

Understanding through the Body:

fMRI and ERP investigations into the neurophysiology of cognitive semantics

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Abstract

I present evidence from an ongoing series of experiments in cognitive semantics using the functional magnetic resonance imaging (fMRI) and event related potential (ERP) techniques. These experiments were designed to investigate predictions stemming from the embodiment hypothesis of cognitive semantics (Lakoff and Johnson 1999; 1980). The embodiment hypothesis argues that linguistic meaning is grounded in our bodily interactions with the world, and that conceptual metaphors borrow and build upon the structures of those bodily interactions. While many bodies of evidence have been assembled to support this claim, most are from the linguistic, cultural and communicative levels of investigation. To remedy this gap in the literature at the neurophysiological level of investigation, I conducted several experiments to determine whether the well-established somatotopic maps of the sensorimotor cortices could be driven by both literal and metaphoric language. Event-related potentials (ERP) experiments investigated whether these cortical maps could be somatotopically driven by subjects who read a list of body part terms and were asked to (1) read purely for semantic content, (2) imagine a pain or movement in the body part read, and (3) imagine making a small motor movement in the body part read. A functional magnetic resonance imaging (fMRI) experiment was designed to evaluate whether these cortical maps were active during the semantic comprehension of both the metaphoric and literal sentences using body-part terms. The cross-methodological comparison of these results suggests that there is a functional contribution from the motor and somatotopic neural maps to semantic processing -- contra modularist arguments that suggest that language is neurally encapsulated and borrows no or minimal structure from perceptual processing. I conclude with a discussion of the theoretical implications of these experiments for cognitive semantics.

¹ Minor typos, grammar and bibliographical corrections were made in October 2005 to the original 2001 paper. An updated and much expanded discussion of these results, including a review of related work, appears as my chapter "Image Schemata in the Brain" in *From Perception to Meaning: Image Schemas in Cognitive Linguistics*, Hampe, Beate and Grady, Joe (eds.) Berlin: Mouton de Gruyter, 2005, pp. 165-196.

Cognitive Semantics: Conceptual Metaphor and the Embodiment Hypothesis

Cognitive semantics arose as a direct challenge to the view of meaning in formal semantics and the analytic philosophy of language. The traditional approaches all agree that meaning is first and foremost a matter of literal reference between language and the world, while figurative language, such as metaphor, is seen as a parasitic, secondary process which relies on indirection to link language to its referent. However, in *Metaphors We Live By* Lakoff and Johnson (1980) presented substantial evidence that much of our mundane, ordinary language conveys meaning through *systems* of extended metaphors. To distinguish their theory from the traditional account of metaphor as an isolated ‘figure of speech’ that makes an indirect reference, Lakoff and Johnson dubbed these patterns ‘conceptual metaphors’ to emphasize that they were not mere matters of language but instead the result of *systematic* patterns of conceptualization. They argued that we use these conceptual metaphors to reason about the world, and the metaphoric projection of inferential structure is an important vehicle for both what people found conventionally meaningful and for extending new meanings to terms. The insight that these metaphoric patterns of meaning were systematic and productive became the foundation of the *conceptual metaphor hypothesis* of cognitive semantics.

Moreover, Lakoff and Johnson noted the vast majority of their examples of conceptual metaphors consistently used a small number of source domains to structure their targets. These source domains most commonly drew on the body after one fashion or another as they structured the target domain. Common source domains included grasping and the physical manipulation of objects (“she *handed* me the idea”), bodily motion through space (“We *arrived* at that conclusion by *traversing* the history of philosophy in the 17th century”), the clarity of vision or the occlusion of objects in the visual field (“While the *brilliance* of Descartes’ cogito remains *unobscured* by the passage of time, its homage to the work of the medieval scholar Duns Scotus is *murky* indeed”), the digestive system “I’ll have to *chew* on your proposal a bit and let it *settle* a while before I comment on it,” and so forth. On the basis of the whole body of their evidence in English, Lakoff and Johnson proposed the *embodiment hypothesis* of cognitive semantics:

... we have suggested that there is *directionality* in metaphor, that is, we understand one concept in terms of another. Specifically, we tend to structure the less concrete and inherently vaguer concepts (like those for emotions) in terms of more concrete concepts, which are more clearly delineated in our experience. (Lakoff and Johnson 1980: 112)

Over the next twenty years the embodiment hypothesis received much elaboration, criticism and new sources of evidentiary support, such as from the comparison of metaphors found in widely disparate languages, research gestures accompanying metaphors, sign language, historical analyses of semantic change, psychological experiments and neurocomputational models—though not from studies of actual neurophysiology or from observational neurology.

Stimuli and Experimental Design Considerations

In order to address this gap in the converging evidence, I conducted several neuroimaging experiments concerning both hypotheses. However, in the process of adapting the conceptual metaphor and embodiment hypotheses from the linguistic level of investigation to become testable hypotheses at a more neurophysiological level of investigation (figure 1), several constraints of the experimental paradigms emerged. First and foremost, one needed to know where to look within the brain and have the methodological precision to be able to differentiate patterns of brain activity spatially in response to contrasts in the linguistic stimuli. Second, and as the experimental methods require a large amount of repetition to achieve statistical significance, the source domain must be well-articulated enough to provide for numerous examples. Hence, a source domain was needed that was both well-articulated in language and had clearly established neurocortical maps which would be expected to become active given appropriate linguistic stimuli. Body-part terminology was chosen as the most

obvious candidate that satisfied both constraints, although other candidates such as spatial-relation terms and visual terms might prove fruitful in future studies.

