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Forum Article

Tool use and dexterity: beyond the embodied theory

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Traditionally, the notion of tool refers to any external, manipulable object that is used to make changes to other objects in the environment (Osiurak, Jarry, & Le Gall, 2010; Shumaker, Walkup, & Beck, 2011). Mangalam and Fragaszy (2016a) recently questioned this traditional definition because it ignores the analysis of dexterity involved in tool use. In response, they offered an embodied theory of tool use (also called degree of freedom framework) which stresses that the essence of tool use behaviour lies mainly in the ability of any given biomechanical system to control the degrees of freedom of the body-plus-tool system differently to the body-only system. Based on this theory, they formulated interesting predictions, such as the idea that the dexterity of the body-only system should limit the dexterity of the body-plus-tool system. This perspective is clearly new in the literature on animal tool use, and some of the predictions proposed, such as the aforementioned one, could even find resonance in the field of human tool use. However, the main limitation of the embodied theory offered by Mangalam and Fragaszy may be to place exaggerated emphasis on the transformation of degrees of freedom, thereby underestimating the possibility that dexterity is also a matter of understanding functional parameters of the task.

WHAT IS DEXTERITY?

As stressed by Bernstein (1996), dexterity refers to the exploitation of biomechanical forces in an optimal manner (i.e. optimization of resources). For instance, a hammering movement is dexterous, when the user discards all actions not necessary for the production of hammer velocity. So, energy optimization can be seen as an index of expertise. In line with this, it has been shown that expert stone knappers use considerably shorter trajectories than novices (e.g. Bril, Rein, Nonaka, Wenban-Smith, & Dietrich, 2010). However, dexterity is not only a matter of ‘movements per se’. Rather, for Bernstein (1996, p. 234), it is fundamental to ‘[T]hink not only about the movements themselves, but about the essence of the task … One must concentrate on the ‘what’ of the movement, the ‘hows’ come later by themselves’.

The ‘what’ corresponds to what is also called the functional parameters of the task (see Bril et al., 2010). For stone knapping, these functional parameters are the angle of blow or the point of percussion, namely, all the parameters that constitute the understanding of the mechanical principle underlying stone knapping. As mentioned by Mangalam and Fragaszy (2016a), the gradual refinement of nut cracking by bearded capuchin monkeys, *Sapajus libidinosus*, during ontogeny is a good illustration of development of dexterity in a tool use activity (see also Mangalam & Fragaszy, 2015, 2016b).

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TOOL USE IN HUMANS: FROM THE 'HOWS' TO THE 'WHAT' OF THE MOVEMENT

Most of our understanding of the neurocognitive bases of human tool use comes from left brain-damaged patients with tool use disorders, also called apraxia of tool use (De Renzi & Lucchelli, 1988; Osiurak & Rossetti, 2017). These patients can show severe difficulties in using everyday tools, such as attempting to cut a tomato with a comb or rubbing instead of pounding a nail with a hammer. For a century, it has been, and still is, considered that these difficulties result from impairment of learned motor programs specifying how the hand has to interact with the tool (e.g. for a hammering movement, a broad oscillation from the elbow joint and a power handgrip are critical; van Elk, van Schie, & Bekkering, 2014; Heilman, Rothi, & Valenstein, 1982; Rothi, Ochipa, & Heilman, 1991). In a way, this perspective focuses on the 'hows' of the movement, considering that tool use is first and foremost based on the learning of the movement associated with a tool, thereby neglecting the 'what', namely, the mechanical action between the tool and the corresponding object.

Doubt has been cast on the existence of these so-called motor programs (Goldenberg, 2009; Osiurak, Jarry, & Le Gall, 2011; for discussion, see Hermsdörfer, 2014). For instance, Goldenberg (2013) stressed the high variability of handgrips, movement parameters and spatial orientations that can be used to manipulate everyday tools, such as a screwdriver, which itself can vary in its physical features. The problem is that learned motor programs can instantiate only one particular action. Therefore, for him, these motor programs are not a prerequisite for successful tool use. Rather, the role of motor control is precisely to select the movements that are the most suited to optimize biomechanical energy in a given context. Importantly, this optimization cannot occur if the user is not able to determine the key functional parameters of the task, that is, the 'what' of the movement. In other words, Goldenberg (2013) criticizes the motor program hypothesis of tool use, suggesting that it places disproportionate emphasis on the movement per se.

