9

Language, Action, Interaction

Neuropragmatic Perspectives on Symbols, Meaning, and Context-Dependent Function

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Abstract

Neural mechanisms of cognition are built upon action, action perception, and interaction. This chapter explains how this novel perspective, immanent to the "pragmatic turn" in cognitive neuroscience, is enforced by research on language, semantic concepts, and social communication. Whereas classic approaches attributed these specifically human domains to genetic endowment and encapsulated processes, modern cognitive and brain research has accumulated evidence that mechanisms for speech sounds and symbol forms emerge as a result of sensorimotor functional interaction in the brain, and that conceptual-semantic information is extracted from the interaction of learners with their environment and peers. Correlational Hebbian learning in anatomically prestructured network architectures binds articulatory-motor to auditory-perceptual (phonological) knowledge. This epigenetic neurobiological perspective also explains important aspects of whole form (lexical) storage of symbols and constructions, combinatorial (distributional, syntactic, or grammatical) linkage between stored forms, and context-dependent (semantic, pragmatic) binding between forms, their meaning, and interactive function. Over and above evidence for motor system activation in linguistic and conceptual processing, specific studies demonstrate its causal role for these domains. Thus, action-perception theory offers a novel avenue toward neurobiological explanation of the brain mechanisms for language, concepts, and pragmatic communication.

Introduction

When sensory neurons in an artificial network with random connectivity are repeatedly stimulated, these neurons link up with their connected neighbors to

form a strongly connected neuron set (Doursat and Bienenstock 2007). This *neuron set* (also termed cell assembly, synfire chain, neuronal avalanche, or neuronal ensemble) can be seen as a sensory "representation" (Hebb 1949). Strong experimental evidence indicates that our brains carry such sensory representations (see Plenz and Thiagarajan 2007; Singer and Gray 1995). However, representational mechanisms do not need to be restricted to the sensory-perceptual domain. In many cases, a degree of motor activity accompanies novel experience: We startle, smile, explore, approach, or retreat in view of new objects or persons. In such cases, the purely "sensory" learning model is insufficient; motor movements or (when these are led by specific goals) goal-directed actions need to be taken into account (Braitenberg and Schüz 1992; Fuster 1995; Jeannerod 1994; Rizzolatti and Craighero 2004; Pulvermüller 1999). When modeling action-perception contingencies in neurocomputational models structured according to cortical areas and their neuroanatomical connectivity, action-perception contingencies lead, by way of Hebbian learning, to the formation of distributed neuronal circuits. These *action-perception circuits* incorporate neurons in sensory model areas and adjacent "higher" multimodal ones, and reach into prefrontal, premotor, and, ultimately, primary motor areas (Garagnani et al. 2008; Pulvermüller and Garagnani 2014). They provide a mechanism for the cognitive correlates of objects with a regular and specific usage, including tools or food items, as well as for actions the individual can perform, because action performance always implies specific motor movements along with sensory autostimulation. Representations[1] that connect motor and sensory knowledge with each other can be called "pragmatic";[2] the focus on interlinked action-perception representations and circuits characterizes what has been called the "pragmatic turn" (Engel et al. 2013). Such action-perception representations may be more powerful neuronal devices than unimodal sensory representations, because they arise from correlated activity in sensory and motor areas, and therefore, their likely neural mechanisms are large widely distributed circuits spread out over multiple cortical areas.

The postulate that action representations and mechanisms are systematically coupled to perceptual ones has a long history in the cognitive and brain sciences

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[1]   When speaking about action-related engrams, Engel et al. (2013) propose to replace the term "representation," with "directive." However, in theories of language and communication in *linguistic pragmatics* (Austin 1962; Fritz 2013; Searle 1969; Stalnaker 2002; Wittgenstein 1953), directives represent only one subtype of social-communicative action; namely requests, commands, and the like. Thus, the use of the term "directive" might suggest an exclusion of other relevant action and interaction types (e.g., assertions or expressions of feelings, planning, and bargaining) (see, e.g., Searle 1979). Therefore, I will use the term "pragmatic representations" to refer to knowledge about all types of actions (communicative and not) and the perceptions to which they relate.

[2]   In this sense, the term "pragmatics" can be used to speak about a range of different scientific schools, ranging from "enactive," "grounded," and "embodied" cognitive theory (Varela et al. 1992; Clark 1999; Barsalou 2008; O'Regan and Noë 2001) to pragmatism or pragmatic philosophy (Mead 1938; Dewey 1896; Peirce 1931, vol. 5) and linguistic pragmatics.

(Jeannerod 2006; Fuster 2003; Braitenberg and Schüz 1998; Pulvermüller 1999; Pulvermüller and Fadiga 2010; Rizzolatti and Sinigaglia 2010; Clark 1999; O'Regan and Noë 2001). This hypothesis is radically different from the classic position that modality-specific sensory modules channel information to central systems for attention, memory, language, concepts, and decisions, which, in turn, drive the motor output (see Figure 9.1; Hubel 1995; Fodor 1983). Instead, cognition is seen as being *built from* action and related perceptions, upon motor and sensory brain mechanisms (Jeannerod 1994, 2006).

Are Action-Perception Mechanisms Sufficient for Cognition?

A wealth of data support this pragmatic position of interwoven action-perception circuits. *Mirror neurons* are active in motor planning and execution as well as in the perception (visual or auditory) of specific actions (Rizzolatti et al. 1996; Kohler et al. 2002; Rizzolatti and Craighero 2004). This dual role may be due to their membership in action-perception circuits that formed as a consequence of cortical anatomy and mapping of neuronal correlations by Hebbian synaptic plasticity. *Memory mechanisms* are known to rely on both posterior (e.g., temporal or parietal) areas but also draw upon prefrontal neurons; the parallel functions of neurons in different lobes may relate to their membership in the same distributed action-perception circuits (Fuster and Alexander 1971; Fuster 1995; Pulvermüller and Garagnani 2014). Mechanisms for mapping motor movements on perceptions are necessary for repetition and imitation of behavior, which seem to play a crucial, though basic, role in normal cognitive and language development (Rizzolatti and Craighero 2004; Pulvermüller and Fadiga 2010). Over and above such (basic) perceptual recognition of movements that individuals have previously performed by themselves, it has been argued that the *understanding* of others' actions may depend, to a degree, on action-perception mapping between different individuals, and that the mental simulation of others' actions may be a main component of the understanding of language, symbols, social-communicative function, intentions, and, more generally, meaning (Kiefer and Pulvermüller 2012; Pulvermüller 2013; Glenberg and Gallese 2012; Barsalou 2008; Meteyard et al. 2012). However, arguably, it is not clear how these aspects of higher cognition emerge from circuits that store action-perception contingencies. Animal and (especially) human cognition as well as social interaction certainly require more than imitation, repetition, and simulation (Borg 2013; Jacob and Jeannerod 2005; Hickok 2009; Lotto et al. 2009; Hickok and Hauser 2010; Csibra 2007). In view of a neuromechanistic theory of human cognition, it is thus crucial to explore which cognitive mechanisms are explained by an action-perception perspective and whether there are natural limits to this line of thought.

