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Reply to comment

The scope and limits of action semantics
Reply to comments on ‘Action semantics: A unifying conceptual framework for the selective use of multimodal and modality-specific object knowledge’

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In our target paper [1], we have provided an integrative review of the current state of affairs regarding research on the use of conceptual knowledge for action. In short, we argue that humans have developed declarative and procedural knowledge about objects, i.e. action semantics that enable them to use objects in a purposeful and effective manner. We were impressed by both the quantity and the quality of the commentaries on our position paper. We would like to thank the commentators for their valuable contributions, pointing out supportive evidence for our framework, indicating additional and complementary strands of research in this field and raising important conceptual and theoretical challenges for our proposed model. Here we take the opportunity to briefly indicate how additional lines of research could be integrated in our framework and how potentially conflicting findings could be reconciled.

Joachim Hermsdörfer suggests that the overlap between the kinematics of pantomimed and object-directed actions points towards the existence of a common motor program, while at the same time task context also modulates the low-level features of action execution [2]. The suggestion that the context may exert both an indirect effect (i.e. through a top-down selection of motor programs) and a direct effect on movement execution (e.g. by providing participants with stronger task constraints and sensory feedback through a direct interaction with an object) provides an excellent illustration of the role of context, as proposed in our model of action semantics. A similar role of context on the activation of motor programs is proposed by Anna Borghi [3], who showed that the context (i.e. provided by the task, the inclusion of other objects, semantic information or the presence of other persons) can have a strong influence on the activation of object affordances.

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Borghi makes a valuable and important suggestion to implement our framework in a computational model and to relate it to current developments in robotics [4]. A similar suggestion was made by Michael Masson, who notes that the framework of action semantics does not lead to testable predictions but rather to general suggestions for future experiments [5]. We are aware of this issue and we would like to point out we ourselves and others have proposed computational models to implement the notion of action hierarchies and to model the execution of goal-directed actions [6–8]. At the same time, a big challenge in the field of robotics is to bridge the gap between embodied systems that take the sensorimotor experiences in the real world as the starting point for learning [9,10] and symbolic systems that represent learned knowledge in a symbolic connectionist network [11,12]. The notion of 'action semantics' refers precisely to the interplay between different levels of knowledge representation that enables us to act in the real world. The challenge of implementing such a conceptual model in a computational model is non-trivial and we hope that our framework may guide future researchers working in the field of robotics and artificial intelligence to implement our framework in a model that allows generating testable predictions.

Guy Vingerhoets rightly points out that there is a hemispheric asymmetry between the use of action semantics, which is lateralized to the left hemisphere and is effector-independent, and the online control of movements, which is associated with a bilateral activation of the fronto-parietal action network and is effector-dependent [13]. The asymmetrical neural organization of different components of object-directed actions fits well with the proposed distinction between action goals, which are effector-independent (i.e. the spatial goal location associated with using an object) and action means that are effector-dependent (i.e. the specific way in which an object is grasped; cf. [1]). However, at the same time we would like to note that the neural organization of goals and grips remains a matter of ongoing debate and that the representation of both goal- and grip-related information has been localized to the posterior parietal cortex and the left inferior parietal lobe [14–17]. The observation that the lateralization of action semantics mirrors the left hemispheric specialization for language processing and production has actually resulted in several theoretical proposals regarding the evolutionary origin of these functions [e.g. language could have evolved out of gestural communication; cf. [18]].

A comparable evolutionary argument is put forward by Scott Glover [19], who makes the interesting suggestion that the expansion of the left IPL in humans compared to primates may have supported the co-evolution of semantic and tool use systems and that the need for a highly specialized effector for object manipulation may have driven the development of right-handedness [20]. This observation places the framework of action semantics in an evolutionary perspective and fits well with the finding that the dexterity of human tool use marks a discontinuity between humans and non-human primates [for a recent review of tool use in humans and primates, see [21]]. We concord with the criticism that the distinction between dorsal and ventral streams in our model represents an oversimplification and we are strongly in favor of a more nuanced view on this topic, stressing the interconnectedness of many brain areas that are typically considered part of the dorsal or the ventral stream [see for instance [22]]. We note that the dorsal–ventral distinction is not central to our model (see Fig. 1) and that these labels were merely used to indicate that higher order visual areas that are typically considered 'core regions' of the ventral stream, play an important role in action semantics as well [23,24].

In our review we extensively discuss developmental studies focusing on the acquisition and learning of action semantics. Arthur Glenberg and Tamir Soliman propose a complementary hypothesis, according to which the learning of tool use involves the incorporation of the object in the body representation [25]. This perspective is supported by single-cell studies in monkeys [26,27], studies with neuropsychological patients and behavioral studies in humans, using the cross-modal congruency task as a measure of the multisensory integration of objects in the body representation [28]. In fact, in several studies we have investigated how the use of manipulable objects facilitates body-object integration [29–32], resulting in what Soliman and Glenberg call a joint 'Hand-Tool Body Schema' (HTBS; [33]). For instance, we found that the presentation of manipulable objects (e.g. a cup) compared to non-manipulable objects (e.g. a car) resulted in the extension of peripersonal space around the body, likely related to the retrieval of the sensorimotor programs associated with using these objects [32]. Furthermore, we found that the interaction with a novel haptic robotic interface, enabling people to perform actions at remote locations (e.g. surgeons, space engineers), also resulted in an extension of peripersonal space to the distal location at which the robot was actually performing the movements generated by the participant [29,30]. This finding relates to the comment made by Soliman and Glenberg [33] who discuss the question whether internal forward models involved in tool use code for the proximal or distal effects of tool use. The results of the study with the robotic interface indicate that actions are coded primarily in terms of the distal outcomes of the tool use action – even when there is no direct physical connection between the user and