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Disembodying (Tool-Use) Action Understanding

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The idea that the understanding of others' actions is embodied by our sensory/motor systems is popular in current theories of cognition. The discovery of mirror neurons has contributed to this popularity. The three-level framework of Thompson et al. (2019; i.e., action identification, goal identification, intention identification) offers a comprehensive view of the role played by mirror neurons in action understanding. In this framework, mirror neurons are involved only in action identification (i.e., the identification of the observed motor action) and not in goal identification and intention identification. Here, we proposed to extend this framework to an aspect commonly overlooked by studies on mirror neurons: Tool use. We will not discuss the intention identification level, which certainly needs specific cognitive skills (i.e., mentalizing). We will focus on the question of whether the understanding of others' tool-use actions is supported by information provided by observed motor actions.

The observation of tool-use actions provides two sources of information. The first concerns the motor action, linking the model's hand and the tool (i.e., hand-tool relationship; e.g., grasping a hammer with a power grip). The second concerns the mechanical action, linking the tool and the object (i.e., tool-object relationship; e.g., using a hammer with a nail). This distinction somewhat mirrors the two lower levels of Thompson et al.'s (2019) framework (i.e., action identification and goal identification, respectively). Embodied cognition accounts commonly assume that modality-specific systems are involved in the representation of conceptual knowledge: "Viewing an object immediately activates the appropriate hand shape for using it [...]. Seeing a car key activates a precision grip for grasping and turning (Barsalou et al., 2003; p. 86). In line with this, it has been suggested that tool use is based on the storage of specific motor programs containing information about the motor action carried out by the hand and the arm to manipulate a given tool (i.e., focus on hand-tool relationship). These

programs are also involved in the observation of others' tool-use actions, allowing the observer, through a "mirror-neuron-like" mechanism, to understand the observed tool-use action (Buxbaum et al., 2005).

We recently conducted a meta-analysis on neuroimaging studies that challenged this perspective (Reynaud et al., 2019; **Figure 1**). We categorized the neuroimaging studies into two categories: Non-tool-use action observation (i.e., involving motor action only) and tool-use action observation (i.e., involving motor action and mechanical action). Our findings confirmed the activation of brain areas classically reported in studies on action observation (e.g., intraparietal sulcus, premotor cortex). More interestingly, the contrast *tool-use action observation minus non-tool-use action observation* revealed activation of only the left inferior frontal gyrus and the area PF within the left inferior parietal lobe. At first glance, the activation of the area PF reported in this meta-analysis could be interpreted as evidence for a mirror-neuron-like mechanism involving the aforementioned tool-use motor programs. This interpretation is nevertheless difficult to sustain for several reasons.

< Insert **Figure 1** about here >

First, the contrast *tool-use action observation minus non-tool-use action observation* allowed us to isolate the observed mechanical action. However, tool-use motor programs are thought to contain information about the motor action, and not the mechanical action. Therefore, these programs are not appropriate candidates to explain brain activation in this contrast given that it concerns specifically the mechanical action and not the motor action. Moreover, the activation of the area PF found in this meta-analysis was also reported in another neuroimaging meta-analysis on tool-use action understanding (Reynaud et al., 2016; **Figure 1**) in a non-observational context (i.e., the stimuli were pictures of tools and objects and not video-clips of someone using a tool

with an object as in Reynaud et al., 2019). This other meta-analysis revealed that the left area PF was activated when participants had to focus on the mechanical action between a tool and an object (i.e., tool-object relationship). Again, this finding is difficult to interpret in terms of motor programs because of the absence of any “motor” information. Instead, this suggests that the left area PF might be involved when people attempt to understand mechanical actions between tools and objects whatever the context (i.e., non-observational or observational). This also confirms neuropsychological evidence indicating that damage to the left inferior parietal lobe – and presumably the area PF – generates tool-use disorders, characterized by difficulties in performing appropriate mechanical actions or in selecting appropriate tools (i.e., tool-object relationship; Goldenberg and Spatt, 2009).

