Where's the action? The pragmatic turn in cognitive science

Andreas K. Engel[1], Alexander Maye[1], Martin Kurthen[2], and Peter König[1,3]

[1] Department of Neurophysiology and Pathophysiology, University Medical Center Hamburg-Eppendorf, 20246 Hamburg, Germany
[2] Swiss Epilepsy Centre, 8008 Zürich, Switzerland
[3] Institute of Cognitive Science, University of Osnabrück, 49069 Osnabrück, Germany

In cognitive science, we are currently witnessing a 'pragmatic turn', away from the traditional representation-centered framework towards a paradigm that focuses on understanding cognition as 'enactive', as skillful activity that involves ongoing interaction with the external world. The key premise of this view is that cognition should not be understood as providing models of the world, but as subserving action and being grounded in sensorimotor coupling. Accordingly, cognitive processes and their underlying neural activity patterns should be studied primarily with respect to their role in action generation. We suggest that such an action-oriented paradigm is not only conceptually viable, but already supported by much experimental evidence. Numerous findings either overtly demonstrate the action-relatedness of cognition or can be re-interpreted in this new framework. We argue that new vistas on the functional relevance and the presumed 'representational' nature of neural processes are likely to emerge from this paradigm.

From representation to action

Since its formation as a discipline that aims for a naturalistic account of the mental, cognitive science has been dominated by a view of cognition as computation over mental representations [1–4]. This classical paradigm has been highly fruitful and has stimulated important research in the early decades of cognitive science. However, significant criticisms have been voiced, claiming that the classical view may be strongly biased, if not misleading in nature [5–21]. As an alternative, an action-oriented paradigm is emerging [9,11,15,17–19,21,22], which was earliest and most explicitly developed in robotics [5,7,8,10,13] and more recently began to impact on cognitive psychology [17,22] and neurobiology [20,23–27].

The basic idea is that cognition should not be understood as a capacity for deriving world-models, which might then provide a database for thinking, planning, and problem-solving. Rather, it is emphasized that cognitive processes are so closely intertwined with action that cognition would best be understood as 'enactive', as the exercise of skillful know-how in situated and embodied action [9,28]. Here, we explore the implications of such an action-oriented view for cognitive neuroscience and review neurobiological evidence that supports the pragmatic turn.

Action-oriented views in cognitive science

Pioneering the 'enactive approach' to cognition, Varela, Thompson, and Rosch defined cognition as 'embodied action' [9]. They emphasized that cognition is not detached contemplation of the world, but a set of processes that determine possible actions. According to their view, the criterion for success of cognitive operations is not to recover pre-existing features or to construct a veridical representation of the environment. Instead, cognitive processes construct the world by bringing forth action-relevant structures in the environmental niche. In a nutshell, cognition should be understood as the capacity of generating structure by action, that is, of 'enacting' a world [9].

Clark has developed a slightly less radical version of such an action-oriented view [15,16]. He argues 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 dealt with in a highly context-dependent manner. This leads Clark to a notion of 'action-oriented representation', which refers to the idea that internal states simultaneously describe aspects of the world and prescribe possible actions.

The notion that action is not just a product of cognitive operations, but constitutive for cognition is also a key ingredient of the sensorimotor contingency theory put forward by O'Regan and Noë [17,21]. According to their view, the agent's acquired knowledge of sensorimotor contingencies, that is, the rules that govern sensory changes produced by motor actions, are critical for both development and maintenance of cognitive capacities.

The concept of a pragmatic turn

We will use the notion 'pragmatic turn' to denote the action-oriented paradigm emerging in cognitive science. The term 'pragmatic' is used here, first, to highlight our conjecture that cognition is a form of practice. Second, we introduce the term to refer to action-oriented viewpoints, such as those developed by the founders of philosophical pragmatism [29,30], albeit without suggesting a return to exactly the positions put forward by these authors.

Corresponding author: Engel, A.K. (ak.engel@uke.de, ak.engel@mac.com).

Keywords: pragmatic turn; action-oriented approach; enactive approach; motor cognition; premotor theory of attention; sensorimotor contingencies.

