

In: Stewart J, Gapenne O, Di Paolo E (eds) *Enaction: towards a new paradigm for cognitive science*. Cambridge, MIT Press: 219-243

8 Directive Minds: How Dynamics Shapes Cognition

Andreas K. Engel

The future progress of cognitive science looks set to involve ever-increasing efforts to anchor research to the real world poles of sensing and acting. Thus anchored, time, world and body emerge as significant players in the cognitive arena. How could we ever have forgotten them?

—A. Clark 1995, 101

In the cognitive sciences, we currently witness a “pragmatic turn”¹ away from the traditional representation-centered framework toward a paradigm that focuses on understanding the intimate relation between cognition and action. Such an “action-oriented” paradigm has earliest and most explicitly been developed in robotics, and has only recently begun to have a notable impact on cognitive psychology and neurobiology. The basic concept is that cognition should not be understood as a capacity of deriving world-models, which then might provide a “database” for thinking, planning, and problem solving. Rather, it is emphasized that cognitive processes are not only closely intertwined with action but that cognition can actually best be understood as “enactive,” as a form of practice itself. Cognition, on this account, is grounded in a prerational understanding of the world that is based on sensorimotor acquisition of real-life situations.

The goal of this chapter is to explore possible implications of such a “pragmatic turn” for cognitive neuroscience. In addition to reviewing major conceptual components of this new framework, I will discuss neurobiological evidence supporting this notion. Specifically, I will relate this new view to recent findings on the dynamics of signal flow in the nervous system and on encoding dimensions of neural activity patterns. As I will argue, new vistas on the “meaning,” the functional roles, and the presumed “representational” nature of neural processes are likely to emerge from this confrontation.

8.1 Criticizing Orthodoxy: Problems with Representationalism

Numerous authors have criticized the “orthodox” stance of cognitive science (e.g., Winograd and Flores 1986; Varela, Thompson, and Rosch 1991; Dreyfus 1992; Kurthen 1994; Clark 1997; Engel and König 1998; O’Regan and Noë 2001; Noë 2004), and hence I confine myself to some short critical remarks. In a nutshell, the following core assumptions characterize the classical cognitivist view:

- Cognition is understood as computation over mental (or neural) representations.
- The subject of cognition is not engaged in the world, but conceived as a detached “neutral” observer.
- Intentionality is explained by the representational nature of mental states.
- The processing architecture of cognitive systems is conceived as being largely modular and context-invariant.
- Computations are thought to occur in a substrate-neutral manner.
- Explanatory strategies typically reference to inner states of individual cognitive systems.

These assumptions, which go back to the work of Fodor (1979), Newell and Simon (1972), and other protagonists of the representational theory of mind (RTM), seem to be present, albeit with different accentuation, in all versions and schools of cognitivist theorizing.

A key question in the debate is whether the representational account adequately describes the nature of cognition, and the relation between cognitive system and world. As stated earlier, the RTM implies (1) realism: perceptually relevant distinctions are “fixed” and observer-independent; (2) a separation of cognitive system and world: the subject is conceived as detached observer, who is not “engaged in” the world; and (3) passiveness of the cognitive system, which behaves in a merely receptive way, just “re”-acts, and takes copies of prespecified information. Many authors have argued that, along all these lines, the orthodox stance misconstrues the relation between cognitive system and world, and that it actually fails to appreciate the very nature of cognitive processes (Winograd and Flores 1986; Varela, Thompson, and Rosch 1991; Dreyfus 1992; Kurthen 1994; Clark 1997).

Long before the emergence of research on “active sensing,” philosophers have emphasized the active nature of perception and the intimate relation between cognition and action. The American pragmatist John

Dewey stated: “Upon analysis, we find that we begin not with a sensory stimulus, but with a sensorimotor coordination . . . and that in a certain sense it is the movement which is primary, and the sensation which is secondary, the movement of the body, head and eye muscles determining the quality of what is experienced. In other words, the real beginning is with the act of seeing; it is looking, and not a sensation of light” (1896, 358–359).² With striking convergence, the same thought can be found more than forty years later in the writings of French phenomenologist Merleau-Ponty, who concluded that

the organism cannot properly be compared to a keyboard on which the external stimuli would play. . . . Since all the movements of the organism are always conditioned by external influences, one can, if one wishes, readily treat behaviour as an effect of the milieu. But in the same way, since all the stimulations which the organism receives have in turn been possible only by its preceding movements which have culminated in exposing the receptor organ to external influences, one could also say that behavior is the first cause of all stimulations. Thus the form of the excitant is created by the organism itself. (1962, 13)

Perception, according to these authors, is a constructive process whose operations are highly selective. Perceptual acts define, first of all, relevant distinctions in the field of sensory experience, and this occurs by virtue of the cognitive system’s neural and bodily organization, as well as “top-down” factors (Engel, Fries, and Singer 2001), such as previous learning, emotion, expectation, or attention. Cognition, on this account, is not neutral with respect to action, but arises from sensorimotor couplings by which the cognitive agent engages in the world (Varela, Thompson, and Rosch 1991; O’Regan and Noë 2001). Eventually, this overturns the central notions of RTM: the purpose of cognitive processing is the guidance of action, not the formation of mental representations.

8.2 The Concept of a Pragmatic Turn

The “pragmatic” stance can be seen as a direct antagonist of the cognitivist framework, implicating a point-by-point opposing view regarding each of the assumptions that have been mentioned thus far:

- Cognition is understood as capacity of “enacting” a world.
- The subject of cognition is an agent immersed in the world (as suggested by the phenomenological concept of “being-in-the-world”).
- System states acquire meaning by their relevance in the context of action.

- The architecture of cognitive systems is conceived as being highly dynamic, context-sensitive, and captured best by holistic approaches.
- The functioning of cognitive systems is thought to be inseparable from its substrate or incarnation (“embodiment”).
- Explanations make reference to agent-environment or agent-agent-interactions (“situatedness”).

Clearly, it’s time for a turn, and the central credo of the proponents of the new paradigm could be phrased as “cognition is action” (Varela, Thompson, and Rosch 1991; Kurthen 1994).³ That said, the adherents of this motto are facing challenges that may be even more severe than the ones discussed for the cognitivist legacy mentioned earlier; obviously, the pragmatic credo needs both explication and elaboration. It needs to be spelled out what the implications of this view possibly are, and whether it has the potential to inspire a new style of thinking, or—even more importantly—new styles of designing and performing experiments. In what follows, I will try to contribute a few modest ideas to this emerging field of debate.

The pragmatic turn, as envisaged here, is rooted in European and American philosophical movements of the late nineteenth and early twentieth centuries. Tracing these roots would require a detailed analysis that is far beyond the scope of this chapter, and only few remarks will be made to highlight some of the important links. On the one hand, American pragmatism has been influential, with John Dewey (1859–1952) and George Herbert Mead (1863–1931) as two leading protagonists. Dewey’s early sensorimotor approach to perception has been cited already (Dewey 1896), and many aspects developed in later writings such as his “event ontology” and his genetic analysis of mind as emerging from cooperative activity (Dewey 1925) are highly relevant in this context. Along a similar vein, Mead’s theory of the emergence of mind and self from the interaction of organic individuals in a social matrix (1934) and his analysis of perception and the constitution of reality as a field of situations through the “act” (1938) bear high relevance to pragmatic cognitive science and deserve further exploitation.