Starting from established knowledge about mirror neurons and action-perception coupling in the brains of monkeys and humans, I discuss the idea that
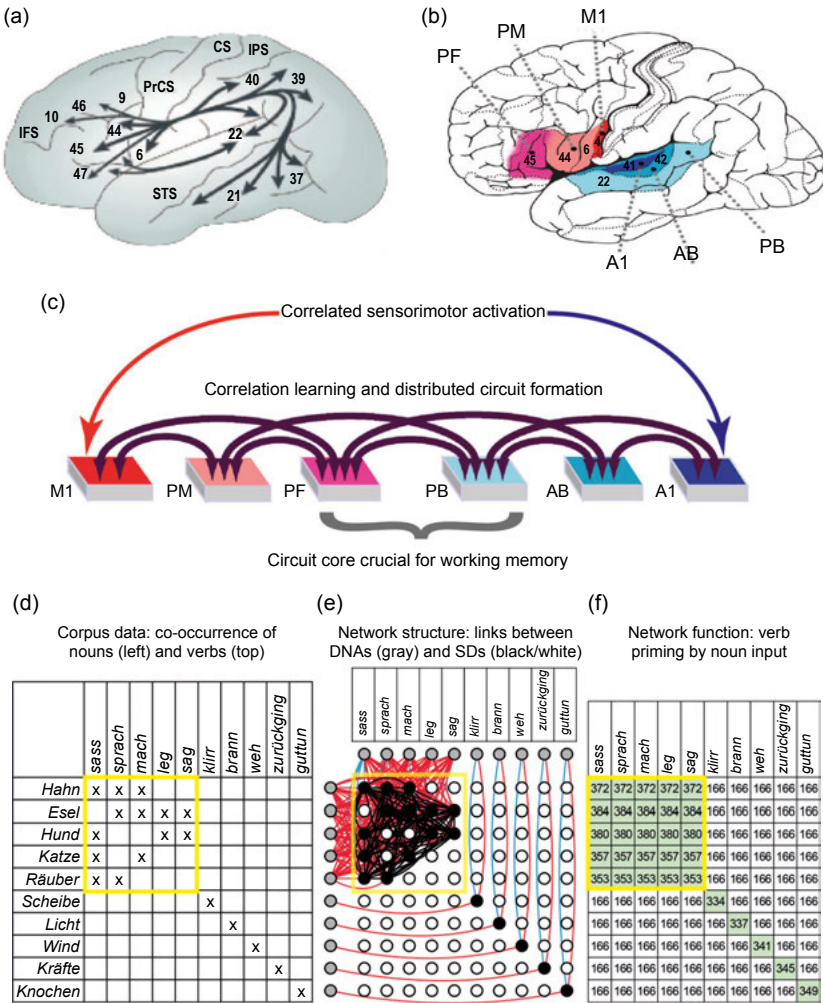
(a)

CS IPS

PrCS

40 39

9

46

10

IFS

44

45 6 22

47

STS 21 37

(b)

PM M1

PF

44 6

45

41 42

22

A1 AB PB

(c)

Correlated sensorimotor activation

Correlation learning and distributed circuit formation

M1   PM   PF   PB   AB   A1

Circuit core crucial for working memory

(d)

Corpus data: co-occurrence of nouns (left) and verbs (top)

	sass	sprach	mach	leg	sag	klirr	brann	weh	zurückging	guttun
Hahn	x	x	x							
Esel		x	x	x	x					
Hund	x			x	x					
Katze	x		x							
Räuber	x	x								
Scheibe						x				
Licht						x				
Wind							x			
Kräfte								x		
Knochen									x	

(e)

Network structure: links between DNAs (gray) and SDs (black/white)

(f)

Network function: verb priming by noun input

	sass	sprach	mach	leg	sag	klirr	brann	weh	zurückging	guttun
	372	372	372	372	372	166	166	166	166	166
	384	384	384	384	384	166	166	166	166	166
	380	380	380	380	380	166	166	166	166	166
	357	357	357	357	357	166	166	166	166	166
	353	353	353	353	353	166	166	166	166	166
	166	166	166	166	166	334	166	166	166	166
	166	166	166	166	166	166	337	166	166	166
	166	166	166	166	166	166	166	341	166	166
	166	166	166	166	166	166	166	166	345	166
	166	166	166	166	166	166	166	166	166	349

Figure 9.1 Cortico-cortical connectivity, word form circuit formation, and combinatorial semantic learning. (a) Long-range cortico-cortical connections within the perisylvian language cortex and adjacent areas. Abbreviations: IFS, inferior frontal sulcus; PrCS, precentral sulcus; CS, central sulcus; IPS, intraparietal sulcus; STS, superior temporal sulcus; numbers indicate Brodmann areas (Rilling et al. 2008; reprinted with permission from Macmillan Publishers Ltd.). (b) Neuroanatomical subdivision of inferior frontal and superior-temporal cortex into six areas: M1, primary motor; PM, premotor; PF, prefrontal; A1, primary auditory; AB, auditory belt; and PB, auditory parabelt areas (Garagnani et al. 2008; reprinted by permission from John Wiley and Sons). (c) Schematic connection structure of the six areas highlighted. Correlated activation in M1 and A1 during articulations leads to spreading activation in the network and distributed circuit formation for syllables and words. Their richer connectivity determines that PF and PB develop circuit cores (Garagnani and Pulvermüller 2013), where word form circuits link with each other in combinatorial learning.

