Action and Language—Action-Based Neurolinguistics Approach

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Abstract

There are a lot of increasing evidences to support the strong links between action and language. Action based approach proposed the hierarchical structure of language based on action control and concerned with action goal, context, intention, mirror neurons and object affordances. Action semantics proposed that action control and use of object need not only low-level action control, but also semantic knowledge. Action Semantics are hierarchically organized and selectively activated depending on the action intention of the actor and the context. This framework integrated declarative and procedural action knowledge, thus challenging the traditional divide between semantics and pragmatics and they might draw on common representational resources.

Keywords

Action, Language, Mirror Neurons, Object Affordances, Action Semantics

Subject Areas: Linguistics

1. Introduction

In cognitive science, the ongoing "pragmatic turn" denotes an action-oriented paradigm which suggests that cognition should not be understood as providing models of the world, but as action-based model. Varela, *et al.* (1991) [1] first defined cognition as "embodied action", they argued that cognition is a set of processes about determining possible actions and a capacity of generating structure by action. Clark (1998, 1999) [2] [3] then proposed that cognition does not build upon universal models of the world, but is subject to constraints of the context-dependent environment. Thus, action is not only the result of cognition processing, but also the important component of cognition and the ground of cognition. The center point of this paradigm is "cognition is action" [1] [4]. And the main assumption of this paradigm is that cognition is fundamentally grounded in action and perception and such grounding allows the individual to enter into a relationship with its environment, thereby cognition is about real-world action rather than symbolic representation. Action and perception interaction

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for neural development and plasticity strongly support the view of pragmatic turn, such as the development of neural circuits in the visual system and the acquisition of visuomotor skills depend on sensormotor interactions of the environment [5]. There is a lot of increasing evidence supporting action-related neuronal response properties. For instance, activation of visual cortical neurons changes profoundly, when self-induced movements compared to passive viewing of stimuli [6] [7]. Furthermore, activation of parietal and premotor neurons depends on action context. In premotor cortex, the spatial profile of multimodal fields depends on body and limb position [8]. Given the strong evidence about action-related neuronal response, it seems that cognition is not only strongly interconnected with action, but based on action [1] [3] [9].

From the view of contemporary cognitive neuroscience, meaning is the result of our interactions with the outside world. Language connects all the possible actions in a network thereby expanding individual action experiences. Language's nature is in this view not only epistemic, but also pragmatic primarily. Accordingly, action-based approach propose, that the solution of contextually appropriate action might extend to contextually-appropriate language through evolution. The main reason of focusing on the relation between language and action is that the basic function of cognition is the control of action. Based on evolution, multi-cellular creatures need nervous system to express active movement, and systems evolution demands action. Nevertheless, just as effective action requires coordination with other systems in the brain, language needs coordination with perceptual and emotional systems throughout the brain. Thereby, although brain has capacities for perception, emotion, they serve to the capacity of action, and this kind of action related account of language suggest the investigation of language should begin from the domain of action.

There are a lot of evidences to demonstrate the strong links between action and language. Such as, Glenberg & Robertson [10] demonstrated the importance of action systems to language comprehension which was demonstrated by Glenberg & Kaschak (2002) and Zwaan & Taylor (2006) as well [11] [12]. It has been shown that when processing language with content related to different effectors, effector-specific sectors of the pre-motor and motor cortical areas become active [13]. And Glenberg *et al.* (2008) [14] demonstrated that the plasticity caused by motor system might affect the process of concrete and abstract language. Mover, motor activation occurs very soon after a stimulus is presented, and only 22 msec after peak activation in auditory temporal areas [15]. This early activation is difficult to regard motor effects to reflect motor imagery after understanding is completed but might reflect the embodied simulation of language understanding. So, we might investigate language based on action due to the strong links between action and language.