That the sensorimotor cortex of human beings contains large and well-articulated maps of the human body has been well-established since the midpoint of this century. Wilder Penfield (Penfield and Rasmussen 1950) observed that when performing brain surgery on patients under light anesthesia, patients reported sensations in largely contiguous sections of the body in response to a light stimulation along the primary somatosensory cortex, while stimulating the motor cortex caused the patient to make involuntary motor movements. Moreover, they discovered that the size of the cortical maps is not directly proportional to the size of the body part; instead those parts of the body with more nerve endings and of greater utility, such as the hands, have disproportionately larger neural maps than, for example, the torso (see figure 2). The secondary sensorimotor areas just anterior and posterior to the primary sensorimotor cortices are also known to contain cortical maps used in motor planning and somatosensory integration.

The linguistic stimuli consisted of both single words and short sentences. Participants in the ERP experiments read a list of body-part terms which were presented in an order determined by somatotopy of the primary sensorimotor cortex—e.g. mouth and face terms were followed by hand and arm terms, which were followed by torso terms and then leg and feet terms. This division yielded four subgroups of terms which were expected to excite distinct regions of the sensorimotor cortex, and could further be contrasted with the result to a list of non-body part control terms (a list of common car parts). The participants were further instructed to visualize a pain and movement in two subsequent readings of the list of body parts after completing the passive reading task. Participants in the fMRI experiments read a series of short sentences in which hand terms were used either literally (e.g. “He handed me the hammer”), metaphorically (“I handed him the project”), as well as a series of non-body part control sentences.² The hand metaphor sentences came from three metaphor systems: IDEAS ARE OBJECTS (e.g. “The student grasped the problem”), A BODY IS A LANDSCAPE (e.g. “Devil’s Thumb is a tough climb”), and A NATION IS A PERSON (e.g. “Stalin ruled Russia with an iron fist”). The prediction was that the participant’s primary and secondary sensorimotor hand cortices would show activation in both the literal and the metaphoric conditions, but not in the control condition. In order to map precisely each individual participant’s hand cortex, a sensory stimulation task followed the linguistic tasks.

Experimental Methods

The ERP experiments were recorded using a 26-data channel scalp electrode cap in the Kutas electrophysiology laboratory at the University of California at San Diego; two mastoid reference channels were also recorded as well as four oculomuscular channels. The signal was sampled and recorded every 4 ms; data channels were referenced to the left mastoid. Blinking and other oculomuscular artifacts were discarded from the data. Each word in the list of body-part terms was presented for 500 ms followed by a 500 ms blank interval. Genital terms were omitted from the list of body parts because reading genital terms can cause an emotional response (such as blinking). Both a temporal waveform analysis and current source density (CSD) topographic analysis were performed using custom-written lab software. The CSD maps were calculated by taking the second spatial derivative of the voltage measured each scalp electrode site, then interpolated across a sphere and flattened for a topographic representation of the current sources and sinks. In reading CSD maps the cortical generators, presumably the massed electrical firing of many pyramidal neurons, correlate with the area between an adjacent pair of current sources and sinks. Seventeen right-hand dominant participants performed the passive reading comprehension and imagined pain task; thirteen right-hand dominant participants performed these and the additional tasks of imaging movement lateralized to the left and right sides of the body. All the figures in this paper are from the set of 13 experimental participants.

² Due to practical constraints concerning how long a participant could reasonably stay in a MRI scanner during a single session, separate sentence-length stimuli sets were designed for hand, feet and face terms. I report only on hand sentences in the present paper.

The fMRI experiments were conducted using a 1.5T Siemens MRI scanner at Thornton Hospital on the UCSD campus using a small surface coil centered above the anterior parietal cortex. The small flex coil does not image the entire brain; signal strength rapidly drops off outside of the target areas (in this case the primary sensory and cortices, the premotor cortex and the secondary somatosensory cortex of the anterior parietal lobe). The repetition time (TR) was 4 seconds; 130 repetitions of 26 coronal slices were taken; the first two were discarded to avoid imaging artifacts. Voxel size was 3x3x4 mm. Participants each used a custom bite bar to reduce head movement. The stimuli were projected down the bore and onto a small screen via an adjustable mirror. Right-hand dominant participants³ viewed eight alternating 32-second blocks of hand sentences and control sentences. Three such sequences were averaged together in each semantic comprehension condition. After the semantic data were obtained, one tactile right-hand stimulation sequence was performed with a light stroking of each participant's palm and fingers during the on-blocks; off-blocks were characterized by no stimulation. Participants reported that the stroking caused a slight tickling sensation accompanied by small, involuntary grasping motions. Participants then returned at a later date for the metaphoric-sentence condition. All data were analyzed in the Sereno fMRI laboratory using the Fourier transform algorithm of the FreeSurfer fMRI analysis package available from UCSD and Massachusetts General (Fischl, Sereno, Tootell and Dale 1999). The f -threshold was set at $P < 0.01$ (red); the yellow color indicates activation where $P < .003$. Data are shown on an inflated view of the cortical surface so that no data is hidden the cortical folds. Overlapping regions of interest were hand-traced from the images representing the tactile somatosensory task onto the images representing the linguistic tasks for presentational purposes.