Figure 9.1 (continued) (d–f) Combinatorial learning of noun-verb co-occurrences in an auto-associative neuronal network model. (d) The matrix shows word pair co-occurrences in a mini-corpus that served as input to the network (verbs in top row, nouns in left column; crosses indicate co-occurrences in text). The matrix section of frequent recombination is highlighted in yellow. (e) Neuronal elements for the same words (gray circles), sequence detectors (SDs) sensitive to specific word pair sequences (white and black circles in square arrangement), and connections between them. Black SDs indicate learning of specific sequences of nouns and verbs previously presented to the network. All word circuits previously involved in combinatorial exchanges are interlinked by way of a conglomerate of heavily interconnected sequence detectors, *the combinatorial neuronal assembly* (black SDs and black between-SD links on top left). Emergence of *generalized links* between those nouns and verbs, which frequently occur in combination with the respective other word group (yellow square), by formation of the combinatorial neuronal assembly is a neuromechanistic result of co-activation of *some* (not all) of the relevant SDs. (f) Result of combinatorial learning for network functionality. After learning, activation of any noun involved in the combinatorial schema (yellow square) primes all of the verbs involved to the same degree, regardless of whether the specific word sequence itself had been subject to learning. The dynamics are discrete in the sense of an all-or-none response. Note the generalization to sequences not previously encountered (Pulvermüller and Knoblauch 2009; reprinted with permission from Elsevier).

pragmatic action-perception representations are the building blocks of higher cognition. The more specific and crucial questions that I will address include:

- Are sensorimotor interactions involved in perception? (See section on "Speech Movement Coupled to Perception.")
- Is there a pathway from sensorimotor coupling to action-perception circuits for understanding meaning? (See section on "From Movement to Meaning.")
- Can (aspects of) abstract meaning be captured by action-perception circuits? (Discussed under "Abstract Meaning.")
- How are communicative actions and intentions realized in an action-perception architecture? (See section "Social-Communicative Interaction.")
- And, generally, given that motor systems are *activated* in perception and cognition, do they also *contribute to* and have a *causal effect on* cognitive processing? (Addressed in all sections.)

These questions have been addressed extensively in the domain of language and communication. This chapter highlights recent work as it pertains to the neuroscience of language.

Speech Movement Coupled to Perception: Mirror Neuron Circuits, Repetition, and Simulation

The correlation of motor activity with sensory input is implied by the very fact that, in the un-deprived individual, movements lead to sensory self-stimulation.

Correlations are mapped in the brain and especially in the cortex, whose neu-
roanatomical properties seem to be optimal for functioning as an associative
memory (Braitenberg and Schüz 1998). In the human language areas of the left
hemisphere, there are species-specific strong connections through the dorsal
arcuate fascicle between frontocentral areas adjacent to articulatory motor cor-
tex and temporal areas relevant for acoustic processing (see Figure 9.1; Rilling
et al. 2011). These provide the necessary information highway for mapping
of sensorimotor correlations according to Hebbian learning principles (Artola
and Singer 1993; Caporale and Dan 2008). The mirror circuits that map speech
sounds (or phonemes) onto their articulatory motor schemas may therefore be
a result of learning. Note that in view of the variability of phoneme inventories
across languages, an inborn phonological mapping mechanism is insufficient.
The formation of action-perception circuits can be tracked even in adults who
learn novel, meaningless spoken word forms (Pulvermüller, Kiff et al. 2012;
Shtyrov et al. 2010). A range of data support the activation of motor circuits in
speech perception (Fadiga et al. 2002; Pulvermüller et al. 2006) and their rel-
evance for speech sound classification (D'Ausilio et al. 2009; Möttönen et al.
2013). A degree of discussion still surrounds the question whether frontocen-
tral articulatory motor and premotor cortices take a direct causal role in speech
sound processing (Pulvermüller and Fadiga 2010; Möttönen et al. 2013) or
whether their role is restricted to a post-perception task-dependent decision
stage (Venezia et al. 2012). Recent results provided evidence for a direct causal
role of articulatory sensorimotor cortex in semantic understanding of single
spoken words (Schomers et al. 2015).

In neurocomputational studies, action-perception circuits for speech
sounds, spoken word forms, or motor acts can more generally be employed
to activate a specific motor program upon specific sensory (auditory, visual,
etc.) stimulation (Garagnani et al. 2008). Neurodynamically, the strong links
within the action-perception circuits entail a full activation or "ignition" of
the cell assembly after sensory stimulation, a possible brain basis for percep-
tion and recognition of objects and word forms. Followed upon ignition of
a circuit, reverberatory activity lasts for some time, thus providing a brain
basis for object- and word-specific working memory. Due to the connectivity
structure of action-perception circuits, memory-related reverberating activ-
ity tends to "retreat" to areas where especially strong connectivity to other
areas is present; that is, to higher multimodal cortices (prefrontal and anterior-
temporal). As ignition and reverberation processes provide a neurobiologi-
cal basis for *recognition* and *working memory* for linked action-perception
information (Pulvermüller and Garagnani 2014), they may be essential for
overt immediate or delayed *imitation* and *repetition* of perceived body actions
or heard words. Since a network can accommodate numerous strongly con-
nected circuits, control mechanisms are necessary to prevent overshooting ac-
tivity. Such regulation can be model-implemented by local and global inhibi-
tion mechanisms, which also provide competition between action-perception

circuits. The degree of regulation and competition between circuits can model aspects of *attention* related to task and context (Wennekers and Palm 2007; Wennekers et al. 2006). Modulation of area-specific inhibition also provides a mechanism for blocking motor output during passive listening and mental simulation as well as for "opening the motor gate" for repetition and speech production. Crucially, regulation and gain control provide mechanisms for *inhibiting "mirror actions" in the social context* (Jacob and Jeannerod 2005; Jeannerod 2006). Because the dynamics of action-perception circuits are under the control of regulation, action-perception mapping cannot be entirely automatic, in the sense that it is not suppressible. Still, mapping from perception to action is automatic in the sense that it rapidly arises in passive perception, even if subjects try to ignore the critical stimuli (Pulvermüller et al. 2003; Pulvermüller 2005; Shtyrov et al. 2014).