2. Action Based Approach

There are still no mature theories between motor control and language processes yet. The two types of models of motor control are backward model and forward model: A controller computes the contex-sensitive motor commands to accomplish goals; a predictor predicts effects of literal actions [16]. Wolpert *et al.* (2003) [16] proposed the MOSAIC model, which consists of multiple pairs of predictors and controllers, and a linked pair of predictor and controller consists of a module. In particular context, some modules might be activated. The actual motor command is a weighted function of the outputs from the selected controllers. The weighted motor command also becomes the efference copy used by the predictors. The predictions then are compared to sensory feedback, and those predictions with small errors lead to an increased weight for the associated controller. Haruno *et al.* (2003) [17] proposed a hierarchical version of MOSAIC, HMOSAIC. In HMOSAIC, a module for a goal-directed action selects basic motor act elements, and higher-level modules can select the basic motor acts. At higher levels, the controllers generate vectors of prior probabilities that lower-level modules are relevant, and the higher-level predictors predict the posterior probabilities of the lower-level modules controlling behavior. Glenberg & Gallese (2012) [18] introduced HMOSAIC model to linguistics to become a model of hierarchical control in language as well as action, that is, action-based model (ABL model). In this model, hierarchical control in action production extends to language process. The motor system solves the problem of producing contextuall-appropriate behavior, and the brain takes advantage of this solution to solve the problem of contextually-appropriate language. The ABL model provides an account of how word grounding in action: the controller for articulation of an action word is associated with the controller for the action, thereby the knowledge of a word is predictive and grounded in perception and action. In the ABL model, prediction is driven by the goal-directed action and feedback of perception, and controller and predictor in different hierarchical levels are organized by action goals and might integrate all kinds of information to produce language at last. The brain represents language processes by multi-system information, and the interactive framework between action and language is hierarchical and selective. The ABL model might be illustrated in the following **Figure 1**.

The main points of syntactic hypothesis in the ABL model include three parts: First, the basic function of action control is to utilize hierarchal mechanism to produce effective action and combine action behavior. Second, the foundation of syntax is to combine language elements in a way of producing communicative goal. Third, syntax emerges from modifying hierarchical control of action to produce hierarchical control of speech. The appropriate syntactic behavior is grounded the operation of the HMOSAIC mechanism for integrating particular actions, not from using an abstract syntactic rule. This account of syntactic theory has some predictions. This theory predicts that modules encoding particular sequences of words. The most importantly for the account developed is that it describes a type of mesh of affordances. According to Glenberg and Robertson (1999) [10], sentences are only sensible when the affordances of objects in the sentence can be integrated, as guided by syntactic constructions, to result in goal directed action. We will move to object affordance in detail in next section.

In this way, hierarchical, goal-directed mechanisms of action control, namely paired controller/predictor modules, have been exploited for syntax. Here, we may pay attention to an important syntactic property, that is, syntactic recursion. According to Vicari and Adenzato (2014) [19], the structure of goal-directed intentional action presents recursive mechanisms at the level of motor intentionality. Intentions are satisfied if and only if the corresponding action is realized in a specific way as a causal effect of the intention. And intentions have a self embedding structure that, in complex intentions, can produce long-distance relationships between prior intentions and subsidiary actions. Then the central features of syntactic recursion are already present in motor intentionality. And another related hypothesis that ties language to motor activities is the fact that action properties are at the basis of the origin grammar [20]-[22]. According to Rizzolatti and Arbib (1998) [23], the exaptation of a mirror system for communication is based on the fact that the control and observation of action show a prelinguistic grammar. That is, the neural circuits for controlling the hierarchy of goal-related actions were utilized to serve the function of language by selection pressure. We might conclude that, action and language are strongly connected and action goal, intention, context, mirror system and object affordance play functional roles in language processing, language acquisition and human mind. Language and action are not separated systems, but are closely interconnected and highly interacted to some extent as the embodied view declared. The mechanisms for language acquisition and the language processing show that sensorimotor information itself cannot be regarded as essential but the recruitment of the sensorimotor system in language understanding is instead modulated by the reliance on action goal, intention, and context. Action-based approach in language has a hierarchal and selective structure grounded on action, and has the strong neural foundation to serve language under the pressure of natural selection.