Experimental Results

The analysis of the ERP results reveals several important findings. The temporal window of 300 to 500 ms after onset has been previously associated with semantic comprehension, with a negative peak around 400 ms (Kutas and Hillyard 1980). While the response for both car-part and body-part terms also peaks around 400 ms after stimulus onset, note that the peak waveforms diverge at the frontal and central electrode sites that are closest to the central sulcus during the 400-500 ms window (figure 3). No such significant divergences were observed in comparisons of the reading comprehension and imagined pain or imagined movement task.

A comparison of the body parts and car parts conditions using CSD maps calculated at 500 ms reveals that the response to body parts is much more bilateral than the response to car parts, which exhibits the usual left-lateralized pattern (figures 4ab). Though the CSD maps in which all the body-part terms were averaged together seem rather flat in amplitude when compared to the control (car-part) 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 5abcd), 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 the cortical generators of the ERP activity move toward the midline. Note that in comparing torso and foot CSD maps (figures 5c and 5d) 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 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 walls of the brain.

The fMRI results also show activation in the primary and secondary sensorimotor cortices in response to the body-part sentence stimuli as contrasted with the control sentence stimuli (figures 6abc). Note first that the area mapped in the hand-stroking task both correlates well with previous mapping studies of the somatosensory cortex (Moore et al 2000) and provides an accurate map of the hand sensorimotor regions for each participant. That defines the regions of interest for the linguistic conditions. Most of the activation in response to the

³ At the time this paper was presented, a complete battery of results from only one participant was available; two others were partially analyzed. Twelve right-hand dominant subjects participated during the course of the experiment over the course of the next year.

contrasts between the literal and control sentences and between the metaphoric and control sentences falls inside these regions of interest. The signal recorded from the literal sentence task was stronger than that recorded from the metaphoric sentence task, but it is clear that many of the same cortical areas are being excited in both conditions (figures 7ab). These results show that many of the same brain regions which map sensorimotor stimulation become active when reading sentences either about hand action or which contain hand action terms used metaphorically.

Discussion

From both sets of results, it is clear that the somatotopic neural maps of the primary and secondary sensorimotor cortices can be driven using linguistic stimuli. In itself the idea that “top-down” stimuli such as language can drive such “low-level” perceptual brain regions much may prove to be a surprising finding; however, the more important question is whether these results can be taken as evidence that the semantic processing of body-part language *requires* the active participation of the sensorimotor cortex. Alternately, one might propose that the sensorimotor maps might become active as an after-effect of semantic processing taking place elsewhere in the brain. Such activation could, for example, be due to the effect of some sort of neural “spreading activation” from those brain areas responsible for doing the semantic processing. There are, however, two cross-methodological arguments against this objection.

First, the ERP experiments discussed herein peak in a time window (400-500 ms) that is consistent with other data on semantic comprehension—including the control terms used in this study. If in fact the activation of the sensorimotor cortices was an after-effect of semantic processing that is performed elsewhere, that activation should be at least marginally later than that of the control terms. However, that is not the case (figure 3). In fact, significant differences in the pattern of CSD current density to body-part vs. car-part words can be observed as early as ~250 ms after stimulus onset;⁴ the CSD analysis reveals a more bilateral pattern for body part terms a more left hemispheric pattern for control (car part) terms at 252 ms after stimulus onset (figures 8ab). Furthermore, when the analysis of the ERPs to body-part terms is broken down into the four somatotopic subcategories at 252 ms, the resulting CSD maps to body-part terms have already begun to show a somatotopic distribution (figures 9abcd).

A second cross-methodological argument against the after-effect objection comes from results in observational neurology. While neurologists have long known that patients can develop anomias reflecting selective category deficits for animals, tools, and plants (Warrington and Shallice 1984), a recent study has reported a selective category deficits in body-part knowledge (Suzuki, Yamadori and Fujii 1997) on body-part name comprehension tasks for a stroke patient who had damage to the frontal operculum (i.e. posterior frontal lobe in the premotor and motor areas). The body-part comprehension deficits of a patient with damage to the sensorimotor cortices in comprehending language further contraindicates the after-effect objection; instead, it provides further support for the idea that these areas play a functional role in the semantic processing of body-part terms.

Conclusion: The Neurophysiology of Cognitive Semantics

Given these cross-methodological coherences between the present fMRI and ERP results and the literature available from observational neurology, it is clear that the semantic processing of body-part language *requires* the active participation of the sensorimotor cortices. Thus, this evidence strongly supports the conceptual metaphor and embodiment hypotheses of cognitive semantics. In their recent work, Lakoff and

⁴ This observation at ~250 ms is similar to that found at the same time by Pulvermüller, Härle, and Hummel (2001); however, the reader is advised that in their article they calculated the CSD maps to a difference wave comparing two conditions rather than to a single condition. That makes interpreting their results difficult, as it is unclear where to place the cortical generators and to which condition we might attribute them.

Johnson (1999) have argued that claiming our language and conceptual structure are embodied entails claiming that perceptual, conceptual and linguistic structure share some of the same subprocesses. As they hypothesized:

The embodied-mind hypothesis therefore radically undercuts the *perception/conception* distinction. In an embodied mind, it is conceivable that the same neural system engaged in *perception* (or in bodily movement) plays a central role in *conception*. That is, it is possible that the very mechanisms responsible for perception, movements, and object manipulation could be responsible for conceptualization and reasoning. (Lakoff and Johnson 1998: 37–38)

The present study specifies where and how some of those neural mechanisms play a role both in bodily sensation and movement and in language comprehension. Future studies will expand and deepen this initial research.