From Movements to Meaning: The Case for Action Semantics

The issue of how *meaningful* symbols should be modeled in a pragmatic action-perception network is as yet unresolved. The coupling of knowledge about symbols, including hand gestures, words, and longer constructions, to meaning is achieved through second-stage associative learning. Symbol and action schema become related to each other because different action-perception circuits are being interlinked. In this sense, the comprehension of action words such as "lick," "pick," and "kick" may rely on coupled action-perception circuits for word forms and body part-specific motor schemas (Hauk et al. 2004). One can see this as "mere association" and indeed some researchers chose to move this kind of model in the spiritual neighborhood of behaviorist accounts of meaning and language (Hickok 2010; Mahon and Caramazza 2008). However, the problem that arose from behaviorist approaches to language (e.g., Bloomfield 1933) did not stem from their consideration of behavior as such, but in the static manner in which they construed the relationship between signs, stimuli, and responses (Alston 1964). Semantic links between words and the actions they can be used to speak about are as important for semantic models as are the referential object links immanent to word usage (Chierchia and McConnell-Ginet 2000; Baker and Hacker 2009). These semantic links can, at least in part, be explained neurobiologically by the coupling between action-perception circuits for body actions or objects as well as for symbol form circuits (Pulvermüller 1999). Such learning by correlation mapping is implied by general principles of brain function and, in particular, the cortex's role as an associative memory (Braitenberg and Schüz 1998). In the majority of studies addressing this issue, empirical evidence clearly shows that motor regions (including motor and premotor cortex) are being activated in fMRI experiments on written and spoken action word and action sentence processing (Figure 9.2; for a review, see Carota et al. 2012). Interestingly, words semantically
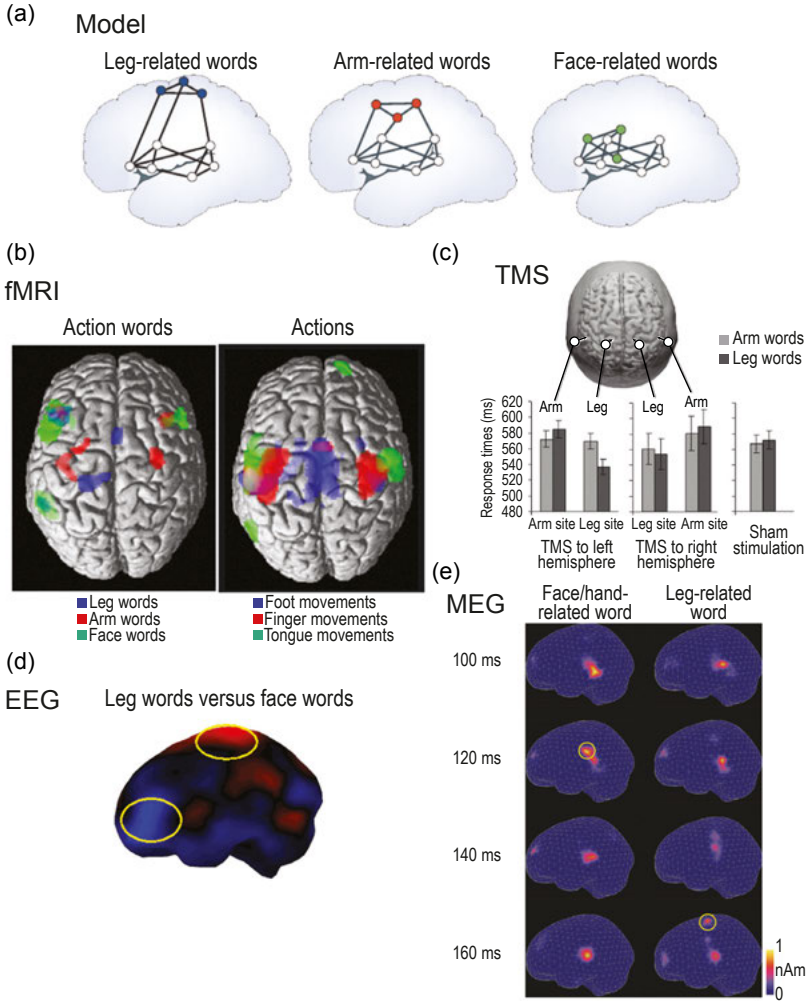
Figure 9.2 Semantic somatotopy model and experimental evidence. (a) Neurobiological model of cortical circuits underlying the processing of words and utterances typically used to speak about actions preferentially involving the face/articulators (e.g., *lick*), arm/hands (*pick*), or leg/feet (*kick*) (Pulvermüller 2001; reprinted with permission from Elsevier). Semantic circuits are postulated in different parts of the motor and premotor cortex. (b) Activation of the motor system, as measured with fMRI, by passively reading *face* (in green), *arm* (red) and *leg* words (blue) and, partly hidden, during motor movements of the *tongue* (green), *index finger* (red) and *foot* (blue) (Hauk et al. 2004; reprinted with permission from Elsevier). (c) Differential facilitation of arm/leg words by magnetic stimulation of the motor cortex controlling the finger/foot using TMS. The brain diagram indicates stimulation loci; bars give average response times of lexical decisions responses expressed by tongue movements (error bars give standard errors) (Pulvermüller, Hauk et al. 2005; reprinted with permission from John Wiley and Sons).

Figure 9.2 (continued) (d) Rapid differential activation of inferior-frontal and superior-central areas by face (in red) and leg words (blue) 200–220 ms after visual word presentation as calculated from EEG recordings (Hauk and Pulvermüller 2004; reprinted with permission from John Wiley and Sons). (e) Rapid activation of frontocentral areas by face/hand (left) and leg verbs (right) 120–200 ms after the recognition point of spoken face/hand-related words (left) and leg words (right), as measured with MEG. Yellow circles indicate early activations of inferior-central areas to face/arm items and, slightly later, dorsocentral activation to leg words; latencies are given relative to word recognition points (modified from Pulvermüller, Shtyrov, et al. 2005; reprinted with permission from The MIT Press).

linked to different body parts preferentially activate the motor representations of these same extremities, so that some (although certainly not all) aspects of action meaning are visibly reflected in the brain response (Hauk et al. 2004; Tettamanti et al. 2005; Kemmerer et al. 2008; Pulvermüller, Cook et al. 2012).[3] Similarly, perceptual circuits for objects linked to word form circuits may underlie referential semantics, although a degree of semantic action-relatedness cannot be denied for many object words (e.g., tool and food words; Carota et al. 2012; Martin et al. 1996).

A range of criticisms have been raised against this pragmatic action-perception perspective on semantic meaning (e.g., Hickok 2010; Bedny and Caramazza 2011). One argument stipulates that word-object and word-action relationships are not 1:1. Some words have different meanings and even within the range of one single meaning, different nuances, or "senses," can be distinguished. This argument, however, does not pose a problem for a neurobiological account, which allows one-to-many relationships to be implemented by interlinking one word form circuit with two or more semantic circuits, and offers regulatory mechanisms to enforce selection between semantic alternatives (Pulvermüller 2002b). Priming in the semantic network—from previously active circuits—contributes to the selection of circuits and circuit parts over competing ones.