1364-6613/$ – see front matter
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The central premise of this new paradigm could be phrased as 'cognition is action' [9–11]. The view that results from the pragmatic turn can be seen as a direct antagonist of the classical framework and its central assumptions can be summarized as follows [9,11,15,17–21,31,32]:

- cognition is understood as capacity of generating structure by action;
- the cognitive agent is immersed in his/her task domain;
- system states acquire meaning by virtue of their role in the context of action;
- the functioning of cognitive systems is thought to be inseparable from embodiment;
- a holistic view of the architecture of cognitive systems prevails, which emphasizes the dynamic nature and context-sensitivity of processing;
- models of cognition take into account the embedded and 'extended' nature of cognitive systems.

It should be noted that the concept of action, as used here, is neither coextensive with that of behavior nor with that of movement [28,30] (Box 1). For instance, describing an action typically makes reference to a goal an agent pursues, whereas behavior can be described without making any reference to teleology [28].

As we will discuss in the following sections, the pragmatic framework is not only conceptually viable but, in fact, already supported by much experimental evidence. Numerous findings in neuroscience either clearly demonstrate the action-relatedness of sensory and cognitive processing or can be re-interpreted more parsimoniously in this new framework.

Box 1. The concept of 'action' in the pragmatic turn

As used in the present paper, the notion of 'action' is not synonymous with 'movement' [22,28]. We use this concept in the enriched sense of 'intentional action' (see the entry on 'action' in the Stanford Encyclopedia of Philosophy, http://plato.stanford.edu/archives/sum2012/entries/action). This notion implies that actions (i) are driven by goals and that they can reach these goals or fail to do so; (ii) often involve some degree of volitional control; (iii) require planning and decisions among alternatives; (iv) involve prediction or anticipation of an intended outcome; (v) are often, albeit not always, associated with a sense of agency, that is, the agent's conscious awareness of carrying out the particular action and of its goals. Evidently, there are many cases of movements (e.g., reflexes) or behaviors (e.g., instincts) that do not constitute intentional actions under this definition.

One of our key hypotheses is that actions, as defined above, are grounded in basic sensorimotor behaviors and that, during development, sensorimotor coordination and sensorimotor contingencies can give rise to more complex forms of action. This is also one of the key predictions of the model of action acquisition by Elsner and Hommel [90]. According to their view, agents first exercise sensorimotor contingencies, that is, they learn to associate movements with their outcomes, such as ensuing sensory changes. Subsequently, the learned patterns can be used for action selection and eventually enable the deployment of intentional action.

An interesting implication is that, as defined here, intentional actions do not necessarily always involve overt movements, such as in the case of, for example, mental calculation. We hypothesize that, developmentally, cognition first develops as the capacity to generate structure by overt action. Secondary processes, such as motor imagery, might then establish the capacity for internal simulation of actions and action plans [23,91].

Action-relatedness of sensory processing

The pragmatic turn is strongly supported 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. The development of neural circuits in the visual system and the acquisition of visuomotor skills critically depend on sensorimotor interactions and active exploration of the environment [33,34]. The same holds for the development of auditory localization behaviors [35,36]. Even in the adult brain, there is considerable plasticity of cortical maps, for example, in the somatosensory and motor systems, which have been shown to depend on action context [37,38]. For instance, highly trained musicians often show functional and structural changes in their sensorimotor systems that result from action-dependent plasticity [38]. These studies demonstrate that appropriate action, which allows exercise of relevant sensorimotor contingencies, is necessary throughout life to stabilize the functional architecture of the respective circuits. This action-relatedness also holds for plasticity that is related to learning the use of sensory implants [39] or sensory substitution devices [40].

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 an action-relatedness of neuronal response properties. Activation of visual cortical neurons changes profoundly if self-induced movements are permitted, as compared to passive viewing of stimuli [41–43]. Interestingly, neurons in early sensory cortices, such as V1, can even signal the timing of action-contingent rewards in awake animals [44]. Furthermore, properties of parietal and premotor neurons strongly depend on action context [45,46]. In premotor cortex, the spatial profile of multimodal receptive fields depends on body and limb position [45]. Tactile and visual receptive fields of premotor neurons are in dynamic register and seem anchored to body parts, even if these are moving (Figure 1), which suggests that such multimodal neurons support predictions about expected changes in sensory input. Action-related changes of sensory response properties of parietal neurons have also been observed in studies that involve learning of tool use [47] (Fig. 1). Given the abundance of sensorimotor gain modulation of neural responses [48], it seems likely that sensory activity patterns are always, to a considerable degree, action-related or action-modulated [15].