3. Object Affordance and Mirror Neurons

Action based approach proposed the hierarchical structure of language based on action control and concerned with action goal, context, intention, prediction of action-perception results etc., in which mirror neurons and object affordances play key roles.

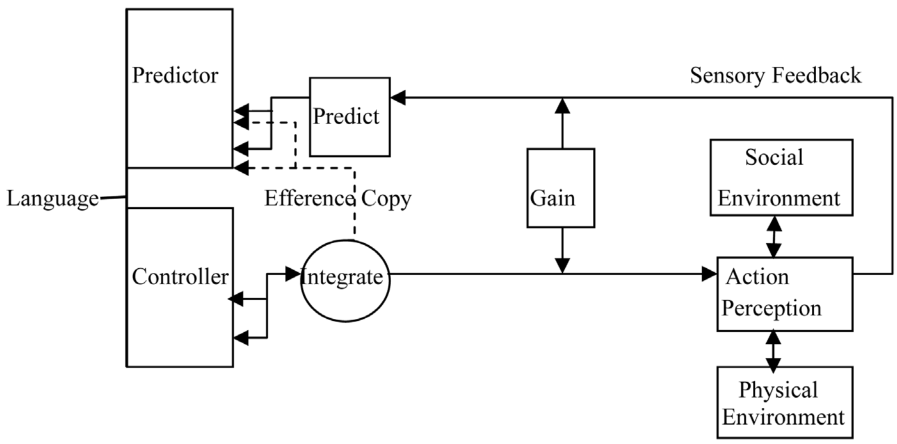

Figure 1. The ABL model.

The neurobiological basis for the language-based modulation of the motor system is most likely related to the properties of a set of neurons, the so-called mirror neurons. Mirror neurons discharge when the individual performs an object-related action and when it observes the same or a similar action done by another individual. This points a mechanism for action or intention understanding [24]. What matters most in driving a mirror neuron's discharge is the goal-related motor act irrespective of the movements required to accomplish it. This evidence led many authors to link mirror neurons to the representation of goals of actions [25] [26]. Fogassi *et al.* (2005) [27] further found that some mirror neurons in PC of monkeys are selective to high-level goals which indicate that the mirror system is sensitive to goals at different levels. The Mirror neurons have a hierarchical organization. High-level goals refer to the neural representation of desired outcomes that have a high rank in the hierarchical organisation of action. Goals refer to the neural representation of desired outcomes that have a lower rank in the behavioural hierarchy and they are more concrete. At a high level of the hierarchy are action intentions. At a lower level, these intentions are realized by integrating set of goal-related motor acts.

This account based-action implies that procedural knowledge is essential to acquisition of object concept as well, thus, information store about object and event should include action planning areas [28] [29]. Some recent neuroimaging data show that the concept of semantic memory not only depends on perception features, but also motor features related to object use [28]-[30]. Knowing what an object is does not mean to possess internal descriptions of this object, but to master a set of sensorimotor skills and possible actions that can be chosen to explore or utilize the object. Object affordances can be defined as the specific possibilities that objects offer for bodily interaction. The concept of affordance was first introduced by Gibson (1966) [31], who observed that the dynamical pattern of the optic flow can be used to guide navigation reactively through the environment. He used affordance to refer to the fact that visual perception of the environment is not just passive perception of objects, but direct perception of the potential actions. Some research has focused on the question whether object affordances are automatically perceived and activated. Several studies suggested that the observation of objects automatically results in the activation of the motor programs [32]. And some studies provided direct evidence for the involvement of dorsal stream is the important motor knowledge for the identification of objects [33] [34]. While other studies suggested that object affordance effects are strongly driven by contextual effects and top-down processing [35] [36]. These studies proposed that object affordance strongly depends on context and intention. This view predicts that there is no context-neutral description of object features and object is defined by the set of possible actions that can be performed on it.