A major argument against a pragmatic action-perception mechanism for semantics held that activation of motor systems may be "epiphenomenal" and follow the understanding of action words rather than reflect it. The *epiphenomenality position* implies that some other, truly semantic process precedes (in this case pseudo-semantic) motor system activations, thus predicting that the motor system's response occurs late relative to the truly semantic one. Neurophysiological studies using EEG and MEG could clarify that motor system activation, which reflects the meaning of action words, emerges rapidly. At

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[3] One study claimed that such "somatotopic semantic" activity does not exist (Postle et al. 2008). However, analyzing the results from their "action observation" localizer with a repeated measures ANOVA with the factors semantic word category (face, arm, leg), motor area (primary, secondary) and somatotopy (face, arm, leg region), yielded a significant interaction of semantic word category with somatotopy, $F_{(4,64)} = 3.8$, GG-eps = 0.64, p = 0.022. I thank Greik de Zubicaray for sharing the data.

the earliest latencies, semantic brain responses could be tracked (Pulvermüller et al. 2001; Hauk and Pulvermüller 2004; Pulvermüller, Shtyrov et al. 2005; Shtyrov et al. 2014). A further criticism was that motor system activation might accompany action semantic processing, but may not be *crucial and causal* for it. Meanwhile, a range of data speak against this *afunctionality position*: the causal effect of transcranial magnetic stimulation (TMS) to motor cortex on the processing of specific action-word subcategories (e.g., faster leg word recognition to leg cortex TMS; Pulvermüller, Hauk et al. 2005); work in neurological patients with predominant involvement of the motor system, and consequent action word processing deficit (Bak 2013; Arevalo et al. 2012; Kemmerer et al. 2012); and interference studies in healthy subjects engaging in motor movement and showing body part-specific effects on action word processing (Boulenger et al. 2006; Shebani and Pulvermüller 2013). The epiphenomenality and afunctionality hypotheses could not be confirmed and no principle objections remain against the position that—at least for some symbols, constructions, and meaning aspects—semantics is reflected and carried by the mind and brain's motor system (Kiefer and Pulvermüller 2012; Pulvermüller et al. 2014).

However, meaning is not exhausted by semantic links between language, the world, and the body. *Combinatorial* or *distributional semantic* models construe meaning relationships between symbols in terms of similarities between the contexts in which they frequently occur (Landauer 1999). The limitation of these approaches comes from the fact that they do not cover semantic links between words and the world, so-called "*symbolic grounding*" in objects and actions (Harnad 1990). In contrast, an action-perception account provides not only natural and biologically plausible mechanisms for symbolic grounding, it also accommodates combinatorial semantics. Two complementary mechanisms are offered:

First, a learned symbol with semantic action-perception grounding can frequently co-occur with a novel meaningless symbol. Co-occurrence between simulated semantic activations brought about by the first symbol's circuit with the emerging circuit of the novel word form leads to "parasitic" contextual incorporation of semantic information into the new circuit, which therefore shares semantic neurons with the already established one (see also Cangelosi and Harnad 2001; Pulvermüller 2002a). This mechanism can lead to the coupling of new combinations of semantic features to novel symbols.

Second, symbol forms frequently appearing in sequence can link their circuits sequentially (Pulvermüller 2010; Buzsáki 2010). Neurocomputational simulation studies suggest that this type of combinatorial learning can lead to discrete combinatorial neuronal assemblies (DCNAs), which link together not individual words but, instead, whole classes of semantically and combinatorially similar symbols (Figure 9.1, d–f; Pulvermüller and Knoblauch 2009). Joint and hierarchical activation of sets of DCNAs has been proposed as a

brain mechanism for grammar and generation of meaningful sentences and constructions (see Pulvermüller 2002b).

Abstract Meaning: Love, Beauty, Ifs, and Buts

A classic argument against action-perception grounding is based on abstract meaning. Whereas the meanings of the words "eye" and "grasp" can be explained, to a degree, by pointing to similar objects or actions and extracting their common features, those of "beauty" and freedom" cannot. It may be that some common sensorimotor knowledge is inherent in *freeing* actions or instantiations of *beauty* (Lakoff 1987), but it seems likely that additional semantic binding principles underpin such concepts. A remarkable observation has recently been offered: Abstract terms show an over-proportionally strong tendency to be semantically linked to knowledge about emotions (Kousta et al. 2011; Meteyard et al. 2012). This additional embodied-semantic link accounts for advantages in processing speed, which abstract emotional terms show compared with otherwise matched control words (Kousta et al. 2011). In addition, abstract words strongly activate the anterior cingulate cortex, a site known to be relevant for emotion processing (Vigliocco, Kousta et al. 2014). Thus, it appears that at least some abstract words are semantically grounded in emotion knowledge.

If, indeed, abstract emotion words receive their meaning through grounding in emotion (Kousta et al. 2011), it is of crucial relevance to explain how emotion grounding is established. Note that an amodal semantic system account does not address this question. Even if such a system contained an inborn emotion concept of *joy*, it is left unexplained how the learner knows to relate the concept to its corresponding word, and not, for example, to *grief*. The classic answer in semantic theory is that this is possible because abstract emotions and other internal states have characteristic ways in which they manifest in the actions and interactions the learner engages in with speakers of the language (Wittgenstein 1953; Baker and Hacker 2009). Therefore, the link between an abstract emotion word and its abstract concept is by way of the manifestation of the latter in prototypical actions. The child learns an abstract emotion word such as *joy*, because it shows *joy*-expressing action schemas, which language-teaching adults use as criteria for correct application of the abstract emotion word (Wittgenstein 1953; Baker and Hacker 2009). Thus, the manifestation of emotions in actions appears to be the glue between word use and internal state and, hence, between sign and meaning. Only after a stock of abstract emotion words has been grounded in emotion-expressing action can further emotion terms be learned from context.