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Figure 1: Levels of Investigation in Cognitive Semantics

Size (in m)	Physiological Structures	Level of Investigation	<i>Typical Cognitive Semantics Theory Explanatory Tasks</i>	<i>Sample Operative Theoretical Constructs</i>	<i>Sample Methods of Study</i>
1 and up	Multiple central nervous systems	Communicative and cultural systems in anthropology, language, science, and philosophy	Uses of widespread cultural metaphors in interpersonal communication; syntactic and semantic change	Complex conceptual metaphor, conceptual blends, disanalogy, subjectification	Linguistic analysis, cross-linguistic typology, discourse analysis, cognitive anthropology, gesture studies
.5 to 2	Central nervous systems	Performance domain; Cognitive, conceptual, gestural, and linguistic systems as performed by individual subjects	Understanding metaphors, extending metaphorical inferences to novel cases, facilitation of related information; use of slang; testing choice of syntactic form given extralinguistic semantic task	Complex conceptual metaphor, conceptual blends, disanalogy, primary metaphor, metaphor mappings, inference generalizations	Verbal report, observational neurology, and psychiatry, cognitive and developmental studies examining reaction time (RT)
10 ⁻¹ to 10 ⁻²	Gross to medium size neural regions (anterior cingulate, parietal lobe, etc.)	Neural systems	Activation course in somatosensory, auditory, and visual processing areas when processing conceptual metaphor or multimodal perceptual experiences	Conceptual metaphor mappings, primary metaphor, conceptual blends, disanalogy, image schemas, topological maps	Lesion analysis, neurological dissociations, neuroimaging with fMRI and PET, ERP methods, neurocomputational simulations
10 ⁻² to 10 ⁻⁴	Neural networks, maps and pathways	Neuroanatomy; Neural circuitry in maps, pathways, sheets	Neuroanatomical connections from visual, auditory, somatosensory regions to language areas	Image schemas, primary metaphor, topographic maps, convergence zones	Electrocellular recording, anatomical dyes, neurocomputational simulations
10 ⁻³ to 10 ⁻⁶	Neurons, cortical columns	Neurocellular systems; Cellular and very small intercellular structures	Fine neuroanatomical organisation of particular structures recruited in lang. processing	Orientation-tuning cells; ocular dominance columns	Electrocellular recording, anatomical dyes, neurocomputational simulations
Less than 10 ⁻⁶	Neuro- transmitters, ion channels, synapses	Subcellular systems; Subcellular, molecular and electrophysical	None—beyond theoretical scope	Neurotransmitter, synapse, ion channels	Neuro- pharmacology, neurochemistry, neurophysics

Figure 2: The sensorimotor cortices and the distribution of body parts along them (adapted from Posner and Raichle 1994).

