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Forum Article

Reply to ‘Tool use and dexterity: beyond the embodied theory’

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A R T I C L E I N F O

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In the essay titled ‘Transforming the body-only system into the body-plus-tool system’ (Mangalam & Fragaszy, 2016), we claimed that the traditional notions of tool use in nonhuman animals operationalize the functionality of an object and its effect on the environment and typically do not account for the user's movement with that object. This omission restricts their utility for predicting the occurrence of tool use or explaining tool use as a biological phenomenon. To advance the field, we proposed an embodied theory of tool use with the premise that the body is transformed into a body-plus-tool system when an individual grasps an object and uses it as a tool. Our theory explains the development of a particular form of using a tool in terms of constraints on movement imposed by the user's body, environment and task. It considers dexterity in terms of the spatiotemporal organization of tool use movement, and complexity in terms of the control of the biomechanical degrees of freedom of the body-plus-tool system.

Osiurak and Danel (2018) express concern that our theory overemphasizes the ‘how’ (movement) and neglects the ‘what’ (goal) of tool use. For the authors, the ‘what’ of using a tool implies the user's understanding of the mechanical principles and functional parameters governing the consequences. Osiurak and Danel suggest that we are reviving a ‘motor program’ notion of tool use, a theory that posited that apraxias of tool use (disabilities in using tools that sometimes accompany brain damage in humans) result from impairment of learned motor programs specifying precisely the user's movement while using an object as a tool. They point out that some apraxic patients can reproduce pantomime movements effectively but cannot determine what they have to do to use even a familiar object, such as a hammer or a knife, as a tool. Knowing ‘how’ (i.e. being able to move appropriately) without knowing ‘what’ to do is of little use to people suffering from apraxia. Further, Osiurak and Danel posit three limitations of our theory of tool use: (1) it suggests that using tools is a matter of biomechanical complexity, ignoring the ‘ability to learn or understand physical actions’; (2) it suggests a unilateral link between biomechanical complexity and dexterity in tool use, privileging taxa with higher biomechanical complexity, and (3) it neglects the possibility that individuals with lower biomechanical complexity can improve dexterity through learning.

We thank Osiurak and Danel for their thoughtful consideration of our ideas, and for giving us this opportunity to clarify them. We are particularly glad to do so because we share with these authors an appreciation for foundational theories in psychology and movement science that are applicable to understanding tool use, although we have divergent interpretations of these theories. We refer the interested reader to an expanded treatment of our theory (Fragaszy & Mangalam, 2018).

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MOTOR PROGRAMS

We first want to clarify that our theory does not include the concept of motor programs. We fully agree with Osiurak and Danel that positing a motor program cannot explain adaptable modulation of action to use objects effectively in different ways (for example, the many ways in which we can use a screwdriver). Instead, our theory draws on concepts from movement science used to explain voluntary movement. An accepted consensus in biomechanics and movement science is that ensembles of specific nerves, joints and muscles constitute hypothetical entities called motor synergies (Latash, 2008; Latash, Scholz, & Schöner, 2007; Tuller, Turvey, & Fitch, 1982). These synergies, unlike motor programs, are understood to control voluntary movement under variable conditions. Motor synergies develop and strengthen with practice. Stronger synergies are associated with more efficient movements, and, at a finer scale, strong synergies allow precise modulation of task-relevant movement variables (such as when skilled human knappers modulate the trajectory of the hammer while knapping stones (Rein, Bril, & Nonaka, 2013), an example mentioned by Osiurak and Danel), tailoring action to particular circumstances. Learning a skilled action, including learning to use an object as a tool, involves the development and refinement of motor synergies (Valk, Mouton, & Bongers, 2016; van der Steen & Bongers, 2011).