This action-centered proposal generates further critical predictions that are testable in neuroscience experiments. In particular, over and above activating

limbic emotion-related circuits, abstract emotion words should specifically excite the motor system controlling the face and arms, with which emotions are typically expressed. Motor system activation for emotion-expressing body parts was indeed found when adults passively processed abstract emotion words (Moseley et al. 2012); this suggests that for one important class of abstract concepts, semantic grounding in emotion-expressing action is of the essence and can, in part, explain the formation of the link between meaning and symbol. But is this motor activation epiphenomenal? Remarkably, individuals with autism, who are known to be limited in their emotion expression, show reduced motor activation to action and correlated reduced performance in processing action-related words (Moseley et al. 2013, 2015).

However, there are also abstract words that do not heavily draw upon affective-emotional information. Indeed, neuroimaging results suggest very different brain correlates of abstract words and constructions, some of which do not involve emotion-processing centers of the limbic systems (Binder et al. 2005; Shallice and Cooper 2013). A characteristic feature of some abstract utterance is the variability of entities that are typically used. For most concrete object-related words, such as *eye*, the entities used to refer to the object may vary (in size, form, color), but it is normally possible to identify a semantic schema that can be illustrated by a prototype, a typical best representative of the schema (Fillmore 1975); atypical variants may activate the schema representation less than the prototype itself (Rosch and Mervis 1975). For some terms, this model breaks down when their meanings cannot be explained by a prototype, but requires several of them. Consider the case of the word *game* (Wittgenstein 1953; Baker and Hacker 2009; Rosch and Mervis 1975), which can refer to diverse activities ranging from cooperative to competitive, from group to solitary, and from playful to more serious action. No single prototype can represent this space of action schemas and, although prototypical members may be similar (soccer and football), others are very different (soccer and the computer game Tetris). To capture such variable *family resemblance*, semantic representations need to link up with variable action and perceptual schemas. At the neurobiological level, variability means low correlation between word forms and semantic prototypes; this implies that, although word meaning may originally be grounded in specific action and perception schemas, the semantic representation in a sense detaches from specific action-perception knowledge (Figure 9.3). This process of variability-related "disembodiment," implied by correlation learning (the "anti-Hebb" "out of sync-delink" rule), may be effective for many abstract words and concepts. Therefore, abstract words grounded in perceptual schemas (e.g., "beauty") may detach from their perceptual schemas stored in posterior inferior-temporal cortex, thus leaving relatively anterior-temporal representations weakly linked to these concrete instantiations, whereas abstract action terms (e.g., "free" or "game") may show the same process of *variability disembodiment* in prefrontal and parietal areas adjacent to sensorimotor cortex. Weak links between neuronal representations
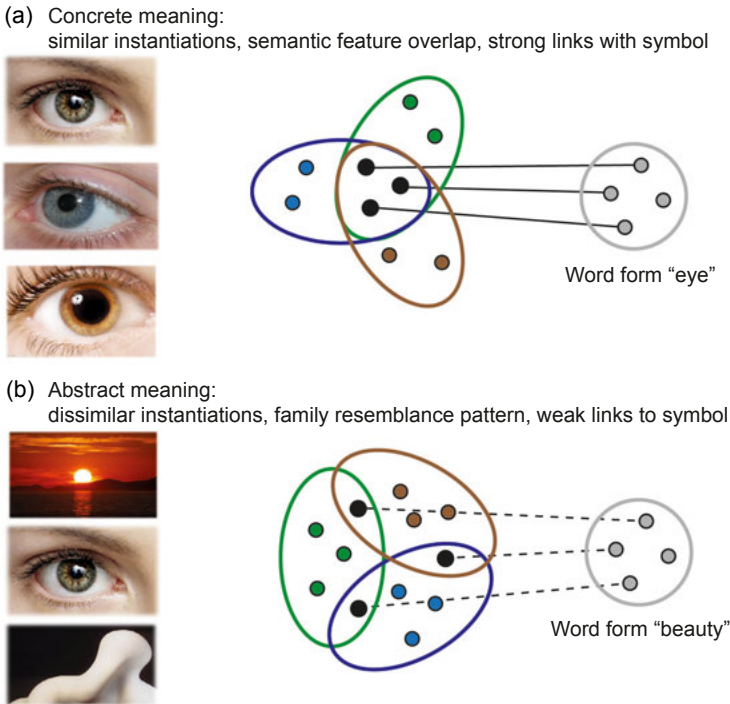
Figure 9.3 Sketch of putative neurobiological mechanisms for concrete and abstract meaning processing. Both concrete and abstract words as well as constructions can be learned when they are used to refer to real-life events, actions, and objects or their features. A major difference lies in the variability of the sensorimotor patterns that foster semantic grounding, which is typically low for concrete and high for abstract symbols. Assuming Hebbian mapping of correlations, this difference in correlation structure yields different neuronal and cognitive mechanisms for concrete and abstract meaning. (a) Concrete semantics: The concrete word *eye* is used to speak about objects with similar shapes and a range of colors. At the neurocognitive level, this leads to exemplar representations which strongly overlap in their sensorimotor semantic feature neurons, possibly dominated by a frequently processed prototype. Sensorimotor semantic overlap (including, in this case, visual center-surround cells responding to a circle in one color on a background of a different one) to feature neurons more specific to individual exemplars (e.g., to specific color). In concrete semantic learning, neurons of the circuit overlap and frequently occurring prototypical exemplars strongly interlink with the word form circuit due to high correlation of their activations. (b) Abstract semantics: The semantic instantiations of an abstract word such as *beauty* are quite variable, exhibiting a *family resemblance pattern of partial semantic similarity* (Wittgenstein 1953). The diagram illustrates the putative neural correlate of such family resemblance, where sensorimotor semantic feature neurons are only shared between subsets of exemplar representations of variable instantiations of the concept. The low correlation of activations of neuronal circuits for word forms and for each exemplar representation results in weak links between neural representations of sensorimotor knowledge (in modality-preferential areas) and those of verbal symbols (in perisylvian cortex; adapted from Pulvermüller 2013).

of abstract terms and their multiple and variable sensorimotor instantiations may be a hallmark of abstract meaning and key to the focusing of abstract semantic circuits on multimodal prefrontal, parietal, and temporal convergence areas. Extension of activation into one subset of sensorimotor neurons would then depend strongly on priming of some of the many instantiations.

