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1 **Tool Use and Dexterity: Beyond the Embodied Theory**

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9 **Keywords**

10 Apraxia; Biomechanical Complexity; Motor Control; Movement; Technical Reasoning

11

12

Introduction

13 Traditionally, the notion of tool refers to any external, manipulable object that is
14 used to make changes to other objects in the environment (Osiurak, Jarry, & Le Gall,
15 2010; Shumaker, Walkup, & Beck, 2011). Mangalam and Frigaszy (2016a) recently
16 questioned this traditional definition on the ground that it ignores the analysis of
17 dexterity involved in tool use. In response, they offered an embodied theory of tool use
18 (also called degree of freedom framework) which stresses that the essence of tool use
19 behavior mainly lie in the ability of any given biomechanical system to control the
20 degrees of freedom of the body-plus-tool system differently compared to the body-only
21 system. Based on this theory, they formulated interesting predictions, such as the idea
22 that the dexterity of the body-only system should limit the dexterity of the body-plus-
23 tool system. This perspective is clearly new in the literature on animal tool use, and
24 some of the predictions proposed – such as the aforementioned one – could even find
25 resonance in the field of human tool use. However, the main limitation of the embodied
26 theory offered by the authors may be to place exaggerated emphasis on the
27 transformation of degrees of freedom, thereby underestimating that dexterity is also a
28 matter of understanding functional parameters of the task.

29

What is dexterity?

30 As stressed by Bernstein (1996), dexterity refers to the exploitation of
31 biomechanical forces in an optimal manner (i.e., optimization of resources). For
32 instance, a hammering movement is dexterous, when the user discards all actions not
33 necessary for the production of hammer velocity. So, energy optimization can be seen as
34 an index of expertise. In line with this, it has been shown that expert stone knappers use

35 considerably shorter trajectories compared to novices (e.g., Bril, Rein, Nonaka, Wenban-
36 Smith, & Dietrich, 2010). However, dexterity is not only a matter of “movements per se”.
37 Rather, for Bernstein (1996), it is fundamental to:

38 “[T]hink not only about the movements themselves, but about the essence of the task... One must
39 concentrate on the ‘what’ of the movement, the ‘hows’ come later by themselves” (p. 234).

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

47 **Tool use in humans: From the ‘hows’ to the ‘what’ of the movement**

48 Most of our understanding of the neurocognitive bases of human tool use comes
49 from left brain-damaged patients with tool use disorders, also called apraxia of tool use
50 (De Renzi & Lucchelli, 1988; Osiurak & Rossetti, 2017). These patients can show severe
51 difficulties in using everyday tools, such as attempting to cut a tomato with a comb or
52 rubbing instead of pounding a nail with a hammer. For a century, it has been – and still is
53 – considered that these difficulties result from impairment of learned motor programs
54 specifying how the hand has to interact with the tool (e.g., for a hammering movement, a
55 broad oscillation from the elbow joint and a power handgrip are critical; Heilman, Rothi,
56 & Valenstein, 1982; Rothi, Ochipa, & Heilman, 1991; van Elk, van Schie, & Bekkering,
57 2014). In a way, this perspective focuses on the ‘hows’ of the movement, considering
58 that tool use is first and foremost based on the learning of the movement associated

59 with a tool, thereby neglecting the ‘what’, namely, the mechanical action between the
60 tool and the corresponding object.

61 Doubt has been cast on the existence of these so-called motor programs
62 (Goldenberg, 2009; Osiurak, Jarry, & Le Gall, 2011; for discussion, see Hermsdörfer,
63 2014). For instance, Goldenberg (2013) stressed the high variability of handgrips,
64 movement parameters, and spatial orientations that can be used to manipulate everyday
65 tools, such as a screwdriver, which itself can vary in its physical features. The problem is
66 that learned motor programs can instantiate only one particular action. Therefore, for
67 him, these motor programs are not a necessary prerequisite for successful tool use.
68 Rather, the role of motor control is precisely to select the movements that are the most
69 suited to optimize biomechanical energy in a given context. Importantly, this
70 optimization cannot occur if the user is not able to determine the key functional
71 parameters of the task, that is, the ‘what’ of the movement. In other words, Goldenberg
72 (2013) criticizes the motor program hypothesis of tool use, suggesting that it places
73 disproportionate emphasis on the movement per se.