On the other hand, there are clear and explicit links to the European phenomenological-hermeneutic tradition, notably, to the early writings of Martin Heidegger (1889–1976) and the writings of Maurice Merleau-Ponty (1908–1961). Essentially, all motifs of the pragmatic turn can be traced back to these two philosophers, as noted by proponents of this new view (Dreyfus 1992; Varela, Thompson, and Rosch 1991; Kurthen 1994, 2007; Clark 1997; Noë 2004). As cited already, Merleau-Ponty strongly advocates an anti-representationalist view, emphasizing that the structures of the

perceptual world are inseparable from the cognitive agent (Merleau-Ponty 1962, 1963) and that therefore “world-making” rather than “world-mirroring” lies at the heart of cognition. Heidegger develops his concept of “being-in-the-world” (“In-der-Welt-Sein,” adopted by Merleau-Ponty using the expression of “être-au-monde”) to overcome the Cartesian split between subject and world and to ground intentionality (Heidegger 1986, 1989). From this new way of seeing the relation between subject and world, characterized by mutual intertwinement, a direct path leads to a redefinition of the cognitive system as “extended mind,” including both the cognitive agent and its environmental niche (Varela, Thompson, and Rosch 1991; Kurthen 1994, 2007; Clark 1997). The relation to the world can be only one rooting in practice, in acting, and practice, in turn, is mediated through the body. Thus, both Merleau-Ponty and Heidegger develop a view on cognition as grounded in concrete sensorimotor activity, in a prerational practical understanding of the world (Heidegger 1986, 1989; Merleau-Ponty 1962, 1963). From these premises, two concepts unfold that are of key importance to pragmatic cognitive science: the concept of “situation” (or “situatedness”) and the concept of “embodiment.”

According to Heidegger and Merleau-Ponty, what we encounter as cognitive agents are never “bare” objects or arrays of contingent features, but rather meaningful situations, that is, contexts we have already structured by prior activity and in which objects are defined as a function of our needs and concerns. Even for the newborn, the world is not a heap of coincident features, as its own needs in concert with the social context define what the world should look like. In his phenomenological analysis of situatedness, Heidegger coins the term *Bewandtnisganzheit* (Heidegger 1989), denoting a “referential nexus” across all components of the situation that is thus characterized by a holistic structure, and a merging or “intertwinement” of cognitive system and world. As part of the pragmatic view advocated here, these considerations suggest that the cognitivist ontology of “neutral features” should be replaced by a holistic ontological framework. Following Merleau-Ponty, the world does not have a prespecified structure that exists prior to and independent of any cognitive activity. Rather, the world is an a priori unlabeled “field of experience” in which cognition (as embodied action) draws relevant distinctions. If indeed the world is organized in “referential wholes” that cannot be decomposed into neutral objects, then the concept of “situation” should figure as the more basic ontological category.

Clark (1997) has discussed a number of consequences arising from this view. “Situatedness,” in his view, implies that cognition does not build

upon universal, context-invariant models of the world, but is subject to constraints of the local spatiotemporal environment, which need to be coped with in a highly context-dependent manner. This leads Clark to a notion of “minimal representationalism” that posits “action-oriented representations.” This denotes the idea that internal states simultaneously describe aspects of the world and “prescribe” possible actions—a view that to him provides a compromise between the cognitivist and the pragmatic framework. Furthermore, Clark uses the concepts of situatedness and embeddedness to counteract the individualist stance of cognitivism. These notions imply a fundamental coupling through ongoing interaction between cognitive agent and environment. Therefore, the latter should be viewed not only as a task domain, but also as a resource that “scaffolds” cognitive acts. Slightly radicalizing this insight, one might then say that, in fact, the cognitive system comprises the brain, the body, and the environmental niche (Kurthen 1994, 2007). As Clark phrases it, “in the light of all this, it may . . . be wise to consider the intelligent system as a spatio-temporally extended process not limited by the tenuous envelope of skin and skull. . . . Cognitive science . . . can no longer afford the individualistic, isolationist biases that characterized its early decades” (1997, 221).

Compared to Clark (1995, 1997), other eminent proponents of the pragmatic turn, such as Varela, O’Regan, Noë, and Kurthen argue for a much more radical rejection of the cognitivist view (Varela, Thompson, and Rosch 1991; O’Regan and Noë 2001; Kurthen 1994, 2007). Drawing on the phenomenological tradition, Varela, Thompson, and Rosch have explored the implications of defining “cognition as embodied action” (1991, 172). As they emphasize, cognition should be considered from the viewpoint of action. Cognition is not detached contemplation, but a set of processes that determine possible actions. Perception, accordingly, must be understood as a process of defining relevant boundaries, not of grasping preexisting features, and “perceiving a world” means distinguishing possibilities for action. The criterion for success of cognitive operations is no longer a “veridical representation” of environmental features, but viable action in a certain situation. In a nutshell, cognition, as Varela, Thompson, and Rosch put it, can be understood as the capacity of “enacting” a world:

The overall concern of the enactive approach to perception is not to determine how some perceiver-independent world is to be recovered; it is, rather, to determine the common principles or lawful linkages between sensory and motor systems that explain how action can be perceptually guided in a perceiver-dependent world.

Consequently, cognition is no longer seen as problem solving on the basis of representations; instead, cognition in its most encompassing sense consists in the enactment or bringing forth of a world by a viable history of structural coupling. (1991, 173, 205)

Exploiting Heideggerian thinking, Kurthen (1994, 2007) has developed a “hermeneutical theory of cognition.” The term “hermeneutic,” in his account, is not referring to the hermeneutic nature of the scientific method, but rather to the idea that cognition itself is construed as a hermeneutical faculty. In his framework, “intentionality is not generated by representation, but . . . by primarily non-representational concrete activity of the cognitive system within its environmental niche” (2007). Kurthen stresses several important ideas: he suggests that only through the embodied nature of the cognitive system can internal states acquire meaning (or significance); however, as he also points out, the “embodied action” approach alone does not yet solve the problems of the orthodoxy, because what is actually needed is an account of teleology. According to Kurthen, embodiment can only be a mediator, a “vehicle” of teleology. What needs to be considered is subsystems of the organism that support motivational and emotional states. “Under this conative view the functional subsystems of the organisms are to be rearranged. While most ‘embodiment approaches’ . . . stress the role of the sensorimotor system in embodied cognition, this system turns out to be of only secondary relevance from a teleological point of view. . . . Needs, desires and other conative states that fuel our actions are rooted in different parts of the organism: in the endocrine system, the autonomous nervous system and its target organs . . . as well as their regulatory centers in the brain stem” (2007, 140).