Meaning can be driven by context in the sense that the meaning of a construction is more than that of its symbolic constituents (elementary parts) plus combinatorial regularities. One may speak of a goose as being well-cooked in a *literal* sense, but if somebody states that someone's "goose is cooked," a different *idiomatic* meaning may be relevant. How might this be modeled neurobiologically? In one branch of linguistics, cognitive and construction grammar, whole constructions are assumed to be paired with meanings and stored in a lexicon-like manner (Goldberg 2006; Langacker 2008). Accordingly, the meaning of an idiomatic construction might be distinct and not (or only distantly) related to the meanings of its composite words. However, compositional semantics suggest that sentence meaning is built from word meaning (see, e.g., Davidson 1967), which makes idioms difficult to model. Some proposals, including the neurobiological account, suggest that both views are correct and therefore both single word and whole construction meaning play a role in idiom comprehension. The correlation of the idiomatic, frequently quite abstract meaning with its variable sensorimotor instantiations may draw upon multimodal brain areas removed from sensorimotor systems, whereas the concrete constituent word meanings may engage sensorimotor systems. Indeed, comparison of brain activation maps elicited by idiomatic and literal sentences revealed that multimodal inferior- and dorsolateral-prefrontal, inferior-parietal, and anterior-temporal areas was stronger for idiomatic sentences than for literal ones (Lauro et al. 2008; Boulenger et al. 2009), consistent with a variable abstract semantic pattern. Over and above this idiomaticity effect, some studies of idiom processing reported motor system activation, which reflected aspects of the meaning of action words included in the idioms (e.g., leg motor cortex activity to "Anna ran for president"; Boulenger et al. 2009), suggesting a degree of compositional semantic processing (but see also Desai et al. 2013; Raposo et al. 2009). Because such motor system activation, reflecting the meaning of constituent action words, was already present when idiomatic and literal sentence meaning could first be disambiguated, the data indicate simultaneous construction retrieval and semantic compositional processing of the action meaning of constituent words in idiomatic sentence comprehension. Crucially, precise mapping-in-time using magnetoencephalography (MEG) showed that the brain correlates of abstract idiomaticity and those of action-grounded constituent word meaning occurred at the same time, already 150–200 ms after onset of the critical, sentence-disambiguating words. These results suggest that compositional semantic processing of action-related words (precentral cortex) and non-compositional semantic processing of abstract

idiomatic constructions as a whole (prefrontal and anterior-temporal areas) simultaneously and jointly contribute to idiom comprehension (Figure 9.4).
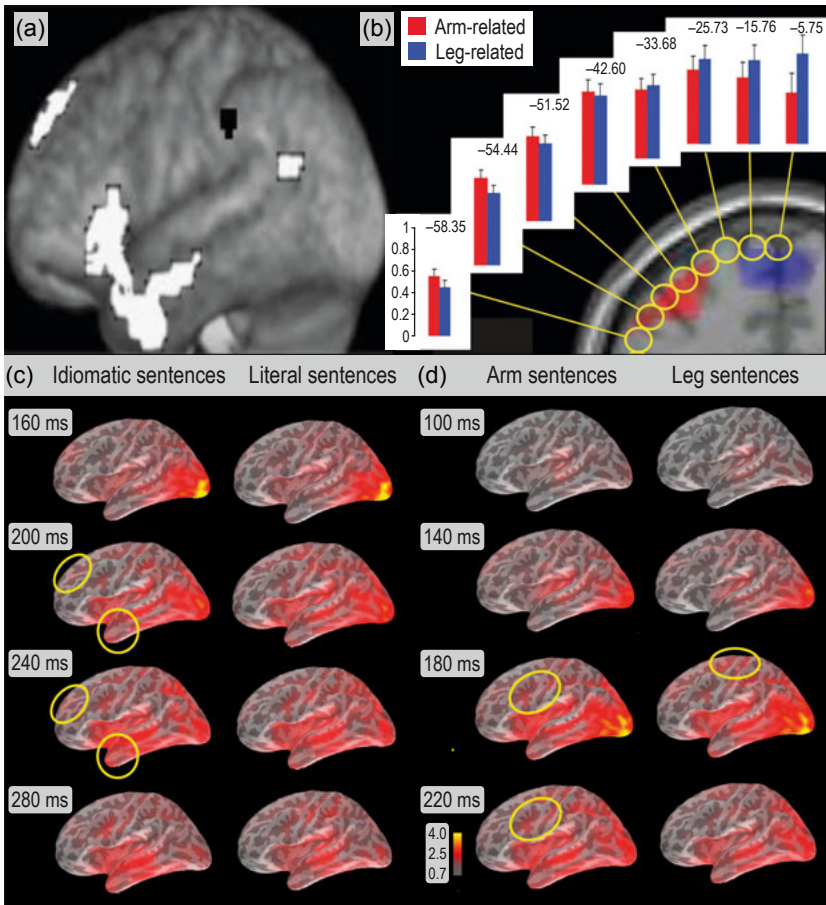

Figure 9.4 Brain activation to idiomatic and literal sentences recorded with fMRI (a, b) and MEG (c, d). (a) Comparison of brain activation elicited during idiomatic and literal sentence processing: white = idiomatic > literal; black = literal > idiomatic (Lauro et al. 2008; reprinted by permission of Oxford University Press). (b) Activation to literal and idiomatic sentences that include arm- (red bars) and leg-related words (blue bars); the red and blue areas indicate where finger and foot movements elicited activity (Boulenger et al. 2009; reprinted with permission from Oxford University Press). (c) Activation time course to idiomatic and literal action sentences (arm and leg sentences collapsed). (d) Activation time course to arm and leg sentences (idiomatic and literal collapsed). Note that constructional idiomaticity and compositional action-relatedness effects were present simultaneously early on (150–200 ms); this suggests that action-embodied compositional and disembodied constructional semantic processes emerge instantaneously at the same time (Boulenger et al. 2012; reprinted with permission from Elsevier).