74 Recent advances also contribute to revise this motor program-based approach.
75 Significant evidence has shown a strong link in left brain-damaged patients between the
76 ability to use everyday tools and novel tools to solve mechanical problems (e.g., folding a
77 wire to make a hook useful for extracting a target out from a box; Goldenberg &
78 Hagmann, 1998b; Hartmann, Goldenberg, Daumüller, & Hermsdörfer, 2005; for reviews,
79 see Osiurak, 2014; Osiurak & Badets, 2016). These findings indicate that apraxia of tool
80 use is not only a matter of manipulation, but also of selecting the appropriate physical
81 properties of tools and objects for a given mechanical action. Neuropsychological and
82 neuroimaging data also demonstrate that the use of both everyday and novel tools
83 involve the same brain area, namely, the left inferior parietal cortex (Goldenberg &

84 Spatt, 2009; Reynaud, Lesourd, Navarro, & Osiurak, 2016). Finally, it has also been
85 shown that patients with apraxia of tool use can improve to use everyday tools after
86 weeks of training. However, they are unable to transfer what they learnt in a given
87 situation to another one (e.g., making coffee instead of making tea; Goldenberg &
88 Hagmann, 1998a; Goldenberg, Daumüller, & Hagmann, 2001; see Osiurak, 2017).

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

99 **Limitations of the embodied theory**

100 Having said this, the next question is what these recent advances on human tool
101 use tell us with regard to the embodied theory offered by Mangalam and Frigaszy
102 (2016a)? In the following lines, we discuss three main limitations, which could prevent
103 this theory from grasping the complexity of tool use behavior.

104 The first limitation is that this theory implicitly suggests that tool use is first and
105 foremost a matter of biomechanical complexity/manipulation (i.e., focus on the ‘hows’
106 component). According to Mangalam and Frigaszy (2016a), dexterous tool use is based
107 on the ability of any given biomechanical system to control the degrees of freedom of the

108 body-plus-tool system differently compared to the body-only system. So, the higher the
109 number of degrees of freedom a biomechanical system has, the more dexterous this
110 system. The corollary is that animals with hands are necessarily more dexterous tool
111 users than animals without hands. This rationale is confirmed by Mangalam and
112 Frigaszy (2016a), who questioned the idea that sponge use by dolphins is an instance of
113 tool use, because they do not control the rostrum-plus-sponge system differently from
114 the rostrum-only system. In the same vein, they suggested: “It is likely that proficient
115 [New Caledonian] crows cannot use a probe as dexterously as chimpanzees can” (p.
116 120). The problem is that, in this framework, animals without hands might be
117 progressively and systematically considered as non-tool-users, because their
118 biomechanical system does not allow them to fit the criterion of “differential control of
119 degrees of freedom”. For instance, the issue is which kind of object a dolphin can use to
120 be considered as a tool? As a matter of fact, tool use by dolphins or crows precisely
121 demonstrates that despite a biological body not well equipped for manipulation, such
122 species can show tool use behavior. Such instances are fascinating because they inform
123 us that the key aspect underlying tool use is not the degree of biomechanical complexity
124 (the ‘hows’ component) but rather the ability to learn or understand physical actions,
125 that is, the ‘what’ of the tool-use action. Mangalam and Frigaszy (2016a) acknowledge
126 that some aspects of the use and manufacture of tools are beyond the embodied
127 approach, such as how New Caledonian crows are able to select probes of appropriate
128 length or diameter. Nevertheless, by focusing on the biomechanical complexity, the
129 embodied theory can revive what has been initially thought in neuropsychological
130 literature, namely, tool use is a matter of manipulation but not of
131 understanding/learning the mechanical relationships between tools and objects.

132 Perhaps the embodied theory of Mangalam and Frigaszy (2016a) is “too
133 embodied” and must also stress the need of systematically completing the assessment of
134 tool behavior with additional experiments in order to specify what animals understand
135 when using tools. For instance, in the case of sponge use by dolphins, the critical issue is
136 whether dolphins understand the mechanical action between the sponge and
137 environmental objects (e.g., Can dolphins select different sponges according to the
138 physical properties of the environment?). If such evidence were available, this would
139 challenge the embodied theory’s criterion of “differential control of degrees of freedom”
140 as critical to characterize behavior as tool use. Instead, this would suggest that, in some
141 cases, the body itself is “built” in the right way allowing the development of skilled tool
142 use (e.g., New Caledonian crows compared to other bird species; Troscianko, von
143 Bayern, Chappell, Rutz, & Martin, 2012). However, in other cases, the ability to
144 understand the ‘what’ might very well obviate the need for greater dexterity (as with the
145 rostrum of dolphins).