A potential interpretation of the activation of the left area PF in the observational tool-use context is that this brain area is engaged in the ability to reason about physical object properties. This is referred to as the technical-reasoning hypothesis (Osiurak and Reynaud, in press). This reasoning is not specific to the observational context. When someone intends to solve a physical problem by using tools, she or he engages in this reasoning to generate the appropriate mechanical actions useful to solve the problem. The same process is also at work when someone observes another individual using tools: The observer reasons about the observed mechanical actions, leading her or him to generate predictions about what is about to be done by the model. In a way, this interpretation completes the Thompson et al.’s (2019) intermediate level (i.e., goal identification), suggesting that the understanding of others’ tool-use actions requires additional cognitive skills, which are neither based on motor information/programs nor on the activity of mirror neurons.

The crucial question is whether the observation of tool-related motor actions contributes to understand others' tool-use actions. Theoretical work is needed to explain how motor information that focuses on hand-tool relationships may be helpful to understand mechanical actions (i.e., tool-object relationships), notably if one agrees that an additional cognitive process such as technical reasoning is specifically engaged at this level. Furthermore, it remains to be demonstrated that the observation of tool-related motor actions *directly* activates the same motor actions in the observer's motor-control system. An alternative proposal is that the observer's technical-reasoning skills allow generating a "representation" of what the model is doing or about to do with tools, leading the observer' motor-control system to anticipate the most economical motor actions to do so (i.e., emulation-like process). Simply, given that the observer and the model are subjected to the same biomechanical constraints, the same motor actions are selected, in turn creating the illusion that the observer's motor actions are *directly* activated by the model's motor actions. This proposal is in line with Thompson et al.'s (2019) framework, assuming that mirror neurons might be, at best, concerned by action identification, but should play a minor role in tool-use action understanding at the goal level. In other words, contrary to other domains (e.g., visual perception of biological motion; Bidet-Ildei et al., 2011; Calvo-Merino et al., 2005), tool-use action understanding might be much more disembodied as commonly assumed.

To conclude, we would like to discuss the dynamics of the three levels of Thompson et al.'s (2019) framework. The question is whether the three levels are regulated by a cascade mechanism (e.g., intention identification→goal identification→action understanding) with potential feedback loops or whether they are systematically activated in parallel, for instance. This overlooked aspect is nevertheless critical to modeling the neurocognitive bases of action understanding. The technical-

reasoning hypothesis assumes that the understanding of mechanical actions (i.e., the goal identification level in Thompson et al.'s terms) is central for tool-use action understanding not only when people use tools but also when they observe others using tools (Osiurak and Reynaud, in press). On the one hand, this hypothesis predicts that we need first to understand the mechanical actions involved in order to then select the appropriate motor actions. This prediction was confirmed by a recent eye-tracking study indicating that, when participants are presented with tool-object pairs, they first pay attention to the part of the tool useful to perform a mechanical action with the object (e.g., the head of a hammer) and then to the manipulative part of the tool (i.e., the handle; Federico and Brandimonte, 2019). On the other hand, the technical-reasoning hypothesis predicts that we cannot infer others' mental states (i.e., the intention identification level in Thompson et al.'s terms) without understanding first the mechanical actions they attempt to perform. In this way, the technical-reasoning hypothesis can also contribute to the development of theoretical and empirical research in order to explore the dynamics of the different levels of action understanding proposed by Thompson et al. (2019) as well as the potential central role of the goal identification level beyond the specific context of tool use.