Evidence in neuroscience suggested that mirror system and object affordance are closely connected, nevertheless their functions and interaction are not very clear. Some recent studies suggest a strong involvement of high-level goals in the selection of affordances. These studies show that the kinematics of reach and grasp actions are modulated by the presence of other persons in the experimental setting [37]. We might see that goals play a key role in the selection of affordances, mirror system, and actions at various levels of abstraction. Thus, the hierarchically organized representation of actions in the brain relies on the representation of their goals. Within the dorsal neural pathway, PC and PMC/IFC implement the mirror system encodes action goals and integrates them with high-level goals. Within the ventral neural pathway, TC detects the features of objects; PFC forms high-level goals. And the overall action intention is the goal-state of the ultimate goal-related motor act of the chain and this hierarchical organization is the source of syntax. The mirror neurons in pre-motor and parietal mirror neurons not only code the goal of an executed or observed motor act, but also code the overall action intention [24]. Kilner (2011) [38] suggested that PFC plays a prominent role in the representation of high-level goals and extends it with the notion that "intentions and goals" are represented in PFC at multiple levels of abstraction. Grounded this assumption, we might suggest that, mirror system and object affordance are hierarchically related, in which mirror system is more close to the encoding of goals and intention, and object affordance is more close to goals and execution of actions. Thereby, mirror system and object affordance might be hierarchically organized in the action-based approach, which take advantage of goal and intention to play key role in language at different abstract levels.

4. Action Semantics

The action-based approach claims that action and language are strongly connected and action goal, intention, context, mirror system and object affordance play functional roles in language processing. Action and semantics are strongly connected as well in many related models. Action planning does not only need low-level processes of motor control, but also rely on the use of semantic knowledge [39]-[41]. Accordingly, action semantics implies an interrelated scope, which involves knowledge about the object affordance and action-language interactions. In these models, Action Semantics [42] integrates findings from different domains to be an integrated framework, which proposed that action control and use of object not only need low-level action control, but also semantic knowledge. In Action Semantics model, action semantics involves multimodal object representations and modality-specific sub-systems, representing functional knowledge, manipulation knowledge and the proprioceptive and sensory consequences. Functional knowledge entails knowledge about the use of objects which relates to "what" information. Manipulation knowledge entails motor representations about the bodily with the object which relates to "How" information. And the proprioceptive and sensory consequences associated with the object use might contribute the sensory feedback and modulate the action control. In addition, action intention represents that an action outcome drives the selection of action goals and determine the different subsystems. In turn, action intention is determined by the context (see **Figure 2**). Thereby, action Semantics are hierarchically organized and selectively activated depending on the action goal and intention of the actor and the context.

This Action Semantics model differentiates action hierarchy which reflects a motor level and control hierarchy which involves production of hierarchically structured behavior. Action Semantics proposed that control hierarchy relates to high-level action goal, while action hierarchy relates to action execution. Some recent studies show that high-level action representations can influence low-level motor representation [43] and high-level action intentions can affect the selection of action semantics, thus this interaction of a control and an action hierarchy allows the flexible processing. We have seen that mirror system is more close to the encoding of goals and intention, and object affordance is more close to goals and execution of actions. Thereby, we might integrate object affordance and mirror system in action semantics model grounded in action as illustrated in the following **Figure 2**.

Action Semantics model raises its perspective on the debates regarding object affordance and action goal as well. This model proposes that object affordance is to a strong extent determined by top-down influences related to action intention, action goal and context. Recent studies indicate that different object affordances might activate depending on the action intention and action context, such as intention to grasp or to point [44]. This framework allows for the automatically activation of object affordance, when supra-threshold activation between multimodal areas and modality-specific areas as well. Accordingly, this model of Action Semantics in this way allows both automatic effects of object affordance and goal and intention driven effects.