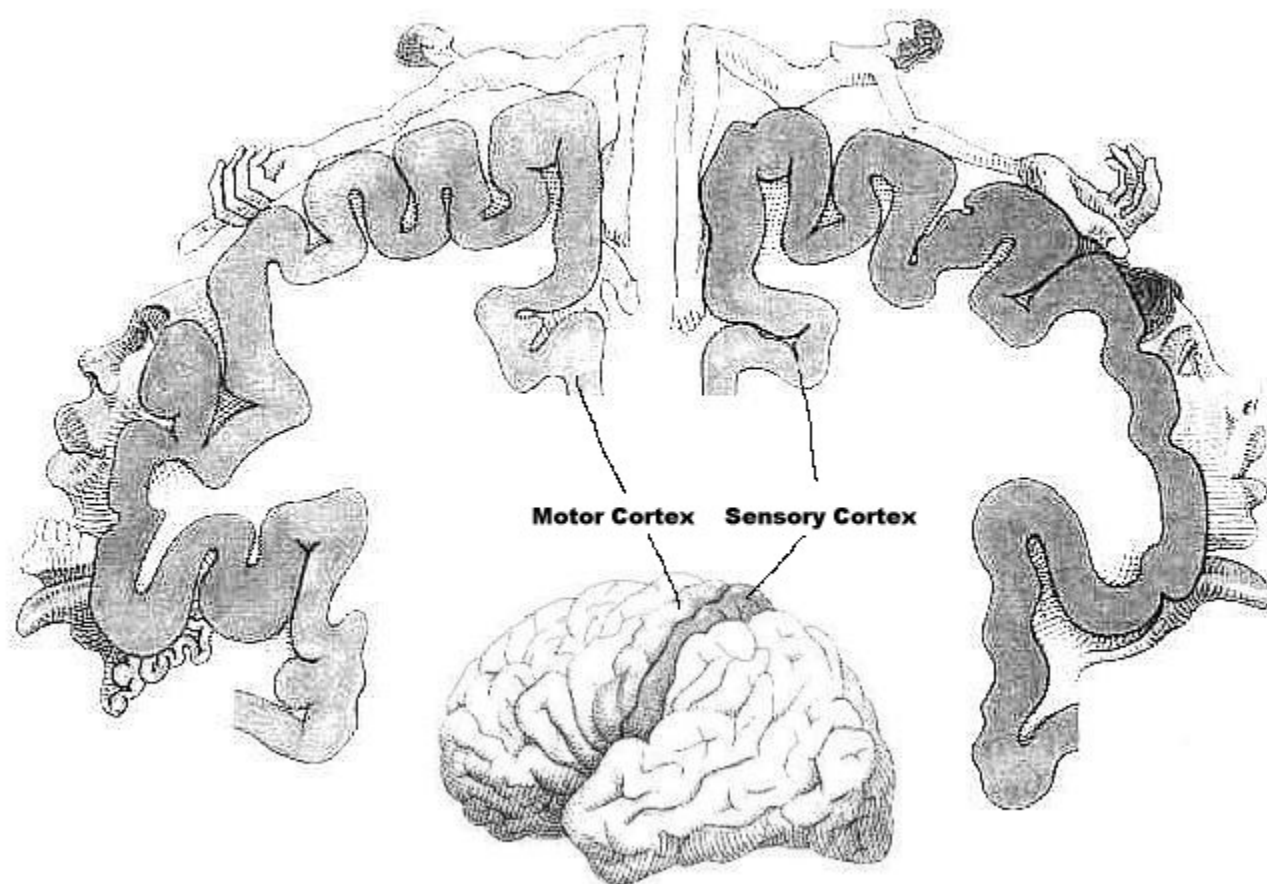
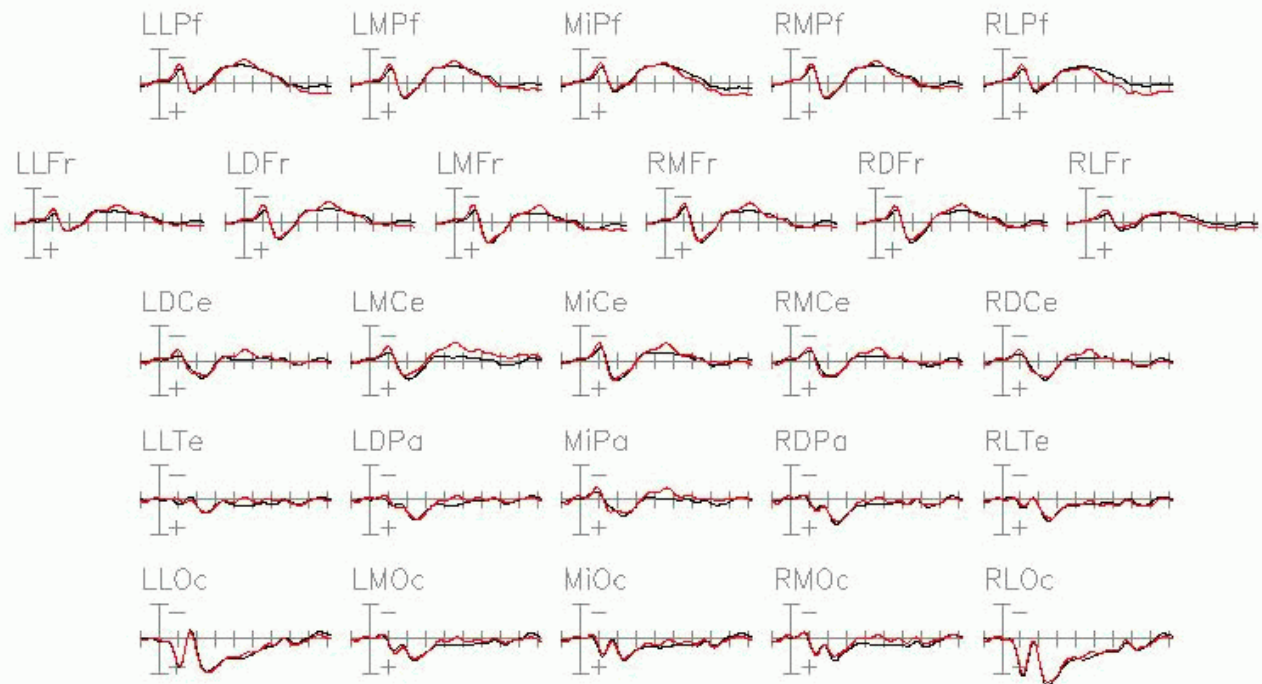


Figure 3: ERP temporal dynamics for reading comprehension tasks (body parts vs control of car parts). Note that the organization of these graphs mirrors the electrode placement over the scalp.