The role of action-effect predictions

An important line of evidence concerns the function of corollary discharge or 'efference copy' signals, which deliver 'motor predictions' necessary for an organism to distinguish self-generated sensory changes from those not related to own action [49–51]. In technical contexts, the same principle is often referred to as a forward model [50,52,53]. The importance of corollary discharge signals is well established in the context of eye movements and grasping or reaching movements [50–52]. This research shows that predictions about the sensory outcome of movement are critical for the interpretation of sensory inputs

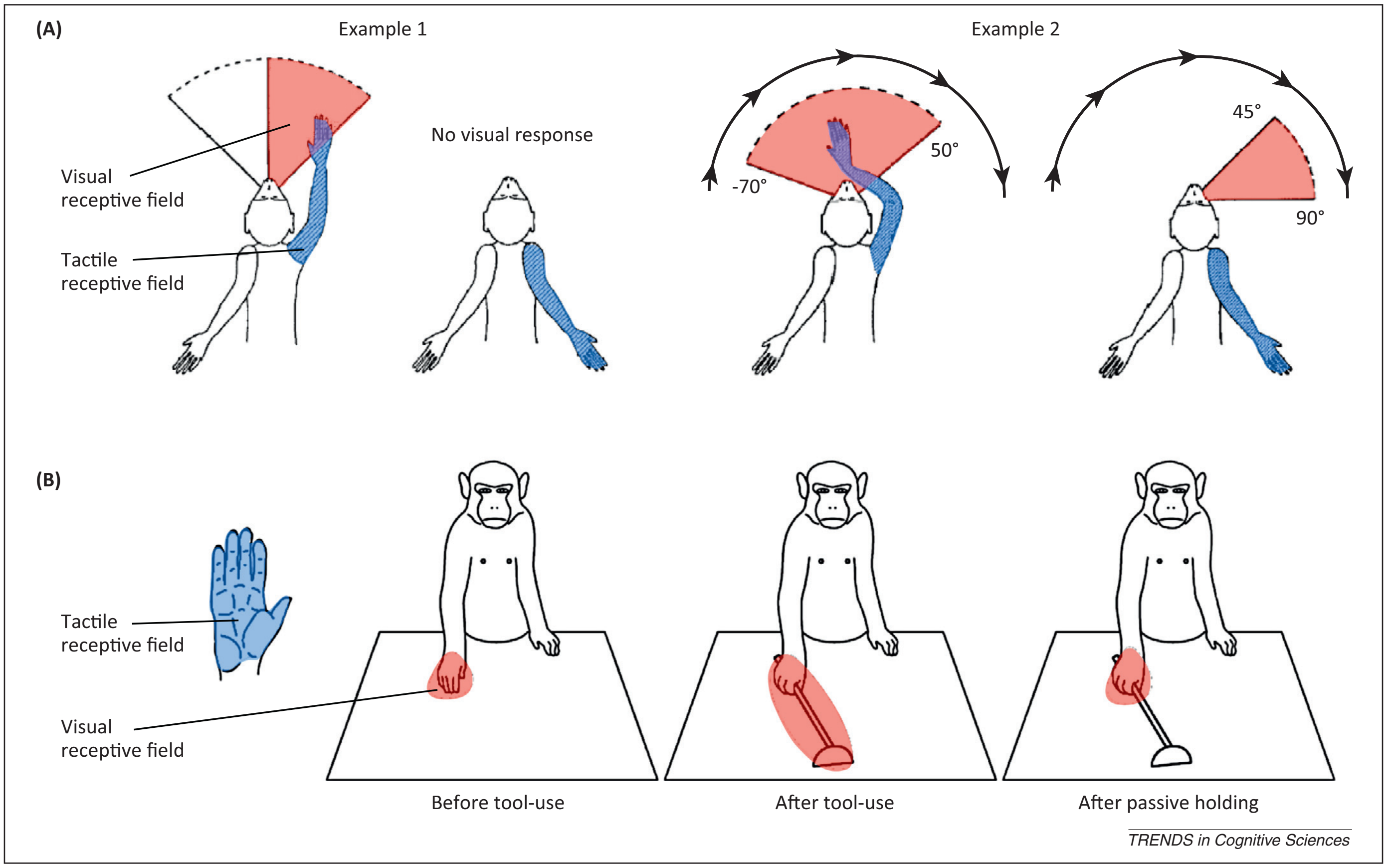

Figure 1. The dependence of multisensory receptive fields on action context. **(A)** Two examples of neurons recorded from ventral premotor cortex in the monkey. The neurons showed bimodal responses, having tactile (blue) and visual (red) receptive fields. In both examples, the visual response depended on the arm position of the animal. Adapted, with permission, from [45]. **(B)** Recording of bimodal intraparietal neurons with tactile (blue) and visual (red) receptive fields. The visual receptive field showed adaptive changes as the animal used a tool for food retrieval, expanding to include the entire length of the tool. In a control condition with passive holding of the same tool, this expansion did not take place. Adapted, with permission, from [47].

and, more generally, for determining the experienced qualities of perception [17,21,40].

Similar principles of predicting sensory inputs also play a key role in more complex cognitive processes, such as language comprehension [54], predictions about sequences of abstract stimuli [55], or predictive remapping of attention before saccades [56]. Recent work in cognitive robotics suggests that the learning of such predictions could also mediate the acquisition of object concepts [57,58] (Box 2), grounding knowledge of objects in repertoires of actions that can be executed upon them [25,59]. Furthermore, prediction of the sensory outcomes of actions is critical for the sense of agency, that is, the conscious experience of oneself as the initiator and executor of one's own actions [50,60]. Malfunctions of such forward models have been implicated in the pathogenesis of schizophrenia [53,61] or the phenomenon of phantom limbs [62]. In all these cases, activity of motor planning regions seems to be involved in generating predictions about sensory events, possibly by modulating neural signals in sensory regions [54,55,63].

The cognitive function of motor circuits