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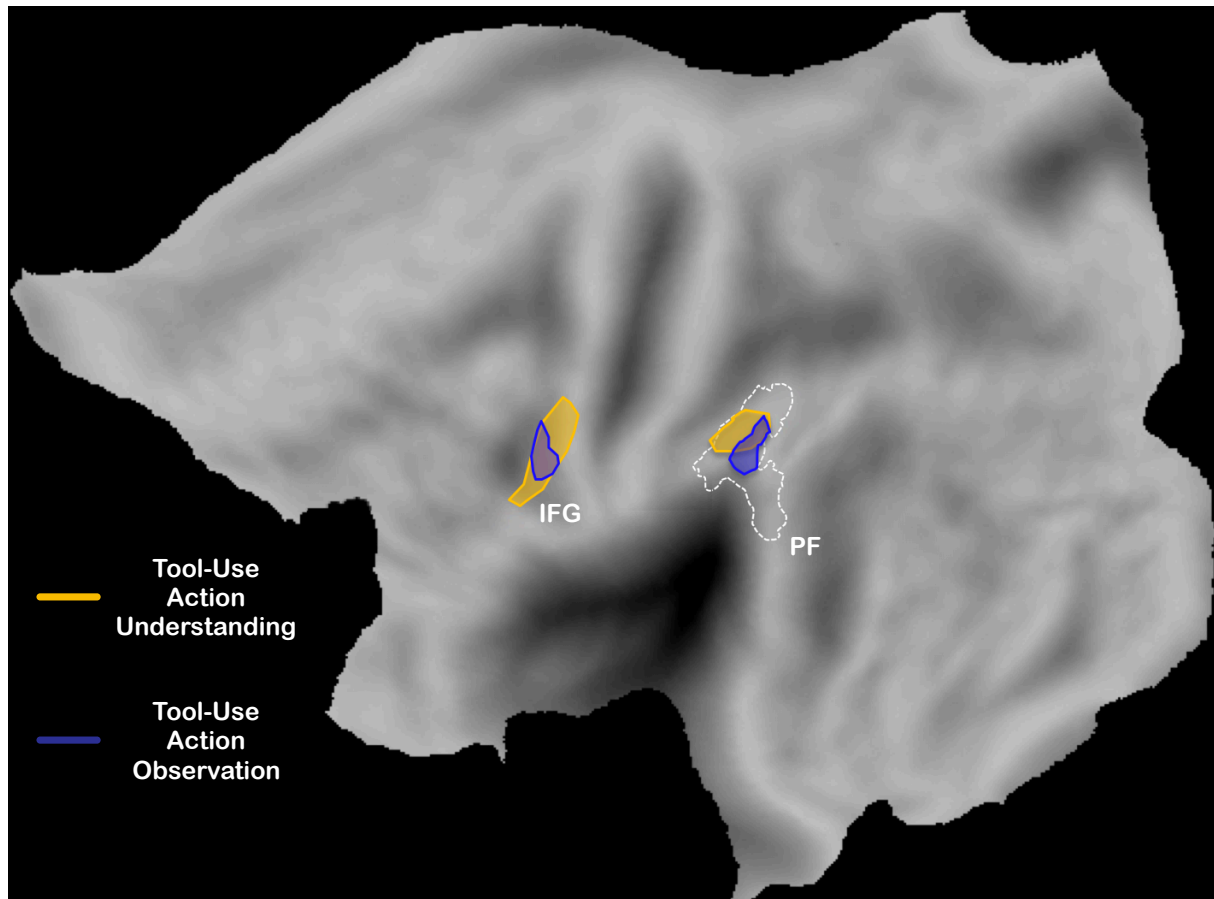


Figure 1. Neural bases of tool-use action understanding and tool-use action observation. The figure depicts the key findings reported in two neuroimaging meta-analyses including different studies. Tool-use action understanding (Orange; Reynaud et al., 2016): The key finding reported here is based on an analysis that included studies in which healthy participants had to focus on the appropriateness of the mechanical action presented (i.e., tool-object relationship). The stimuli used were pictures of tools and objects and not video-clips of someone using a tool with an object. Tool-use action observation (Blue; Reynaud et al., 2019): The key finding reported here is based on an analysis that included studies in which healthy participants had to observe tool-use actions (e.g., someone using a hammer with a nail) or non-tool-use actions (e.g., someone grasping a hammer or a neutral object). Stimuli were video-clips of individuals performing these actions. For tool-use actions, participants could observe not only the motor action performed by the individual (i.e., hand-tool relationship) but also the mechanical action between the tool and the object (i.e., tool-object relationship). By contrast, for non-tool-use actions, participants could observe only the motor action performed by the individual (i.e., hand-tool/object relationship). Therefore, the contrast *tool-use action observation minus non-tool-use action observation* allowed to identify the brain areas specifically involved in the observation of mechanical actions. The activations shown here correspond to this contrast. Interestingly, both the area PF within the left inferior parietal lobe and the left Inferior Frontal Gyrus (IFG) were preferentially activated in these two meta-analyses, suggesting that a common neurocognitive process is at work during tool-use action understanding and tool-use action observation.