The notion that cognition can only be understood by taking into account the organization and function of the body is also a key ingredient of the sensorimotor contingency theory (SCT) put forward by O’Regan and Noë (2001). According to the SCT, the agent’s sensorimotor contingencies—that is, the rules governing sensory changes produced by various motor actions—are constitutive for cognitive processes. “Seeing,” according to the SCT, is not having something on the retina, is not having a detailed internal “representation”; rather, seeing corresponds to knowing you are currently engaged in a visual manipulations, to exploratory activity, mediated by knowledge of sensorimotor contingencies. The brain enables us to see, but the neural activity does not in itself constitute the seeing; rather, the brain supports vision by enabling exercise and mastery of sensorimotor contingencies. I believe that the SCT potentially has interesting implications regarding the significance of internal states

and neural activity patterns. I will elaborate on this issue in the next section.

8.3 Action-Oriented View on Neural Processing

If we decide to go for a pragmatic turn in cognitive science, our view of the brain and its function seem to be changing profoundly. The conceptual premises of the pragmatic stance can be mapped to the neuroscientific level of description, and thus lead us to redefining at least some of the neurobiologist's explananda. What neuroscience, then, has to explain is not how brains act as world-mirroring devices, but how they can serve as "vehicles of world-making" that support, based on individual learning history, the construction of the experienced world and the guidance of action.

The following premises might become part of a framework for "pragmatic neuroscience":

- Primary concern of the experimenter is not the relation of neural activity patterns to stimuli, but to the action at hand and the situation the subject under study is currently engaged in.
- The function of neural circuits has to be studied making reference to the view that cognition is a highly active, selective, and constructive process.
- Sensory processing must be considered in a holistic perspective, and as being subject to strong top-down influences that constantly create predictions about forthcoming sensory events and eventually reflect constraints from current action.
- The function of neurons and neural modules must not be considered in isolation, but with proper reference to other subsystems and the actions of the whole cognitive system.
- The investigation of the intrinsic dynamics of the brain becomes increasingly important, because interactions within and across neural assemblies are constitutive for the operations of the cognitive system.
- Because the representational view is largely abandoned, a new view on the functional roles of neural states needs to be developed; rather than "encoding" information about pre-given objects or events in the world, neural states support the capacity of structuring situations through action.

There is ample neurobiological evidence to suggest a fundamental role of action and of sensorimotor activity in perception and cognitive processing. In the following, I will briefly highlight some key findings that match the premises phrased thus far and thus seem to support a pragmatic stance for cognitive neuroscience.

Key evidence supporting the pragmatic view is provided by findings on the role of exploratory activity and sensorimotor interactions for neural development and plasticity. It has been known for a long time that developmental processes in the nervous system are activity-dependent. For instance, development of neural circuits in the visual system and acquisition of visuomotor skills critically depend on sensorimotor interactions and active exploration of the environment (Held 1965; Majewska and Sur 2006). Even in the adult brain, there is considerable plasticity of cortical maps—for instance, in the somatosensory and motor system—that has been shown to depend on action context and, interestingly, also on attention (Blake, Byl, and Merzenich 2002; Münte, Altenmüller, and Jäncke 2002). Similar evidence is available for the human brain, as in highly trained musicians who often show functional and structural changes in their sensorimotor system resulting from action-dependent plasticity (Münte, Altenmüller, and Jäncke 2002). One conclusion from these studies is that appropriate action, allowing exercise of relevant sensorimotor contingencies, is necessary throughout life to stabilize the functional architecture in the respective circuits.

Another important line of evidence concerns research on the function and neural mechanisms of “corollary discharge” or “reafference” signals, which are necessary for an organism to distinguish self-generated sensory changes from those not related to own action (Desmurget and Grafton 2000; Crapse and Sommer 2008). In technical contexts, the same principle is often referred to as a “forward model.” Supporting the SCT, this research shows that predictions about the sensory outcome of movement are critical for the basic interpretation of sensory inputs. The importance of refference has been shown in the context of eye movements and grasping or reaching movements. Interestingly, similar principles of predicting sensory inputs seem to play a key role also in more complex cognitive processes like language comprehension (Pickering and Garrod 2006) or predictions about the actions of other subjects in social context (Wilson and Knoblich 2005). A point of key interest is that in all these cases, activity of motor planning regions seems involved in generating the prediction about sensory events, possibly by modulating neural signals in sensory regions (Wilson and Knoblich 2005; Christensen et al. 2007). Malfunction of such modulatory signals and associated disturbance of forward models have been implicated in the pathogenesis of psychiatric disorders such as schizophrenia (Frith, Blakemore, and Wolpert 2000).

If guidance of action is a dominant function of the brain, one would predict that neuronal response profiles in sensory or association regions

should strongly depend on action context. Indeed, there is clear evidence for such an action-relatedness. For instance, activation of visual neurons changes profoundly if unrestrained, self-induced eye movements are permitted, as compared to passive viewing of stimuli under controlled fixation (Gallant, Connor, and VanEssen 1998). Furthermore, properties of parietal and premotor neurons strongly depend on action context (Graziano and Gross 1998). In premotor cortex, the spatial profile of multimodal receptive fields depends on body and limb position (Graziano, Hu, and Gross 1997). Tactile and visual receptive fields of premotor neurons are in dynamic register and seem “anchored” to body parts even if these are moving, suggesting that such polymodal neurons support predictions about expected changes in sensory input. Given the abundance of sensorimotor “gain” modulation of neural responses (Salinas and Sejnowski 2001), it seems likely that neural “representations” are always, to considerable degree, action-related or action-modulated (Clark 1997).

In the present context, another highly intriguing finding is that motor and premotor systems are also active during “virtual actions” (Jeannerod 2001), like, for instance, “mental rotation” of objects (Richter et al. 2000). Conversely, “virtual action” apparently can have a profound influence on experienced sensory structure. This is beautifully demonstrated by a study of Bisiach and Luzzatti (1978) in two patients suffering from unilateral neglect due to damage in the right parietal cortex. The term “neglect” denotes a profound inability to access sensory information in peripersonal space contralateral to the lesion. Interestingly, in these patients neglect was also found under conditions of visual imagery: when asked to imagine known spatial settings, the patients could report only the right half of the respective scene; even more striking, when now the same patient imagined turning by 180 degrees, she could suddenly access, in her imagination, the parts of the scene on the formerly neglected side. These observations on the relation between neglect and imagined action suggests a fundamental role of action planning centers in modulation of complex cognitive processes.

From the observations discussed thus far, one may conclude that the functional significance of neural states or activity patterns needs to be redefined, because a representational account ultimately fails to provide a satisfying view. As we have discussed already, neural patterns do not carry “images” of the external world. What these patterns support are not abstract structural descriptions of objects and scenes but, rather, kinds of know-how about sets of possible actions that produce viable segmentations of the scene. Neural activity patterns, on this account, support the organ-

isms capacity of structuring situational contexts; they “prescribe” possible actions, rather than “describing” states of the outside world. In fact, their functional role in the guidance of action is what determines the “meaning” of internal states. Clark summarizes: “the brain should not be seen as primarily a locus of inner descriptions of external states of affairs; rather, it should be seen as a locus of inner structures that act as operators upon the world via their role in determining actions” (1997, 47).