Cal 5.0 μ V/side Window -100→920 ticks 100 onset 100

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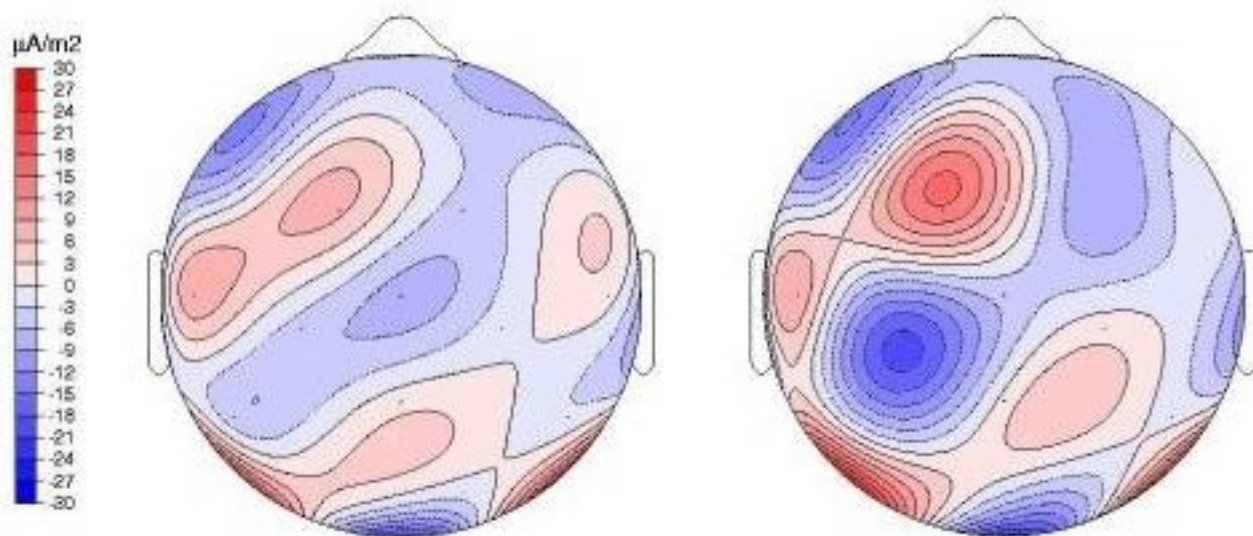
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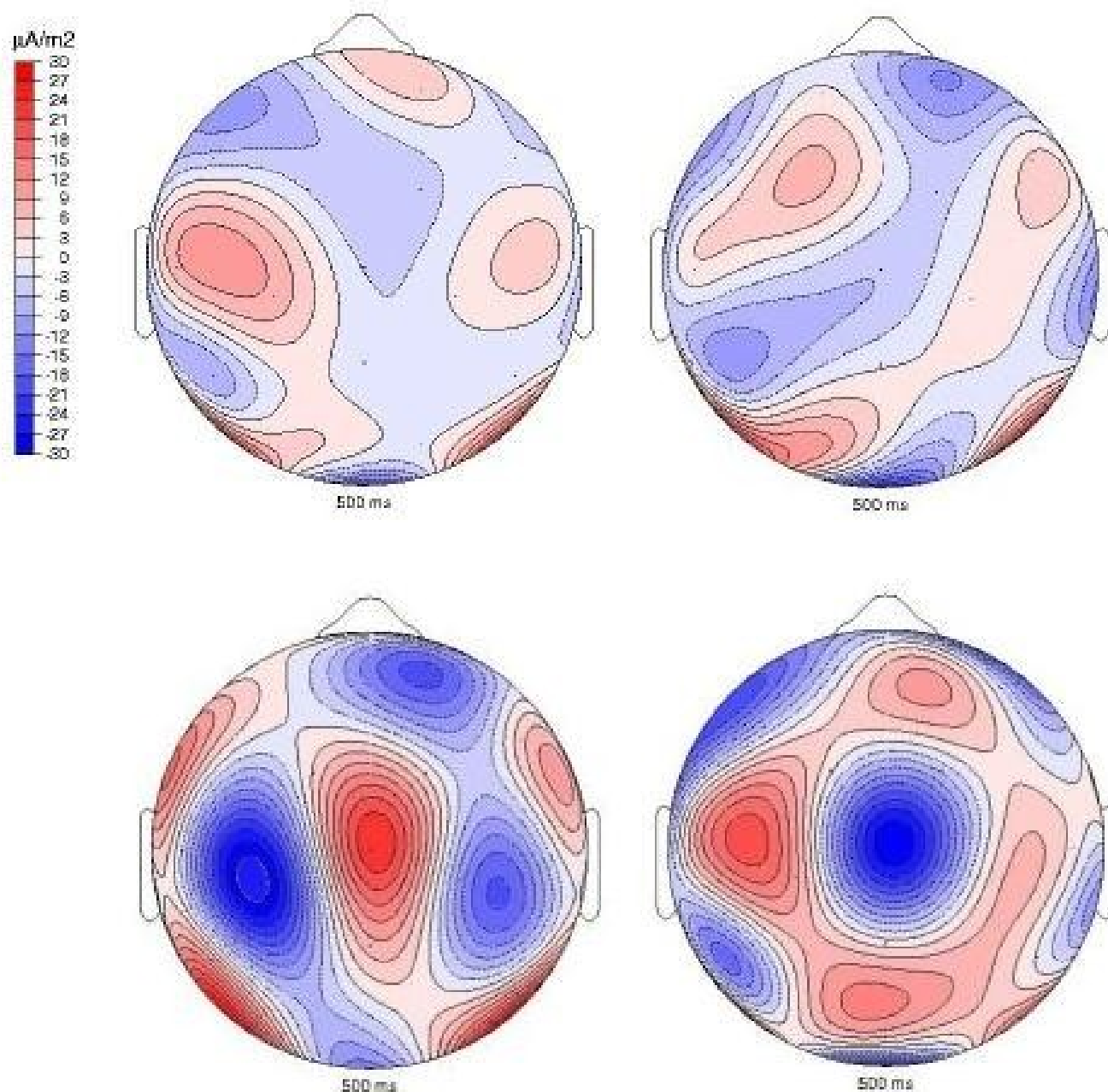
— Bin 1: reading body part terms, Comprehension Task – body parts, 13(288)