Jeannerod (1997, 1999, 2006) [45]-[47] have argued for a representational approach to action and the idea that the organization of action derives from the organization of its representational underpinnings. Action semantics pertains to the representation of action, while action pragmatics pertains to the representational foundation of motor control and execution. In a way action semantics deals with declarative knowledge whereas action pragmatics deals with procedural knowledge. Due to this framework of action semantics integrated declarative

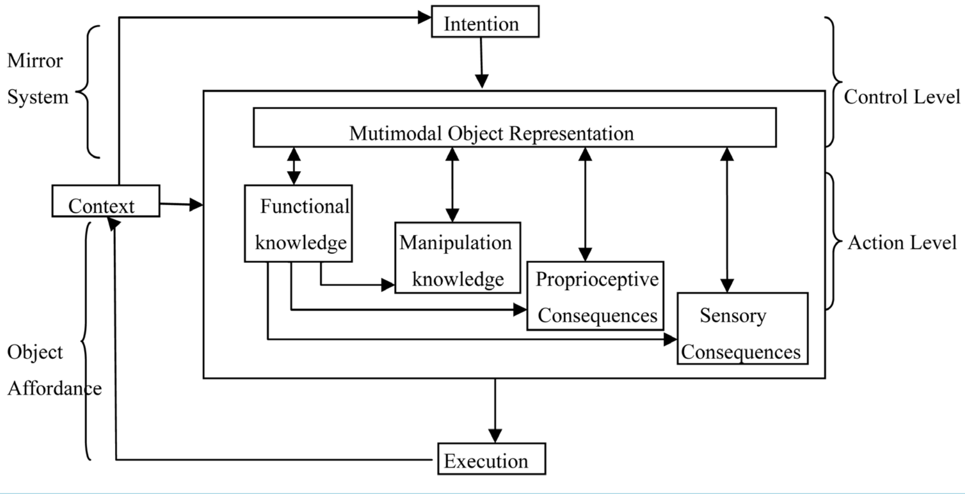

Figure 2. Integrated action semantics model.

(functional; mirror system) and procedural (manipulation; object affordance) action knowledge, this approach challenging the traditional divide between semantics and pragmatics. Cognition is grounded on action and action depends on cognition, thus, understand action needs both semantic and pragmatic representation. A lot of recent research studies show that declarative knowledge might determine the procedural processing, therefore, there exists not only off-line interaction, but on-line interaction between them as well. The processing of verbal and conceptual information may be closely connected to processing of sensory and motor information in the sense that activation of semantic knowledge goes along concomitant activation of sensorimotor knowledge [15] [48]-[53]. And motor control may be closely connected to semantic and conceptual processing in the sense that the kinematics of ongoing movements may be affected by the semantics of concurrently processed words and concepts [54] [55]. All these studies challenge the divide between declarative semantic and procedural pragmatics. We might conclude that action language may affect overt execution and motor expertise may affect action language processing, thus, action control and execution need semantic and pragmatic knowledge at the same time, and action pragmatics and action semantics might draw on a common representational resource. Accordingly, Language and action, semantics and pragmatics are not separated systems, but are closely interconnected and highly interacted to some extent. And the same coding and representational resource of action semantics and action pragmatics might put the resource of joint attention which distinguished human from other animals and opened the door of social cognition.

5. Conclusion

There are a lot of increasing evidences to support the strong links between action and language. The main reason of focusing on the relation between language and action is that the basic function of cognition is the control of action. Action based approach proposed the hierarchical structure of language based on action control and concerned with action goal, context, intention, prediction of action-perception results, mirror neurons and object affordances. Action semantics framework proposed that action control and use of object need not only low-level action control, but also semantic knowledge. Action Semantics are hierarchically organized and selectively activated depending on the action intention of the actor and the context. This framework integrated declarative and procedural action knowledge, thus challenging the traditional divide between semantics and pragmatics. Action control and execution need semantic and pragmatic knowledge at the same time, thereby action pragmatics and action semantics might draw on a common representational resource.

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