The need to redefine the functional role of internal states has apparently been acknowledged by forerunners of the pragmatic turn who, in different versions, made attempts to soften up the connotations of the term “representation” by introducing additional qualifiers. To denote the action-relatedness of internal states and to emphasize that objects and events of the current situation are specified with respect to the cognitive agent, concepts like “deictic representation,” “deictic codes,” “indexical representation,” “control-oriented representation,” or “action-oriented representation” have been introduced (e.g., Clark 1995, 1997). Though all this is helpful, I think that these indecisive attempts to undermine the usage of the notion of “representation” can be moulded more radically—eventually, I suggest, the smarter move is to drop the term “representation” altogether and to replace it by an expression that does not carry about so much of the cognitivist burden.

This is why I will use, in the remainder of the chapter, the expression “directive” rather than “representation” for characterizing the functioning of dynamic patterns of interactions in a cognitive system. Introducing this term as part of the pragmatic framework, it is important to stress that directives are not simply internal states of the brain. They are, of course, supported by neural activity patterns, but they correspond to states of the cognitive system in its entirety. As I see it, such action-oriented patterns will always include certain aspects of bodily dynamics, such as certain biophysical properties of the skeletomuscular system. Actually, they might best be described as *patterns of dynamic interactions extending through the entire cognitive system*. This is why “directive” is *not* just a different term for “action-oriented representation.” The latter is “in the head”; the former denotes the dynamics of the “extended mind.”

What, then, is the relation of directives to actions and objects on the one hand, and to neural states on the other? In my view, directives are immediately related to action selection. Activating directives directly controls the respective action. More generally, directives correspond to dispositions for meaningful actions; as such, they correspond to ways of “knowing how” rather than “knowing that.” Object concepts, then, correspond to

sets of related directives; on this account, knowing what a glass or a tree is does not mean possessing internal descriptions of such objects, but to master sets of sensorimotor skills, paths of possible action that can be taken to explore or utilize the respective object. Objects are not “targeted by” directives but are rather constituted by these, because in fact an object is defined by the set of possible actions that can be performed on it. We do not first perceive a chair by setting up an abstract geometric description, and then compute its suitability for sitting; rather, perceiving a chair *is* to detect the opportunity of sitting. The concept of an object corresponds to “nothing but” the set of possible actions relating to this object; there is no context-neutral “description” above and beyond the directives.

The relation between directives and their neural underpinnings can be phrased as follows: directives correspond to functional roles of neural states; conversely, neural activity patterns support and partially implement directives as their functional roles. Thus, directives provide a network of functional roles, defined by current action, that are supported by (filled by) dynamic patterns in neural activity. It is important to note that neural activity patterns are not directives themselves, but only those “traces” accessible to neurophysiological experimentation. The “neural vehicles” of directives, of course, are highly complex, involving cell populations distributed across numerous brain regions. With all likelihood, this requires dynamic interactions between sets of neurons in different sensory modalities as well as with neurons in premotor and prefrontal cortical regions, the limbic system, and the basal ganglia.

8.4 Exploiting Neural Dynamics

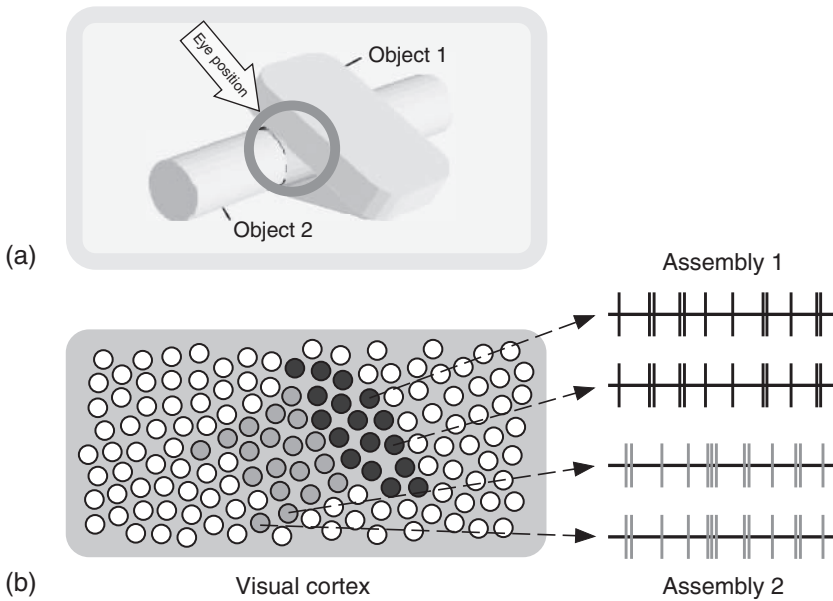
If directives, as suggested earlier, are carried by complex neural patterns, it becomes crucial to investigate the dynamic interactions in highly distributed neuronal populations. Generally speaking, the implementation of directives will require highly specific and flexible interactions in the brain, involving not only sensory regions, but specific coupling to motor signals, as well as to activity in limbic and memory regions. To allow the selective integration of sensory and motor signals during an act such as visually guided grasping, a dynamic “binding principle” is required to coordinate the local processes that are all part of the “neural vehicle” of the grasp directive. In the following, I will briefly discuss a mechanism that can do the job—neural synchrony.

Originally, the notion that synchrony might be important for dynamic integration of neural signals had been proposed in the context of percep-

tual processing and scene segmentation (von der Malsburg 1981; Engel et al. 1992; Singer and Gray 1995). More than two decades ago, this temporal correlation hypothesis (TCH) was already motivated by the insight that perception, like most other cognitive functions, is based on highly parallel information processing involving large neural assemblies spread out across numerous brain areas. One of the key predictions of the TCH in its original version (von der Malsburg 1981) was that neurons that support perception of a sensory object might fire their action potentials in temporal synchrony. However, no such synchronization should occur between cells whose firing relates to different objects (figure 8.1). According to the TCH, synchronization of spatially separate neurons is a key principle of brain function, as it allows the formation of functionally coherent activity patterns supporting particular cognitive functions. In the example illustrated in figure 8.1, locally specific desynchronization of visual cortical neurons would enable the process of figure-ground segregation in the center of the gaze.