An action-oriented view implies that procedural knowledge is fundamental to the acquisition of object concepts [25,59] and, therefore, the storage of information about events and objects should generally involve action planning regions [25,64]. In line with this prediction, recent imaging studies show that object concepts in semantic memory do not only rely on sensory features but, critically, also on motor properties associated with the object's use [25,64,65]. If subjects are trained to perform functional tasks on certain objects, premotor regions become active during visual perception of these objects [65]. A highly intriguing finding is that motor and premotor systems, basal ganglia, and cerebellum are also active during the simulation of events [23,66], which occurs, for instance, during mental rotation of objects [67,68].

Strong support for the cognitive role of motor circuits is also provided by research on the mirror neuron system [69–71], which suggests that the processing of social events, such as observing and coordinating with the actions of others, involves action-generating neural systems. Importantly, recent evidence shows that the mirror neuron system also includes primary motor cortex [72]. The observation of visual and somatosensory responses in primary motor cortex suggests that this area may also be involved in predicting future sensory consequences of actions [72]. Similar conclusions have emerged from studies that demonstrate an involvement of motor and premotor cortex in speech perception and language comprehension [26,73].

Action-relatedness of attention and decision-making

Attention and decision making provide two examples of cognitive processes that classically are assumed to be

Box 2. Deployment of sensorimotor contingencies for object categorization

In a recent study [57], a simple computational model of object recognition was developed in which actions are an integral component of the perceptual process. In this model, sensorimotor contingencies (SMCs) were implemented as multistep, action-conditional probabilities of future sensory observations. Using the LEGO Mindstorms$^{\text{TM}}$ toolkit, a mobile robot was assembled that could move along a line and was equipped with an ultrasound distance sensor (Figure IA). It could use its two arms together with its locomotion to move two different objects into different directions. By activating different SMCs, the system learned to distinguish the two object classes. SMCs were implemented by a set of Markov models with increasing history lengths. A record of past movements and sensory observations determined the system's current action context (Figure IB). In this model, learning of SMCs corresponded to determining the conditional probability of making a sensory observation given the past movements and observations. The robot experiment showed that different objects generated different probability distributions, which could partially overlap. The size of the overlap depended on history length. Short history lengths produced distributions with large overlap for different objects, reflecting the general effect of movements on the sensor readings independently of the object under consideration. With increasing history length, the conditional probability became more and more object-specific, suggesting that SMCs can be used for the learning of object concepts [92].