Recent advances also contribute to revising this motor program-based approach. Significant evidence has shown a strong link in left brain-damaged patients between the ability to use everyday tools and novel tools to solve mechanical problems (e.g. folding a wire to make a hook useful for extracting a target from a box; Goldenberg & Hagmann, 1998b; Hartmann, Goldenberg, Daumüller, & Hermsdörfer, 2005; for reviews, see Osiurak, 2014; Osiurak & Badets, 2016). These findings indicate that apraxia of tool use is a matter not only of manipulation, but also of selecting the appropriate physical properties of tools and objects for a given mechanical action. Neuropsychological and neuroimaging data also demonstrate that the use of both everyday and novel tools involve the same brain area, namely, the left inferior parietal cortex (Goldenberg & Spatt, 2009; Reynaud, Lesourd, Navarro, & Osiurak, 2016). Finally, it has also been shown that patients with apraxia of tool use can improve their use of everyday tools after weeks of training. However, they are unable to transfer what they learn in a given situation to another one (e.g. making coffee instead of making tea; Goldenberg, Daumüller, & Hagmann, 2001; Goldenberg & Hagmann, 1998a; see Osiurak, 2017).

Taken together, these findings suggest that human tool use might be based on specific technical reasoning skills, allowing humans to reason about physical properties of tools and objects (see Osiurak & Badets, 2016; Osiurak & Heinke, 2018; Osiurak, Rossetti, & Badets, 2017). These skills are fundamental to determine the mechanical action involving the tool and the corresponding object, that is, the 'what' of the movement. In this framework, the role of motor control is to adapt movements in order to optimize biomechanical energy based on the representation of the mechanical action generated by technical reasoning (the 'hows' of the movement). In a way, these recent advances contribute to shifting the focus of research on human tool use from the 'hows' to the 'what' of the movement.

LIMITATIONS OF THE EMBODIED THEORY

Having said this, the next question is what these recent advances in human tool use tell us about the embodied theory offered by Mangalam and Fragaszy (2016a)? Here, we discuss three main limitations, which could prevent this theory from grasping the complexity of tool use behaviour.

The first limitation is that this theory implicitly suggests that tool use is first and foremost a matter of biomechanical complexity/manipulation (i.e. focusing on the 'hows' component). According to Mangalam and Fragaszy (2016a), dexterous tool use is based on the ability of any given biomechanical system to control the degrees of freedom of the body-plus-tool system differently to the body-only system. So, the more degrees of freedom a biomechanical system has, the more dexterous this system. The corollary is that animals with hands are necessarily more dexterous tool-users than animals without hands. This rationale is confirmed by Mangalam and Fragaszy (2016a), who questioned the idea that sponge use by dolphins is an instance of tool use, because they do not control the rostrum-plus-sponge system differently from the rostrum-only system. In the same vein, they suggested: 'It is likely that proficient [New Caledonian] crows cannot use a probe as dexterously as chimpanzees can' (p. 120). The problem is that, in this framework, animals without hands might be progressively and systematically considered as not being tool-users, because their biomechanical system does not allow them to fit the criterion of 'differential control of degrees of freedom'. For instance, the issue is which kind of object a dolphin can use to be considered as a tool? As a matter of fact, tool use by dolphins or crows precisely demonstrates that despite a biological body not well equipped for manipulation, such species can show tool use behaviour. Such instances are fascinating because they inform us that the key aspect underlying tool use is not the degree of biomechanical complexity (the 'hows' component) but rather the ability to learn or understand physical actions, that is, the 'what' of the tool use action. Mangalam and Fragaszy (2016a) acknowledge that some aspects of the use and manufacture of tools are beyond the embodied approach, such as how New Caledonian crows, *Corvus moneduloides*, are able to select probes of appropriate length or diameter. Nevertheless, by focusing on the biomechanical complexity, the embodied theory can revive what has been initially thought in neuropsychological literature, namely, tool use is a matter of manipulation but not of understanding/learning the mechanical relationships between tools and objects.

Perhaps the embodied theory of Mangalam and Fragaszy (2016a) is 'too embodied' and must also stress the need for systematically completing the assessment of tool behaviour with additional experiments in order to specify what animals understand when using tools. For instance, in the case of sponge use by dolphins, the critical issue is whether dolphins understand the mechanical action between the sponge and environmental objects (e.g. Can dolphins select different sponges according to the physical properties of the environment?). If such evidence were available, this would challenge the embodied theory's criterion of 'differential control of degrees of freedom' as critical for characterizing behaviour as tool use. Instead, this would suggest that, in some cases, the body itself is 'built' in the right way allowing the development of skilled tool use (e.g. New Caledonian crows compared to other bird species; Troscianko, von Bayern, Chappell, Rutz, & Martin, 2012). However, in other cases, the ability to understand the 'what' might

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