Interestingly, physiological studies in the visual system of cats and monkeys have demonstrated that neuronal synchronization indeed depends on the stimulus configuration. It was found that spatially separate cells show strong synchronization only if they respond to the same visual object. However, if responding to two independent stimuli, the cells fire in a less correlated manner or even without any fixed temporal relationship (Gray et al. 1989; Kreiter and Singer 1996). In the pragmatic framework discussed here, this experimental observation would not be interpreted as indicating a switch in the buildup of “object representations,” but as resulting from the effect that the neuronal populations in visual cortex eventually support different directives, that is, different patterns of action, depending on the outcome of the segmentation process.⁴

Work of the past two decades suggests that correlated activity of neurons is quite ubiquitous in the nervous system and occurs on multiple time scales (for review, see Engel et al. 1992; Engel, Fries, and Singer 2001; Singer and Gray 1995). As observed in many animal studies and confirmed in human EEG and MEG experiments, synchrony is often associated with oscillatory activity, that is, rhythmic recurrence of neuronal discharges. It has been argued that, at least over larger distances, such oscillations may be critical in setting up neuronal communication (Engel, Fries, and Singer 2001; Fries 2005). The available studies demonstrate that specific changes in neural synchrony, leading to dynamic reconfiguration of communication in neural populations, are associated with a wide variety of cognitive processes, such as perceptual integration, attention, memory formation,

**Figure 8.1**

Establishment of coherent neural assemblies by temporal correlations. (a) Visual scene comprising two objects. The circle demarcates the current direction of gaze at a particular region of the scene. (b) The TCH posits that segmentation of the scene is associated with the buildup of two assemblies of cells in visual cortex. The cells that make up each assembly are coherently active. In contrast, the signals of cells that are part of different assemblies are desynchronized (right). In this model, synchrony is supposed to occur with millisecond precision.

© Andreas K. Engel

and even awareness (Engel and Singer 2001; Engel, Fries, and Singer 2001; Herrmann, Munk, and Engel 2004).

A critical prediction of the TCH is that neural synchrony that is observed locally in sensory areas can be modulated, in fact, strongly by large-scale dynamics of the cognitive system (Engel, Fries, and Singer 2001; Varela, Thompson, and Rosch 2001; Herrmann, Munk, and Engel 2004). In the case of perceptual integration, factors like expectation, attention or previous knowledge about the objects encountered are often crucial for the outcome of the segmentation process. The TCH accounts for this by assuming that temporally coordinated signals from other regions of the network can have a strong impact on assembly formation in sensory regions by modulating the local neural dynamics in a top-down manner (Engel, Fries, and Singer 2001). This seems to agree well with predictions that derive

from the pragmatic stance. If feature-specific desynchronization of neurons indeed supports buildup and selection of directives for action, then temporal patterning in sensory populations should strongly be shaped by the action context and, possibly, by direct interactions with assemblies involved in action-planning. Although, at this point, experimental evidence is still sparse, some studies seem to support the idea that neural synchrony may be related to generation of actions.

Recent studies on neural mechanisms of attention provide first hints that the modulatory effects on the timing in sensory assemblies in fact arise from premotor and prefrontal regions. Strong evidence for an attentional modulation of neural synchrony is provided by experiments in behaving macaque monkeys. Steinmetz et al. (2000) investigated cross-modal attentional shifts in monkeys that had to direct attention to either visual or tactile stimuli that were presented simultaneously. Neuronal activity was recorded in the secondary somatosensory cortex. As the study shows, synchrony in this area depended strongly on the monkey's attention, being most prominent in the condition where the animal attentively worked on the tactile task. In the visual system, strong attentional effects on temporal response patterning were observed in monkey V4 (Fries et al. 2001). In this study, two stimuli were presented simultaneously on a screen, one inside the receptive fields of the recorded neurons and the other nearby. The animals had to detect subtle changes in one or the other stimulus. If attention was shifted toward the target location, there was a marked increase in local synchronization. More recently, this finding has been confirmed by Taylor et al. (2005) using a demanding visual task where monkeys had to track changes in an object's shape over time. In humans, several EEG and MEG studies also suggest a clear relation between attention and modulation of neural synchrony in the auditory (Tiitinen et al. 1993; Debener et al. 2003), the visual (Tallon-Baudry et al. 1997; Kranczioch et al. 2006; Siegel et al. 2008) and the tactile system (Bauer et al. 2006).

Interestingly, a number of attention studies suggest that the modulatory bias may, indeed, arise from regions involved in action planning. In a recent study using the so-called attentional blink paradigm (figure 8.2), we have obtained evidence that a network of premotor, parietal, and limbic regions modulates the dynamics of visual processing (Kranczioch et al. 2005). Along similar lines, in recent MEG experiments on visual attention we could show that premotor regions like the frontal eye field are very likely involved in top-down modulation of the timing in sensory assemblies (Siegel et al. 2008). Together with behavioral data showing that

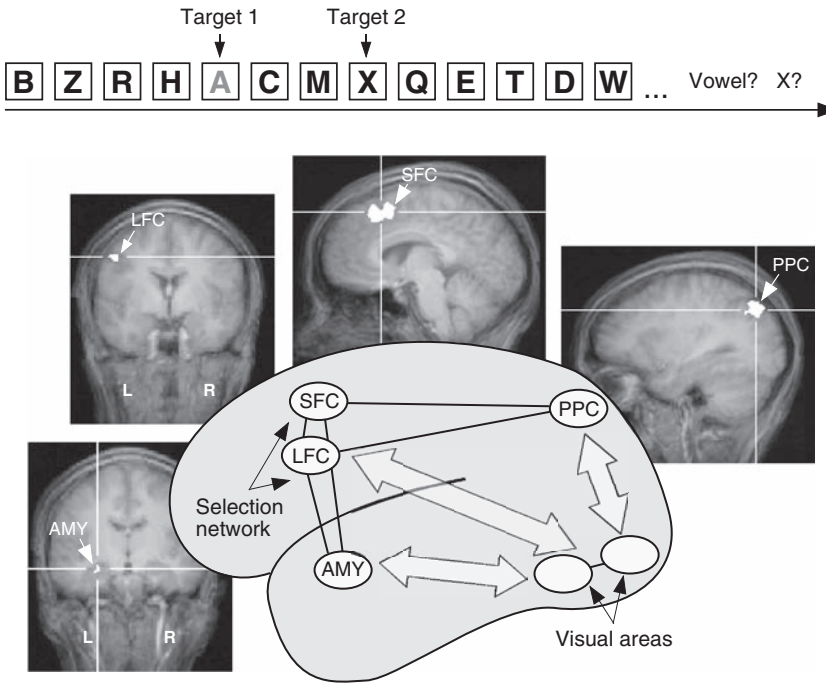


Figure 8.2

Frontoparietal selection networks involved in the attentional blink. *Top panel:* During a typical “attentional blink” experiment, subjects have to attentively process two targets that appear in a stream of distractor stimuli and to respond by button-presses after the end of the stimulus sequence. In the version used by Krancioch et al. (2005), subjects were asked if a green letter (defined to be target 1) had been a consonant or a vowel; in addition, they had to indicate whether a black X (target 2) had been perceived somewhere after target 1. If the two targets appear in close temporal succession, the X often goes unnoticed (the “attentional blink”). *Bottom panel:* Results obtained with fMRI indicate that, in this task, a frontoparietal selection network may be involved in controlling the access of signals to awareness. This network seems to include a region in posterior parietal cortex (PPC), regions in superior and lateral frontal cortex (SFC, LFC), as well as the amygdala (AMY). Big arrows symbolize top-down interactions between the selection network and sensory areas.