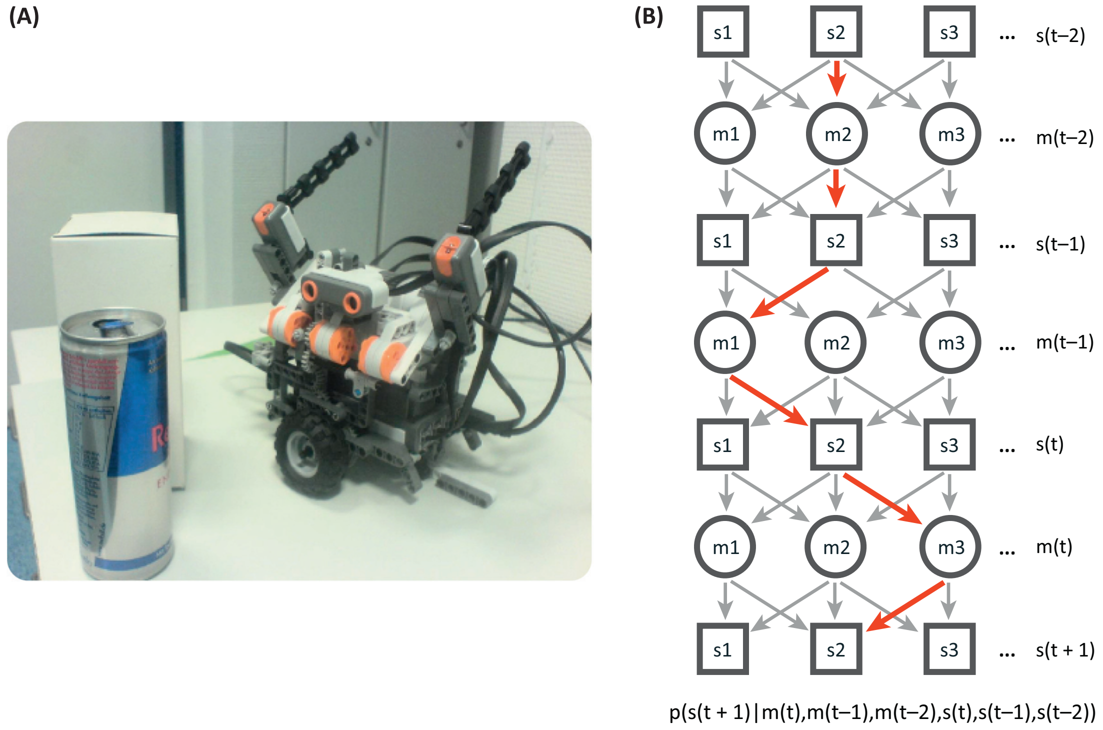

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Figure I. **(A)** The Lego Mindstorms$^{\text{TM}}$ robot for pushing objects to the left or right and the two objects used in [57] (can in the front, box in the back). The robot had to move all cans to the right and all boxes to the left. **(B)** At time t, the robot makes sensory observation s(t), which results from movement m(t − 1). Together with past movement-observation pairs, this information constitutes the current action context $c^h(t) = s(t),\ldots s(t-h), m(t-1),\ldots m(t-h)$. The red arrows illustrate one example for such a sequence. Based on the current context, the agent chooses the next movement m(t), leading to observation s(t + 1) in the next iteration. Learning SMCs corresponds to determining the conditional probability of making a sensory observation s(t + 1), given a movement m(t) and a context $c^h(t)$, and this observation probability can be described as an h-th order Markov model $p^h(s(t+1)|m(t),c^h(t))$. Models with history lengths $h \in [1–3]$ were used. Adapted, with permission, from [57].

interposed between perception and action. Recent studies demonstrate that these are much more closely related to the function of motor and premotor circuits than previously thought [27,74–76].