146 The second limitation concerns the unilateral link drawn between biomechanical
147 complexity and tool use. For Mangalam and Frigaszy (2016a), the biomechanical
148 complexity of a system is critical to the degree of dexterity in tool use. However, the
149 problem is that this hypothesis, if true, is discussed by the authors only in light of tool-
150 using species, thereby overlooking how it can work with non-tool-using species. Indeed,
151 many nonhuman primates do not use tools despite the great biomechanical complexity
152 associated to the hand and bimanual coordination. In the same respect, only few birds or
153 mammals show tool use behavior although their biological equipment is relatively
154 similar to those using tools. So, even if a certain link could be drawn between
155 biomechanical complexity and tool use, this does not resolve the issue of why some
156 animals can use tools whereas others with relatively similar morphological features do

157 not. Again, this reveals the limitation of the embodied theory, which by focusing on the
158 'hows' component somewhat overlooks the perhaps most important component of tool
159 use, the 'what' component.

160 The third limitation concerns the feasibility of the hypotheses developed.
161 According to the embodied theory, it could be interesting to compare the level of
162 dexterity in tool use based on the differential control of degrees of freedom between the
163 body-only system and the body-plus-tool system. Nevertheless, dexterity is defined as
164 the ability to optimize the mechanical energy during a purposeful action (Bernstein,
165 1967). This aspect is independent from the biomechanical complexity of the system. For
166 instance, dolphins can become dexterous sponge users if they are able to improve the
167 orientation of the sponge relatively to barred sand perch. Capuchins become more
168 dexterous if they are able to orient stone hammers in a more appropriate manner to
169 crack nuts. In this vein, even a biomechanical system with a low degree of freedom can
170 improve its dexterity if it progressively learns how to optimize mechanical energy to
171 perform a given action. A good illustration of this aspect is the famous scene of the
172 classic 1932 movie "Freaks" by Tod Browning, depicting an amelic man who opens a
173 matchbook, lights a cigarette and smoke it with only his mouth. This scene shows the
174 incredible ability of this man to carry out the appropriate movements, avoiding losing
175 energy in executing useless and awkward movements. The opposite pattern
176 corresponds to patients with motor apraxia who can do ineffective movements to grasp
177 and handle objects, despite the high degree of freedom of their biomechanical system. In
178 this context, the critical issue is not to compare "objectively" how species possessing
179 different biomechanical complexities can perform tool use action (e.g., measuring the
180 time needed to solve a tool use task). Rather, if dexterity is at the heart of the

181 investigation, then the focus has to be on the learning curves in order to grasp the ability
182 of the species to improve its dexterity over time.

183 **Conclusion**

184 The embodied theory offered by Mangalam and Frigaszy (2016a) opens new
185 interesting avenues for the study of tool use in nonhuman animals, but also in humans.
186 They introduced the problem of motor control in the literature of animal tool use, which
187 has been largely overlooked so far. Nevertheless, this theory may place exaggerated
188 emphasis on the role of biomechanical complexity in tool use ('hows' component),
189 somewhat ignoring the key role of functional parameters in tool use ('what' component)
190 and that dexterity and biomechanical complexity must not be confounded. In a way, this
191 approach is very close to classical neuropsychological models, which have tended to
192 consider that the learning of motor programs is necessary to use tools, and not the
193 understanding of the underlying mechanical action. Yet, to paraphrase Goldenberg
194 (2013), tool use is the cognitive side of motor control. In line with this, the risk with the
195 embodied theory by Mangalam and Frigaszy (2016a) is that it conceives only the
196 biomechanical side of motor control involved in tool use, and not its cognitive side. To
197 conclude, perhaps a more integrative model is needed, wherein the embodied theory
198 might address the 'hows' component and an additional theory on how animals solve
199 physical problems by using tools might focus on the 'what' component. Such a model
200 might be an ideal framework for the development of studies on animal, but also human
201 tool behavior, allowing us to tackle the fascinating issue of the evolutionary and
202 ecological function of each component (for discussion on this aspect, see Osiurak, 2017).

203

204

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211

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