© Andreas K. Engel

movement preparation can lead to attentional shifts and to changes in the acquisition of object-related information (Craighero et al. 1999; Eimer and van Velzen 2006; Fagioli, Hommel, and Schubotz 2007), these findings support what sometimes is called a “premotor theory of attention”: the idea that selection of sensory information should be modulated and focused by constraints arising from current action planning and execution. If so, this would suggest that attention may be “nothing but” a bias in sensory processing that is introduced by the selection of particular directives in the context of current or imminent action.

If synchrony in sensory regions supports the buildup of directives, one would also predict that temporal patterns that transiently emerge in certain regions must be “read out” through interaction with other brain regions such as frontal cortex or the basal ganglia and thus increase in impact in the generation of a specific action. In this way, synchronized neural assemblies could support particular directives, thus adopting a specific functional role in the respective action context. Indeed, there is some evidence to suggest that synchrony may provide a dynamic binding principle for structuring and selecting sensorimotor couplings. Synchronization between sensory and motor assemblies has been investigated in a number of studies in cats, monkeys, and humans during execution of tasks requiring sensorimotor coordination (Murthy and Fetz 1996; Roelfsema et al. 1997; Aoki et al. 2001). The results of these studies clearly show that synchrony between sensory and motor assemblies occurs specifically during task epochs requiring the linkage of perception and movement. The specificity of such interactions might allow, for instance, the selective channeling of sensory information to different motor programs that are concurrently planned or executed. Interestingly, the studies on awake cats (Roelfsema et al. 1997) provide evidence that dynamic interactions between motor regions and parietal cortex already occur before the appearance of the task-relevant stimulus, probably reflecting the animal’s state of expectancy.

In this context, experiments in awake monkeys are of particular interest that specifically have addressed the relation between neural synchrony and selection of a motor act (Riehle et al. 1997). Riehle et al. showed that in a delayed reaching task (figure 8.3), synchrony occurred particularly at those times when the monkey was expecting a “Go” signal to appear on the screen. Interestingly, in those trials in which the “Go” signal appeared after prolonged periods of expectation, the number of significantly synchronized events increased over the delay period (figure 8.3), and spike synchrony became more precise as the “Go” cue approached. This indicates that, during selection of the reach directive, there is a relationship between

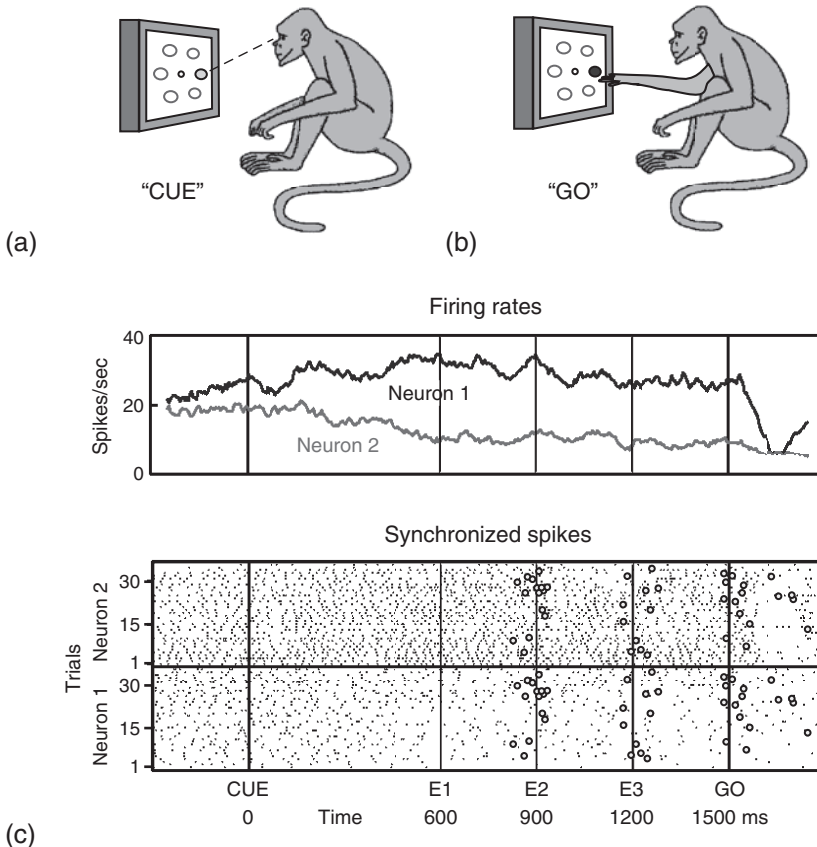


Figure 8.3

Synchrony expresses predictions about sensory events in primary motor cortex. The figure illustrates an experiment performed by Riehle et al. (1997) in which monkeys were trained on a delayed-pointing task. (a) During each trial, a first stimulus was given as a spatial "Cue" indicating the target position of the requested hand movement. (b) A second stimulus in the same location served as a "Go" signal instructing the animal to make the required movement. (c) Randomized across trials, the interval between "Cue" and "Go" corresponded to either 600, 900, 1200, or 1500 ms. The panels in (c) show data from trials where the "Go" signal appeared after 1500 ms. *Top panel:* For most recorded neurons, the firing rates did not modulate with the monkeys expectancy or the "Go" signal. *Bottom panel:* However, analysis of spike synchronization revealed that correlated firing increases significantly above chance level during time points (E2, E3) where the monkey expects the "Go" stimulus to occur and, finally, shortly before and during the moment when the second stimulus is given. Synchronized spikes are indicated by circles in the bottom panel.

Modified from Engel, Fries, and Singer 2001

growing stimulus expectancy and the synchronization in the motor network. Although highly surprising from the viewpoint of classical representationalism, an action-oriented view clearly predicts that traces of expectancy should appear in motor regions, even if the expectation—*prima facie*—concerns a perceptual event. It is tempting to speculate that these dynamic patterns actually implement procedural knowledge of sensorimotor contingencies as required by the SCT.

8.5 Epilogue

In this chapter, I have—trying to build on recent developments in the field—introduced two concepts that might be useful in the discussion on how to create a *better* science of the mind. The first is the concept of a pragmatic turn, which denotes more of an agenda than a paradigm already in place. As should have become clear, the punch line is to eventually transform the whole theory of cognition into a theory of action. Notably, this is not a behaviorist move, as the dynamics of the cognitive system is in the very heart of the enterprise, and clear reference is made to “states in” the cognitive system. I have tried to show that an action-oriented framework is not only conceptually viable, but in fact is already supported by much experimental evidence. Numerous findings in neuroscience either overtly demonstrate the action-relatedness of cognitive processing, or can be reinterpreted more elegantly in this new framework. In particular, research in the young field of neural dynamics seems to support central intuitions of the pragmatic turn, providing an avenue toward understanding how coordinated action can emerge from the highly distributed architecture of a cognitive system. The second notion I have introduced is that of a “directive,” which I nominate as a conceptual antagonist to the cognitivist notion of “representation.” Future work will tell if my hypotheses on “directives” can be consolidated into a robust theory of intrinsic dynamics of cognitive systems.