— Bin 6: Comprehension – reading car part terms, Comprehension Task – body par

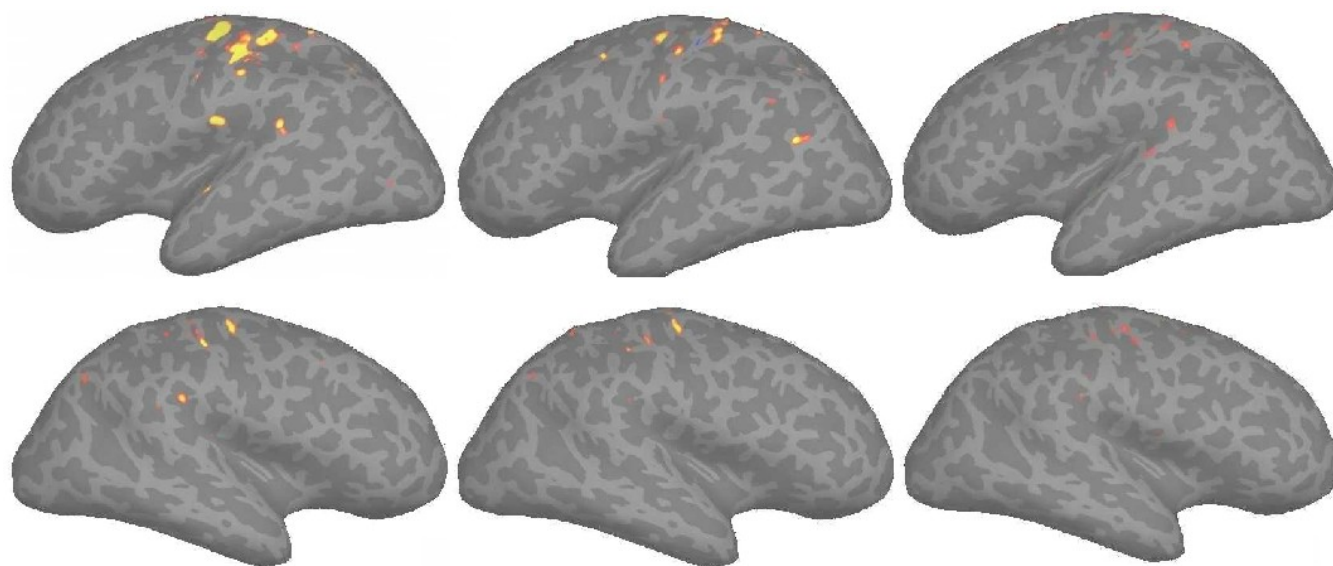
Figures 4ab: Somatotopic distribution of body part terms vs. control of car part terms as represented in current source density topographic maps. The response to all body part terms is on the left; while the response to the control (car part) terms is on the right. These CSD maps are from 500 ms after stimulus onset.



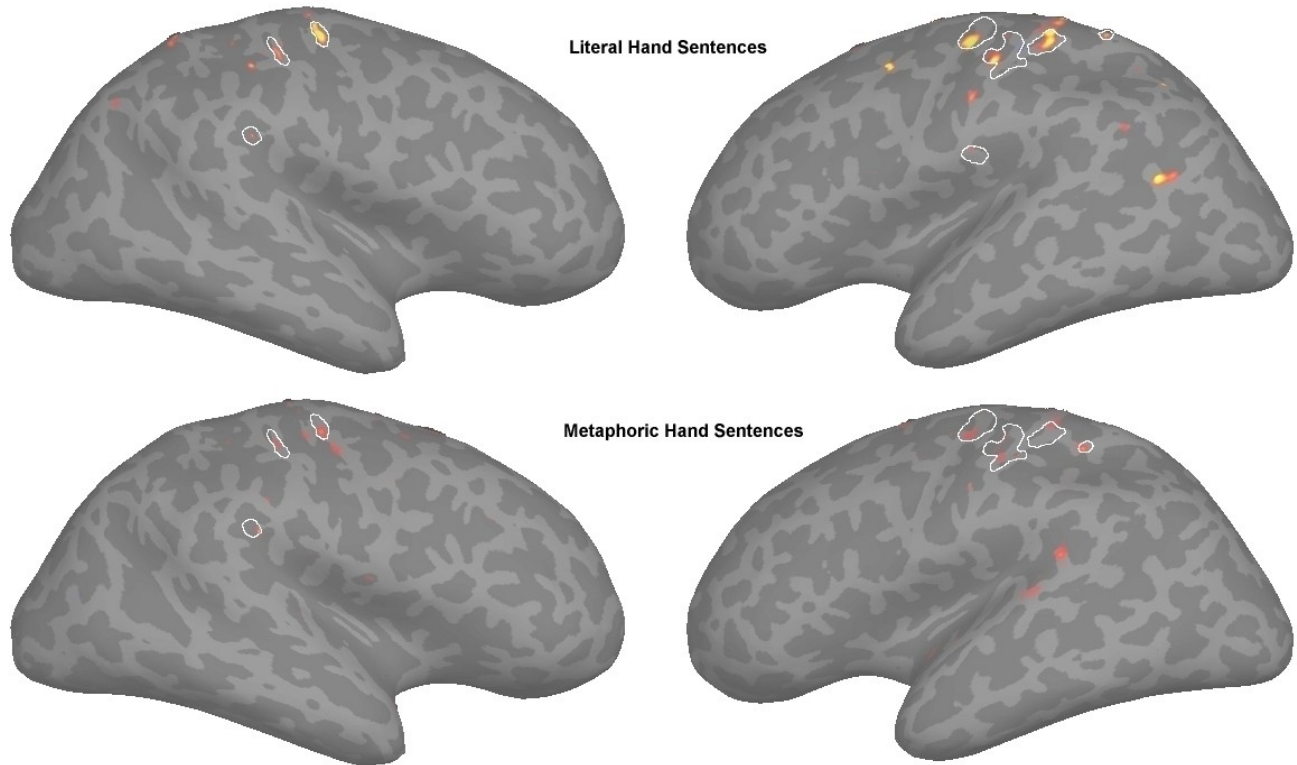
Figures 5abcd: Somatotopic distribution of face, hand, torso and feet body part terms as represented in current source density topographic maps. The response to mouth and face words is at the top left, to hand words is on the top right, to torso words is on the bottom left, and to feet words is on the bottom right. These CSD maps are from 500 ms after stimulus onset.