As part of the so-called 'premotor theory of attention' [77], it has long been suggested that the selection of sensory information should be modulated and focused by constraints that arise from current action planning and execution. In agreement with this prediction, several studies have shown that movement preparation can lead to attentional shifts and to changes in the acquisition of object-related information [78–80]. Functional imaging studies and neurophysiological recordings have provided evidence that the modulatory bias imposed by attention may indeed arise from premotor regions, in particular the frontal eye fields [81–85]. Magnetoencephalography (MEG) studies have shown that premotor regions, such as the frontal eye field, are involved in attentional modulation of sensory processing through selective enhancement of dynamic coupling, expressed by coherence of fast neuronal oscillations between premotor, parietal, and sensory regions [86].

Similar evidence has also been obtained in recent studies where subjects had to report their percept in the face of ambiguous [87] or near-threshold stimuli [88]. Analysis of neural coherence during ambiguous stimulation revealed that large-scale interactions in a network of premotor, parietal, and temporal regions modulate the subjects' percept (Figure 2). Studies on perceptual decision making showed that motor and premotor areas encode decision-related

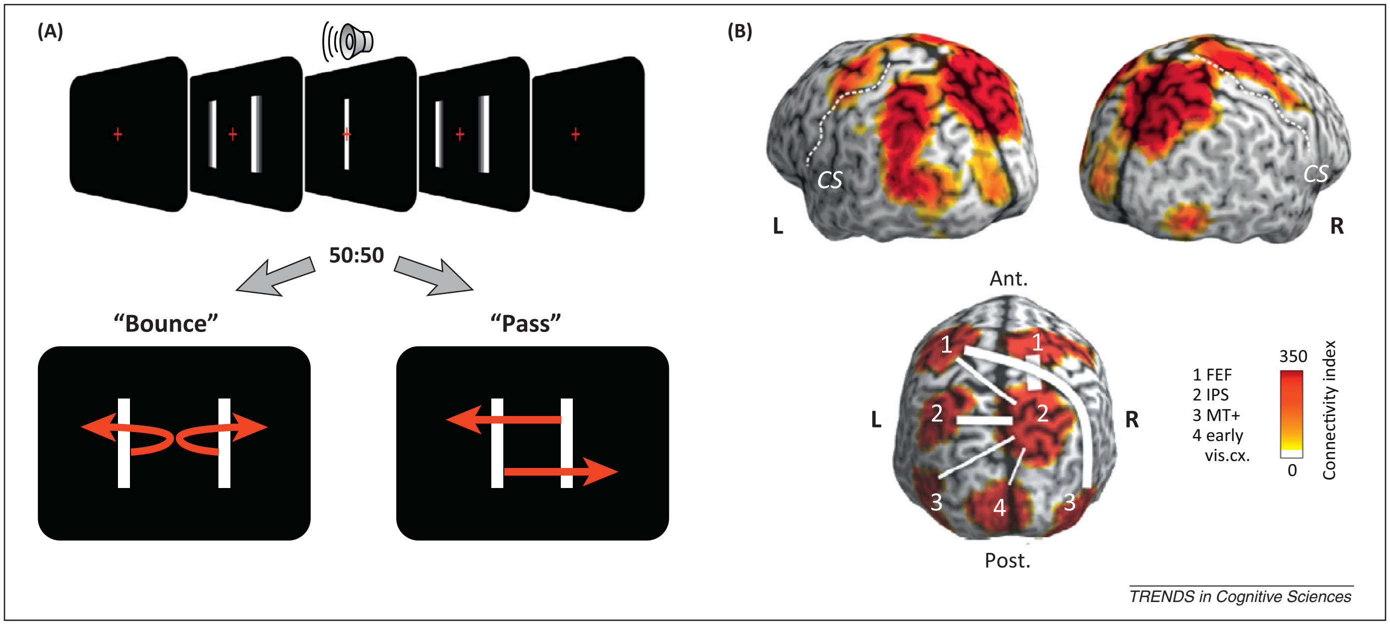

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Figure 2. The role of premotor circuits in the control of cognitive states. **(A)** The electroencephalogram was recorded in human subjects during perception of an ambiguous audiovisual stimulus. On each trial, participants watched a screen on which two bars approached, briefly overlapped, and moved apart again. At the time of overlap of the bars, a brief click sound was played. Participants perceived this stimulus either as two bouncing or as two passing bars, with the percept spontaneously changing across trials. **(B)** Presentation of the stimuli was associated with enhanced, beta-band coherence (15-30 Hz) across a large-scale cortical network that included bilateral frontal eye fields (FEF), posterior parietal cortex (PPC), and visual areas involved in motion processing (MT+). The strength of beta-band coupling (white lines in lower panel) in this network predicted the subjects' percept: stronger beta-band coherence predicted perceiving the bars as bouncing, whereas weaker coherence predicted the percept of passing bars. Adapted, with permission, from [87].

information that classically is supposed to be processed primarily at sensory levels [27,88]. Taken together, these studies suggest that attentional selection and perceptual decision making may be described as biases in sensory processing imposed by the current action context.

Challenging representations

The studies discussed above are part of a growing body of evidence suggesting that cognition is fundamentally action-bound, subserving the planning, selection, anticipation, and performance of actions. Thus, cognition and action are not only closely interrelated – cognition seems fundamentally grounded in action [9,15,17–19,22]. If valid, this conclusion would enforce a radical change in how we conceive of the functional significance of neural activity patterns. According to the view advocated here, even activity patterns in sensory regions cannot be taken as encoding action-invariant structural descriptions of objects and scenes. Rather, in close interaction with distributed activity in parietal and frontal regions, such patterns support the organism‘s capacity of structuring action-related contexts.