Social-Communicative Pragmatic Function

Context dependence of linguistic-pragmatic meaning is most obvious in the use of the same utterance (i.e., word or construction) for entirely different action purposes. A word such as *water* can be used in the very same meaning and sense to name an object (i.e., to tell somebody how it is called) or for a request (e.g., to ask somebody for a drink). In pragmatic linguistics, language actions, such as naming and requesting, are called *speech acts* (Searle 1969). If the same utterance is used for different speech acts, the utterance is embedded in different contexts and connected with different intentions and goals. In other words, the utterance is produced with different *predictions* regarding subsequent actions and events, and thus in different *action sequence structures* (Figure 9.5). Neuroscience research has explored the brain basis of different intentions and sequences connected with a body movement (e.g., grasping an object to eat or to place it). Results show that mirror neurons in inferior frontal and parietal cortex indexed goal relatedness, and the proposal is that such neurons index not only basic acts, but their associated *action chains*, including the goal, as well (Fogassi et al. 2005; Iacoboni et al. 2005). Social-communicative interactions are normally more complex than simple action chains (Fogassi et al. 2005) or linearly predictable actions (Pickering and Garrod 2013b) and involve tree-like, sometimes recursive, structures (Fritz 2013; Levinson 2013). Thus, linguistic-pragmatic descriptions take advantage of action tree structures covering the action options opened by a given speech act (Alston 1964; Ehlich 2007; Stalnaker 2002; Fritz 2013; Levinson 2013). Such tree structures also link communicative actions and their goals and intentions manifest in the preferred response actions. A flexible binding mechanism is required to temporarily link the basic action or utterance (e.g., use of the utterance *water*) to the interaction structure of the speech act characterized by the more distant intention (e.g., to be given the object). The relationship between actions is iterative and can have several "layers," because an utterance can be used to request an object, which, in turn, may be performed to please one's companion, and so on (Stalnaker 2002; Fritz 2013).

The brain mechanisms for the postulated action sequence schemas can be assumed to draw upon sensorimotor as well as multimodal cortical areas. When utterances appear in different contexts, their action-perception circuits ignite and bind with the circuits of specific sequence schemas. In the naming context, the circuit for the word form *water* may activate, including its word form part and its object-related referential semantic part. The referential word-object link is known to draw upon inferior-temporal ventral-visual stream circuits (Pulvermüller 1999; Hickok and Poeppel 2007). In contrast, when using the same word to request an object, the sequence schema opens up expectations of a range of partner actions (e.g., handing over the water, or, alternatively, denying the request). Thus, in the request context, motor and action sequence circuits in frontocentral cortex need to be sparked in addition to utterance-related
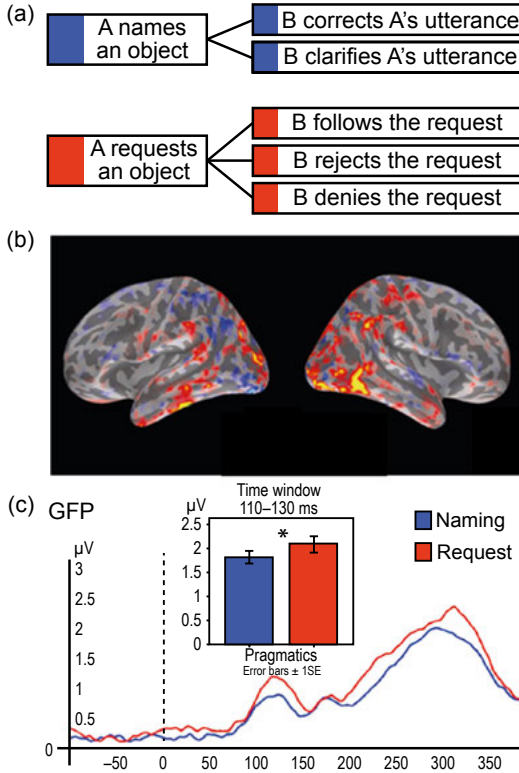
Figure 9.5 Sequence structure and brain correlates of social-interactive communicative speech acts performed with the same words. (a) Action sequence structures for the speech acts of *naming* (in blue) and *requesting* (in red), and results of MEG and EEG experiments on understanding of *naming* and *request* actions. (b) Topographical differences in brain activation 50–90 ms after critical (written) word onset obtained with MEG and distributed source estimation (*request > naming* in red/yellow, *naming > request* in blue). (c) In the EEG response, stronger brain activation was seen in *request* (red line) compared with *naming* (blue line) contexts from 100 ms. Global field power (GFP) is plotted against time (in ms) (after Egorova et al. 2013, 2014).

circuits (Pulvermüller et al. 2014). This neuropragmatic approach predicts that word forms and utterances elicit context-dependent, speech act-specific patterns of activation in motor systems and beyond.

In EEG and MEG experiments, experimental subjects saw actors in communicative contexts, where the same words were used to name and request the same objects. Already ~100 ms after the word critical for understanding the speech acts could be recognized, brain activation distinguished between naming and request actions. There was stronger activation to request and a relevant part of the additional cortical sources were in frontocentral motor

systems (Figure 9.5; Egorova et al. 2013, 2014).[4] These results on the brain basis of speech-act processing suggest a local cortical difference which, in part, confirms the above predictions. Such first steps toward understanding the neuronal basis of "how to do things with words" in social communication contexts (Austin 1962) need to be extended in the future, by investigating, for example, populations with deficits in social-communicative interaction with putative relationships to mirror neuron circuits (e.g., autism; Rizzolatti et al. 2009). This topic, under investigated in the neurobiology of language, is at the heart of language as a social phenomenon, as an interactive game activity characterized by action sequences, goals and intentions, commitments about the theory-of-mind assumptions of communication partners, and the use of social-communicative information and knowledge related to linguistic form.

Outlook

A novel pragmatic neuroscience emphasizing the binding between action and perceptual information in the service of mechanisms for higher cognitive processing can draw on a rich reservoir of brain language research supporting this general framework. In particular, it seems feasible to model crucial aspects of semantic knowledge in terms of action-perception circuits specifically linking linguistic symbolic form with meaning grounded in action and perception. Abstract and affective-emotional semantics can be modeled in this framework taking advantage of expression of emotion in action and correlation mapping between symbol forms and sometimes quite variable sensorimotor information, also taking into account combinatorial learning. The emerging picture for semantic circuits is that of richly structured neuronal assemblies, joining together form and meaning information and allowing for fine-grained differential activations reflecting variation in contextual priming and semantic nuances. Temporary binding circuits for meaningful forms into their contextual action-schema networks may account for brain activation, which reflects the communicative context and intentions for which language is used in social interaction. At almost all levels, experimental data indicate that motor systems, along with perceptual ones, are involved in and, critically, exert causal effects on, semantic pragmatic processes.

Acknowledgments

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[4]   A range of recent research focuses on neuropragmatic differences in brain activation that distinguishes between speech act types. One research stream focuses on Searle's distinction between direct and indirect speech acts (Searle 1975). There is indication that this distinction may also be manifest in local brain activation (Bašnáková et al. 2014; van Ackeren et al. 2012).