In an earlier section of this chapter, I outlined how key assumptions may be changing in a “pragmatic neuroscience.” As I have mentioned, a key question is whether these conceptual shifts may eventually lead us to a different style of experimentation, to different settings and paradigms, to new “laboratory habits.” I think, they will and actually many harbingers have arrived and begin taking effect. More and more researchers in the field implicitly seem to set up their own prescriptions for a pragmatic cognitive science, starting to use natural stimuli, complex sensorimotor

paradigms, massively parallel recording techniques, and—most importantly—less restrained subjects. The fans of the pragmatic turn should be the first to realize that the return of the active cognizer to the lab is, above all, a matter of practice, rather than of theory.

Acknowledgments

This work has been supported by grants from the European Commission (IST-027268 “Perception on Purpose”; NEST-043457 “Mindbridge”) and the Volkswagen Foundation (project “Representation”).

Notes

1. The term “pragmatic” is used here to make reference to action-oriented viewpoints such those developed by the founders of philosophical pragmatism, William James, Charles Sanders Peirce or John Dewey. Grossly simplifying, pragmatism entails, for instance, that an ideology or proposition is true if it works satisfactorily, that the meaning of a proposition is to be found in the practical consequences of accepting it, and that unpractical ideas are to be rejected. However, using the term “pragmatic turn,” I am *not* meaning to suggest a return to exactly the positions put forward by these authors.

2. Note the striking resemblance between the notion of “sensorimotor coordination” used by Dewey and the concept of “sensorimotor contingencies” introduced by O’Regan and Noë (2001).

3. The concept of “action” contrasts with that of “behavior” and also with that of “movement.” Evidently, there are many instances of action that do not involve any (overt) movement. Mental calculation would provide such a case. The description of “acts” or “actions” typically makes references to goals that often the agent has adopted on the basis of an overall practical assessment of his options and opportunities. “Behavior,” in contrast, can be described and explained (at least according to certain psychological schools) without making reference to mental events or to internal psychological processes. Clearly, therefore, the pragmatic turn cannot not lead back to “behaviorism.”

4. In the studies mentioned, the effects were observed under anesthesia (Gray et al. 1989) and in the awake, albeit passively stimulated animal (Kreiter and Singer 1996). This does not, in principle, contradict my interpretation. The findings seem to suggest that, even if the stimuli are not task-relevant, there is a disposition of the cortical network to synchronize in a stimulus-specific way *because certain rules relevant for the generation of directives have been inscribed by learning into the network*. Of course, the effects should be stronger if the scene segmentation is directly task-relevant.

References

- Aoki, F., Fetz, E. E., Shupe, L., Lettich, E., and Ojemann, G. A. (2001). Changes in power and coherence of brain activity in human sensorimotor cortex during performance of visuomotor tasks. *Bio Systems* 63:89–99.
- Bauer, M., Oostenveld, R., Peeters, M., and Fries, P. (2006). Tactile spatial attention enhances gamma-band activity in somatosensory cortex and reduces low-frequency activity in parieto-occipital areas. *Journal of Neuroscience* 26:490–501.
- Bisiach, E., and Luzzatti, C. (1978). Unilateral neglect of representational space. *Cortex* 14:129–133.
- Blake, D. T., Byl, N. N., and Merzenich, M. M. (2002). Representation of the hand in the cerebral cortex. *Behavioural Brain Research* 135:179–184.
- Christensen, M. S., Lundbye-Jensen, J., Geertsen, S. S., Petersen, T. H., Paulson, O. B., and Nielsen, J. B. (2007). Premotor cortex modulates somatosensory cortex during voluntary movement without proprioceptive feedback. *Nature Neuroscience* 10:417–419.
- Clark, A. (1995). Moving minds: situating content in the service of real-time success. In *AI, connectionism, and philosophical psychology: Philosophical perspectives, vol. 9*, ed. J. E. Tomberlin, 89–104. Atascadero, CA: Ridgeview Pub Co.
- Clark, A. (1997). *Being there: Putting brain, body, and world together Again*. Cambridge, MA: MIT Press.
- Craighero, L., Fadiga, L., Rizzolatti, G., and Umiltà, C. (1999). Action for perception: A motor-visual attentional effect. *Journal of Experimental Psychology. Human Perception and Performance* 25:1673–1692.
- Crapse, T. B., and Sommer, M. A. (2008). Corollary discharge across the animal kingdom. *Nature Reviews. Neuroscience* 9:587–600.
- Debener, S., Herrmann, C. S., Kranczioch, C., Gembris, D., and Engel, A. K. (2003). Top-down attentional processing enhances auditory evoked gamma band activity. *Neuroreport* 14:683–686.
- Desmurget, M., and Grafton, S. (2000). Forward modelling allows feedback control for fast reaching movements. *Trends in Cognitive Sciences* 4:423–431.
- Dewey, J. (1896). The reflex arc concept in psychology. *Psychological Review* 3:357–370.
- Dewey, J. (1925). *Experience and nature*. Chicago: Open Court.
- Dreyfus, H. L. (1992). *What computers still can't do*. Cambridge, MA: MIT Press.

- Eimer, M., and van Velzen, J. (2006). Covert manual response preparation triggers attentional modulations of visual but not auditory processing. *Clinical Neurophysiology* 117:1063–1074.
- Engel, A. K., and König, P. (1998). Paradigm shifts in the neurobiology of perception. In *Intelligence and artificial intelligence: An interdisciplinary debate*, ed. U. Ratsch, M. M. Richter, and I.-O. Stamatescu, 178–192. Berlin: Springer.
- Engel, A. K., and Singer, W. (2001). Temporal binding and the neural correlates of sensory awareness. *Trends in Cognitive Sciences* 5:16–25.
- Engel, A. K., Fries, P., and Singer, W. (2001). Dynamic predictions: Oscillations and synchrony in top-down processing. *Nature Reviews: Neuroscience* 2:704–716.
- Engel, A. K., König, P., Kreiter, A. K., Schillen, T. B., and Singer, W. (1992). Temporal coding in the visual cortex: new vistas on integration in the nervous system. *Trends in Neurosciences* 15:218–226.
- Fagioli, S., Hommel, B., and Schubotz, R. I. (2007). Intentional control of attention: Action planning primes action-related stimulus dimensions. *Psychological Research* 71:22–29.
- Fodor, J. A. (1979). *Representations: Essays on the foundations of cognitive science*. Cambridge, MA: MIT Press.
- Fries, P., Reynolds, J. H., Rorie, A. E., and Desimone, R. (2001). Modulation of oscillatory neuronal synchronization by selective visual attention. *Science* 291:1560–1563.
- Fries, P. (2005). A mechanism for cognitive dynamics: Neuronal communication through neuronal coherence. *Trends in Cognitive Sciences* 9:474–480.
- Frith, C. D., Blakemore, S.-J., and Wolpert, D. M. (2000). Explaining the symptoms of schizophrenia: Abnormalities in the awareness of action. *Brain Research: Brain Research Reviews* 31:357–363.
- Gallant, J. L., Connor, C. E., and VanEssen, D. C. (1998). Neural activity in areas V1, V2 and V4 during free viewing of natural scenes compared to controlled viewing. *Neuroreport* 9:85–89.
- Graziano, M. S. A., Hu, X. T., and Gross, C. G. (1997). Visuospatial properties of ventral premotor cortex. *Journal of Neurophysiology* 77:2268–2292.
- Graziano, M. S. A., and Gross, C. G. (1998). Spatial maps for the control of movement. *Current Opinion in Neurobiology* 8:195–201.
- Gray, C. M., König, P., Engel, A. K., and Singer, W. (1989). Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature* 338:334–337.
- Heidegger, M. (1986). *Sein und Zeit*. Tübingen: Niemeyer.