Therefore, it seems appropriate to conclude, as Clark has phrased it [15], that brain states prescribe possible actions, rather than describing states of the outside world. These considerations have lead several forerunners of the pragmatic turn to the insight that the concept of 'representation' needs to be reworked profoundly. 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 such as 'deictic representation' [8], 'deictic codes' [14], 'indexical representation' [13], 'control-oriented representation' [12], or 'action-oriented representation' [15] have been introduced.

Dynamic directives

We suggest that, rather than trying to reshape the notion of representation, it may be more appropriate to replace it by a term that does not carry so much of the cognitivist burden. As an alternative, one of us (A.K.E.) has proposed to use the term 'directive' to denote the action-related role of large-scale dynamic interaction patterns that emerge in a cognitive system [20]. On this account, directives can be defined as dispositions for action embodied in dynamic activity patterns. On hand in procedural memory as dispositions for meaningful actions, directives are immediately related to action selection. Activating a directive is assumed to tightly control planning and execution of the respective action. Importantly, the data reviewed in the preceding sections suggest that directives are not encoded only by activity in movement-related brain circuits, but extend across sensory and memory structures, as well.

Object concepts, according to this view, correspond to sets of related directives. Knowing what an object is does not mean to possess internal descriptions of this object, but to master sets of sensorimotor skills and possible actions that can be chosen to explore or utilize the object [17,18,25,57–59]. This view predicts that there is no context-neutral description of object features. For instance, perception of a chair is not equivalent to setting up an abstract geometric description of this object, but, rather, to detecting an affordance such as the opportunity of sitting [6]. Objects are structured by directives in the sense that an object is defined by the set of possible actions that can be performed on it.

Having introduced this concept as part of the pragmatic framework, it is important to stress that directives do not strictly equate with internal states of the brain. Rather, the

Box 3. Towards an agenda for pragmatic neuroscience

The pragmatic turn has both conceptual and practical implications for a future neuroscience agenda. Conceptually, a new view on the functional roles of neural states needs to be developed: rather than encoding information about pre-existing objects or events in the world, neural states support the capacity of structuring situations through action [9,15]. An interesting consequence of this view is that the meaning, or contents, of neural states would eventually be determined by their functional role in the guidance of action, not by a mapping to a stimulus domain, as assumed in many representationalist accounts. Thus, the action-oriented view advocated here might open up a new perspective on the grounding of neural semantics [11,93,94].