'WHAT' AND 'HOW'

Returning to Osiurak and Danel's primary concern, that our theory ignores the 'what' of tool use, some background information may illuminate why we structured the theory as we did. We (like Osiurak and Danel) are working from the ecological theory of behaviour (Gibson, 1966, 1977, 1979) which takes the premise that perception and action are inextricably bound together and that perception of affordances (opportunities for action to reach a goal) is direct. Ecological theory posits that an individual's detection of affordances guides his/her actions and, vice versa, actions inform detection and management of affordances. In our understanding, this theory does not recognize a distinction between the 'what' and 'how', as Osiurak and Danel use these terms, of using an object as a tool. In our view, perceiving and acting upon affordances necessarily include both the 'what' (the goal) and the 'how' (the action required to achieve the goal). Note that our understanding of 'affordance' differs somewhat from Osiurak's (2013). This concept was vaguely defined by Gibson (1979) and debates about its definition continue; it is beyond the scope of this piece to take up this debate. We do not agree that the goal of action is to understand the mechanical principles and functional parameters governing the consequences, as Osiurak and Danel appear to imply. Nor is this conception true to Bernstein (1996), the source Osiurak and Danel quote for the distinction between the 'what' and 'how' of action. In Bernstein's words, concerning the 'what' of the task, 'the essence of the task [is to] jump as far as possible, draw as straight a line as possible, hit a tennis ball as close in a desired direction as possible … ' (Bernstein, 1996, p. 234, p. 234). Thus, for Bernstein (1996), as for us, the 'what' is the functional outcome of action at the organismic level, which we think is contained in the concept of affordance. We surmise that Osiurak and Danel's conception of the 'what' of an action as 'understanding' something is grounded in contemporary representational theories of cognition, rather than in Bernstein's works (Bernstein, 1967, 1996). It is worth explaining to those unfamiliar with Bernstein's life and publications that he was a Russian neurophysiologist writing in the 1920s–1940s. His works only became known outside Russia following their translation into English and other languages in the 1960s. His work published in 1996 (and quoted here) was written decades earlier and translated and published posthumously. Thus, the cognitive spin on Bernstein's phrasing about the 'what' and 'how' of action does not originate with Bernstein.

COMPLEXITY AND DEXTERITY

Osiurak and Danel (2018) are correct that, according to our theory, tool use involves controlling the degrees of freedom of the body-plus-tool system, which differ from the body-only system. However, they are incorrect that, according to our theory, a greater number of degrees of freedom in the body-plus-tool system necessarily implies more dexterous tool use (and therefore primates, with hands, are necessarily more dexterous tool users than other orders with bodies that provide fewer degrees of freedom of movement with a grasped object). Here we think they mistook dexterity as synonymous with complexity. We wrote: 'The greater the DoFs [degrees of freedom] of the body-only system, the greater should be the ways in which a tool can reduce and redistribute them; the greater the DoFs of the body-only system, the greater should be the complexity in the use of that tool as measured in terms of the control of the DoFs of the body-plus-tool system' (p. 119). Theoretically, animals of any morphology are equally likely to use objects as tools, so long as they can grasp an object, in the mouth, foot, trunk or any other body part. Dexterity is not measured by the number of degrees of freedom in the system but rather by how effectively an action is executed across varying situations. One could have a complex system with many degrees of freedom, and act with little dexterity (as is often the case for a novice learning a new skill). Alternatively, one could have a simpler system with fewer degrees of freedom and act with great dexterity. For example, crows probing into a hole in a tree trunk using a stick held in their beak appear to use the probe dexterously (although their dexterity has not yet been measured). The number of degrees of freedom in the system is not a defining feature of the crow's dexterity. We did mention (p. 119–120) that crows are likely to have less perceptual information available to them about the probe and its movements relative to their body and to the target surface than would a primate holding the probe in a hand and looking at the probe and the target with binocular vision. The differences would result from the differences in the sensory systems of birds' beaks and primates' hands and the position of the probe and the target with respect to the head and eyes of both animals. We predicted that the difference between the crow and primate in the information available through movement would affect how the two species use probes, with generally an advantage to primates. This prediction rests on an argument about perceptual systems, not biomechanical degrees of freedom.

Osiurak and Danel understood correctly that our theory implies a directional link between the biomechanical complexity of a [body] system and the maximum possible level of dexterity in using a tool. Assuming that a primate holding a stick in the hand possesses more degrees of freedom in the body-plus-tool system than does a bird holding a stick in the beak, we predict that the primate has the potential to reach greater maximum dexterity than the bird (and we also predicted, as noted above, that differences in the perceptual systems of birds and primates would lead to birds gaining less precise perceptual information as they are acting with a probe.) We note that we need to agree upon objective, quantitative measures of dexterity that apply across diverse body systems to test this prediction, and others that follow from our theory. Meanwhile, it is important to keep in mind that an individual with a biomechanically more complex body will not necessarily have

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