distribution along this arc, as well as some left hemispheric bias. All figures are from an average of 13 participants, depict the averaged activity 500 ms after the onset of each stimulus and were collected using a 26-channel scalp electrode cap.

Figures 2d-g. Current source density (CSD) maps of the scalp electrophysiological response to single word body-part stimuli divided into four subgroups. The upper leftmost figure shows the response to face body-part terms, the upper right figure shows the response to hand body-part terms, while the lower left figure shows the response to torso body-part terms and the lower right to foot body-part terms. These figures exhibit the distribution of the body image along the sensorimotor cortices with the face toward the temples, the hands slightly above them, the torso located near the midline with the legs and feet plunging down along the medial walls. The reversal of polarity between the torso and the feet is likely caused by this curvature of the cortex as it descends along the medial walls.
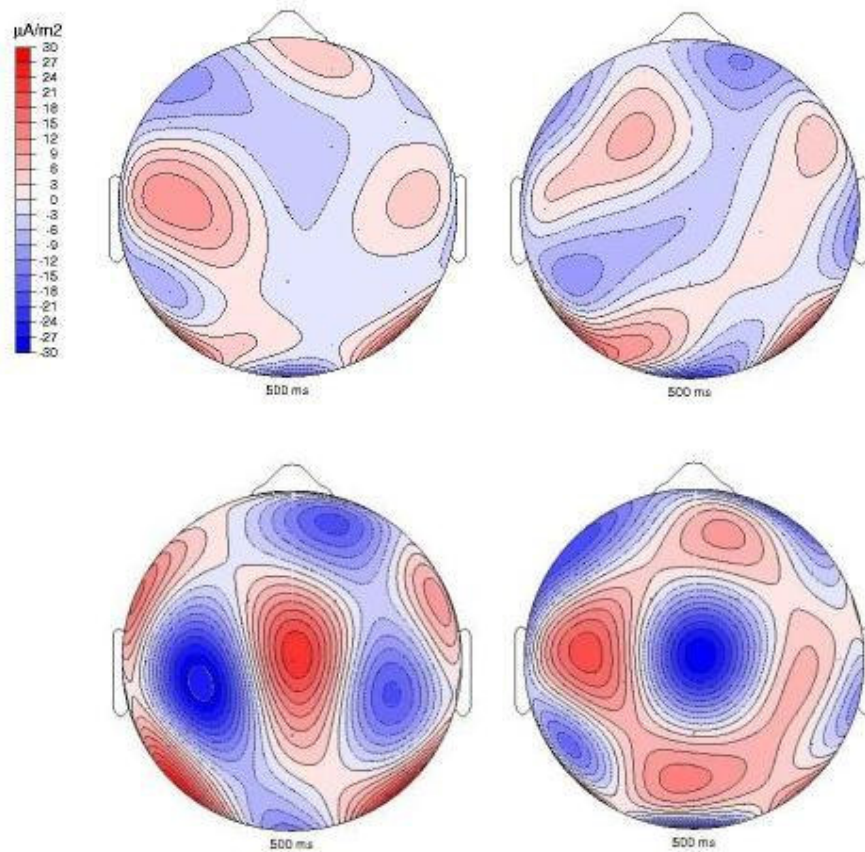
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