If neural states are individuated through their role in action generation, then the primary focus of experimentation should be on studying the relation of neural activity patterns to action contexts, rather than on investigating their dependence on external stimuli – a view that has been dominating classical neurophysiology for decades. An action-oriented paradigm clearly implies that cognition has to be viewed as a highly active, selective, and constructive process. Therefore, there is increasing interest in the role of top-down influences that support predictions about forthcoming sensory events [31,95,96] and eventually reflect constraints from current action. In most instances, the implementation of directives will require both 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. Therefore, it is becoming increasingly important to investigate the large-scale dynamics of interactions across brain regions [31,76,97].

Evidently, the notion of a pragmatic turn has consequences for actual research praxis. A key question is whether these conceptual shifts may eventually lead to the development of different experimental settings and paradigms, and to new 'laboratory habits'. Clearly, research in a framework for pragmatic neuroscience would require researchers to avoid studying passive subjects, but, rather, to use paradigms that involve active exploration [98,99]. This, in turn, would require novel technology for recording neural activity and biosignals during execution of actions, for tracking a subject's actions and for manipulating sensorimotor contingencies [99], as well as novel approaches for analysis of unprecedentedly large data sets that result from massively parallel recordings.

notion of directive refers to states of the cognitive system in its entirety, which includes the body and part of the environmental niche [19,32]. For instance, such action-oriented patterns include bodily dynamics arising from biophysical and physiological properties of the skeletomuscular system. In our view, they might best be described as patterns of dynamic interactions extending through the entire cognitive system. Therefore, 'directive' is not just a different term for 'action-oriented representation'. The latter denotes states 'in the head', whereas the former refers to the dynamics of the embodied and embedded mind.

Concluding remarks

We have discussed a novel action-oriented framework for cognition that receives increasing support from researchers who strive to cope with problems not adequately solved by classical approaches in cognitive science. At this point, the pragmatic turn presumably denotes more an agenda than a paradigm already in place. We have argued that such an action-oriented framework is conceptually sound and supported by a large body of experimental evidence. Moreover, this agenda has a number of important implications for the research praxis in the cognitive sciences (Box 3).

Box 4. Outstanding questions

- The pragmatic turn emphasizes the role of procedural learning and skills. How can episodic memory and declarative knowledge be grounded in procedural learning and its neural mechanisms?
- What is the role of habits and habit formation in an action-oriented conceptual framework?
- Can learning of sensorimotor contingencies account for complex processes, such as tool use and action planning?
- Can sensorimotor contingencies be exploited to acquire abstract cognitive concepts, such as the notion of an electromagnetic field or a prime number?
- Can sensorimotor contingencies account for processes such as social cognition?
- Are there dependencies between action repertoires and levels of consciousness? For instance, would conscious awareness deteriorate in chronically and severely movement-disabled patients with, for example, amyotrophic lateral sclerosis?
- How are directives acquired and how are appropriate directives selected during learning?
- How can relations be defined across directives, leading to clustering of similar directives?
- Which features of neuronal dynamics at early sensory processing levels are dependent on directives and action repertoires?
- At which processing level do differences between directives executable in the present context and directives executable only in principle become apparent?

If we decide to effect a pragmatic turn in cognitive science, our view of the brain and its function is likely to change profoundly. The conceptual premises of the pragmatic turn are likely to enforce a redefinition of basic neuroscientific explananda. What neuroscience, then, has to explain is not how brains act as world-mirroring devices [3,4,89], but how they can serve as 'vehicles of world-making' [9] that support, based on individual learning history, the construction of the experienced world and the guidance of action.

The punchline of this new view is to eventually transform the whole theory of cognition into a theory of action. Notably, this is not a behaviorist move, because the dynamics of the cognitive system is at the very heart of the enterprise and clear reference is made to its internal states. On the other hand, due to its interactionist and externalist flavor, this view is seamlessly compatible with most theories of embodied, embedded, and enactive cognition and with 'extended mind' approaches. Future work will tell if these conceptual installments will lead to the development of more powerful theories of the functioning of cognitive systems (Box 4).

Acknowledgements

We gratefully acknowledge support by grants from the EU (IST-2005-27268, NEST-Path-043457, FP7-ICT-270212, ERC-2010-AdG-269716), the Volkswagen Foundation (II/80609) and the DFG (GRK1247, SFB 936/A2/A3/B6).

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