- Heidegger, M. (1989). *Die Grundprobleme der Phänomenologie*. Frankfurt: Klostermann.
- Held, R. (1965). Plasticity in sensory-motor systems. *Scientific American* 11 (65): 84–94.
- Herrmann, C. S., Munk, M. H. J., and Engel, A. K. (2004). Cognitive functions of gamma-band activity: Memory match and utilization. *Trends in Cognitive Sciences* 8:347–355.
- Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage* 14:S103–S109.
- Kranczioch, C., Debener, S., Schwarzbach, J., Goebel, R., and Engel, A. K. (2005). Neural correlates of conscious perception in the attentional blink. *NeuroImage* 24:704–714.
- Kranczioch, C., Debener, S., Herrmann, C. S., and Engel, A. K. (2006). EEG gamma-band activity in rapid serial visual presentation. *Experimental Brain Research* 169:246–254.
- Kreiter, A. K., and Singer, W. (1996). Stimulus-dependent synchronization of neuronal responses in the visual cortex of awake macaque monkey. *Journal of Neuroscience* 16:2381–2396.
- Kurthen, M. (1994). *Hermeneutische Kognitionswissenschaft*. Bonn: Djre Verlag.
- Kurthen, M. (2007). From mind to action: The return of the body in cognitive science. In *The body as interface: Dialogues between the disciplines*, ed. S. Sielke and E. Schäfer-Wünsche, 129–143. Heidelberg: Winter Verlag.
- Majewska, A. K., and Sur, M. (2006). Plasticity and specificity of cortical processing networks. *Trends in Neurosciences* 29:323–329.
- Mead, G. H. (1934). *Mind, self and society*. Chicago: University of Chicago Press.
- Mead, G. H. (1938). *The philosophy of the act*. Chicago: University of Chicago Press.
- Merleau-Ponty, M. (1962). *Structure of behavior*. Boston: Beacon Press.
- Merleau-Ponty, M. (1963). *Phenomenology of perception*. New York: Humanities Press.
- Münte, T. F., Altenmüller, E., and Jäncke, L. (2002). The musician's brain as a model of neuroplasticity. *Nature Reviews: Neuroscience* 3:473–478.
- Murthy, V. N., and Fetz, E. E. (1996). Oscillatory activity in sensorimotor cortex of awake monkeys: Synchronization of local field potentials and relation to behavior. *Journal of Neurophysiology* 76:3949–3967.
- Newell, A., and Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

- Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
- O'Regan, J. K., and Noë, A. (2001). The sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences* 24:939–1031.
- Pickering, M. J., and Garrod, S. (2006). Do people use language production to make predictions during comprehension? *Trends in Cognitive Sciences* 11:105–110.
- Richter, W., Somorjai, R., Summers, R., Jarmasz, M., Menon, R. S., Gati, J. S., et al. (2000). Motor area activity during mental rotation studied by time-resolved single-trial fMRI. *Journal of Cognitive Neuroscience* 12:310–320.
- Riehle, A., Grün, S., Diesmann, M., and Aertsen, A. (1997). Spike synchronization and rate modulation differentially involved in motor cortical function. *Science* 278:1950–1953.
- Roelfsema, P. R., Engel, A. K., König, P., and Singer, W. (1997). Visuomotor integration is associated with zero time-lag synchronization among cortical areas. *Nature* 385:157–161.
- Salinas, E., and Sejnowski, T. J. (2001). Gain modulation in the central nervous system: Where behaviour, neurophysiology, and computation meet. *Neuroscientist* 7:430–440.
- Siegel, M., Donner, T. H., Oostenveld, R., Fries, P., and Engel, A. K. (2008). Neuronal synchronization along the dorsal visual pathway reflects the focus of spatial attention. *Neuron* 60:709–719.
- Singer, W., and Gray, C. M. (1995). Visual feature integration and the temporal correlation hypothesis. *Annual Review of Neuroscience* 18:555–586.
- Steinmetz, P. N., Roy, A., Fitzgerald, J., Hsiao, S. S., Johnson, K. O., and Niebur, E. (2000). Attention modulates synchronized neuronal firing in primate somatosensory cortex. *Nature* 404:187–190.
- Tallon-Baudry, C., Bertrand, O., Delpuech, C., and Pernier, J. (1997). Oscillatory gamma-band (30–70 Hz) activity induced by a visual search task in humans. *Journal of Neuroscience* 17:722–734.
- Taylor, K., Mandon, S., Freiwald, W. A., and Kreiter, A. K. (2005). Coherent oscillatory activity in monkey V4 predicts successful allocation of attention. *Cerebral Cortex* 15:1424–1437.
- Tiitinen, H., Sinkkonen, J., Reinikainen, K., Alho, K., Lavikainen, J., and Naatanen, R. (1993). Selective attention enhances the auditory 40-Hz transient response in humans. *Nature* 364:59–60.
- Varela, F. J., Thompson, E., and Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Varela, F., Lachaux, J.-P., Rodriguez, E., and Martinerie, J. (2001). The brainweb: Phase synchronization and large-scale integration. *Nature Reviews: Neuroscience* 2:229–239.

von der Malsburg, C. (1981). *The correlation theory of brain function*. Internal Report 81/2. Göttingen: Max Planck Institute for Biophysical Chemistry. Reprinted in *Models of neural networks II*, ed. E. Domany, J. L. van Hemmen, and K. Schulten, 95–119. Berlin: Springer 1994.

Wilson, M., and Knoblich, G. (2005). The case for motor involvement in perceiving conspecifics. *Psychological Bulletin* 131:460–473.

Winograd, T., and Flores, F. (1986). *Understanding computers and cognition*. Norwood, NJ: Ablex Publishing Corp.