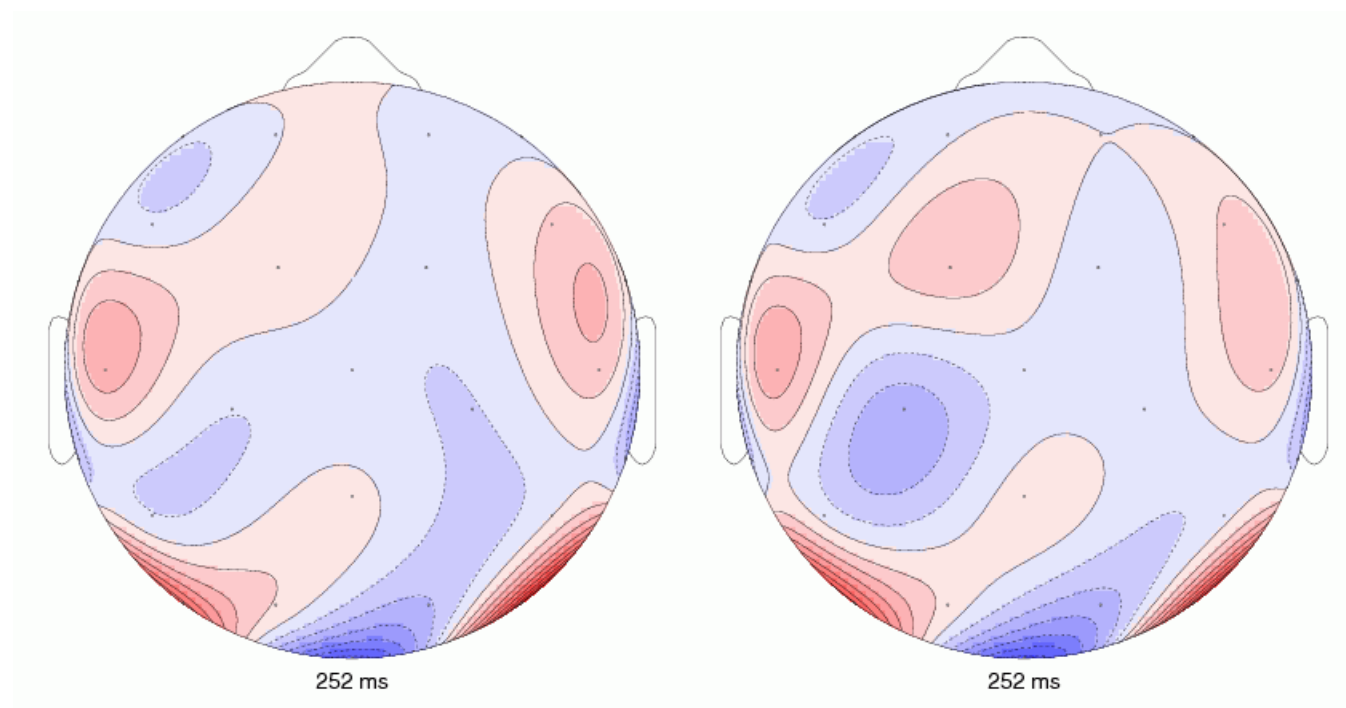
Figures 6abc: Lateral views of fMRI results mapped onto an inflated view of the cortex for a single subject. The leftmost column is the response to a right-hand stroking task, the middle column is to literal hand sentences, and the rightmost is to the metaphoric hand sentences. The left hemisphere is on top, the right hemisphere is below.



Figures 7ab: Lateral views of fMRI results mapped onto an inflated view of the cortex for a single subject with the regions of interests outlined in white. The region of interest was defined the sensorimotor cortex response to a right-hand stroking task. The leftmost column is the response to the hand stroking task, the middle column is to literal hand sentences, and the rightmost is to the metaphoric hand sentences. The left hemisphere is on the right, the right hemisphere is on the left; the top pair indicates the response to the literal hand sentences, while the bottom pair indicates the response to the metaphoric hand sentences.



Figures 8ab: Somatotopic distribution of body part terms vs. control of car part terms as represented in current source density topographic maps. The response to all body part terms is on the left; while the response to the control (car part) terms is on the right. All CSD maps are from 252 ms after stimulus onset.



Figures 9abcd: Somatotopic distribution of face, hand, torso and feet body part terms as represented in current source density topographic maps. The response to mouth and face words is at the top left, to hand words is on the top right, to torso words is on the bottom left, and to feet words is on the bottom right. All CSD maps are from 252 ms after stimulus onset.

