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Research report

Are tool properties always processed automatically? The role of tool use context and task complexity

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ABSTRACT

Previous work with healthy adults supports the idea that perception of the orientation of a tool's handle may automatically activate cognitive components for grasping and use. An important source of evidence for this automatic activation view comes from studies showing interference when automatically activated action representations are inconsistent with the behaviors demanded by a task (e.g., Tucker and Ellis, 1998). Here, we evaluated whether such effects occur in a grip selection task in which responses were chosen based on a learned rule (Rule task) versus anticipatory planning (Plan task). Participants were asked to pantomime grasping horizontally presented objects with handles. In the Rule task, a color cue indicated on which side of the tool's handle the thumb had to be placed. In the Plan task, participants had to choose the most comfortable way to grasp and rotate the object into a specific end-position. Across three experiments we found evidence of interference on grip selection exclusively during the Rule task, and only when it was preceded by a prime task that involved tool use. These findings suggest that prior activation of cognitive components through use of tools can be effective over time and interferes with grip selection based on use of a pre-learned rule. Absence of interference effects during the plan task, even when preceded by the Use task, suggest that engagement of similar mechanisms during active planning overwrites this automatic activation of previously effective components. Possible cognitive and neural mechanisms are discussed.

1. Introduction

Every day we skilfully grasp and use tools with a certain purpose. Tool use actions start with a reaching and grasping movement. Typically the way we grasp objects is influenced by its properties (e.g., size, shape) and by what we intend to do with it (e.g., transport or use). Thus, some macroscopic features of object grasping movements, such as hand shape and hand orientation, appear to be planned in advance, taking relevant features of the following action into account (Johnson-Frey et al., 2004; Rosenbaum et al., 1990; Stelmach et al., 1994; Zhang and Rosenbaum, 2008). When asked to transport a hammer to the side, you can grasp it with a simple straight movement directed to the handle or by rotating your hand, regardless of whether the hammer's handle is pointing toward or away from your body. Instead, if you intend to use

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the tool, your grasp will be defined by its function. Radial tools like a hammer will evoke an initial grasping movement that leads to positioning the thumb toward the functional end. Instead, when grasping to use an ulnar tool like a stamp, the initial grasping movement will lead to positioning the thumb toward the handle's end. This is called functional grasping (Creem and Proffitt, 2001; Randerath et al., 2009). Depending on the tool's orientation, functional grasping sometimes requires the user to produce an awkward grasping movement to profit subsequently. It enables a fluent transition into an efficient use movement and can be distinguished from non-functional grasping. A non-functional grip is unsuited for tool use and would require an adjustment of the grip posture. When asked to grasp and demonstrate the use of a tool, healthy adults always take the following use action into account and produce functional grasping (Randerath et al., 2009; Sunderland et al., 2011). Clearly, for both transporting or using the tool it is important to process the tool's structure and orientation. When using the tool, an additional factor influences the initial grasping movement – the knowledge about how to use it. For planning tool use actions, it is assumed that different cognitive components in a distributed left hemisphere brain-network have to be retrieved and integrated, such as tool use semantics (Assmus et al., 2007; Johnson-Frey, 2004). Brain damage especially in the left hemisphere caused by stroke can lead to apraxia, an impairment involving defective motor actions during tool use. Lesion- and Transcranial Magnetic Stimulation (TMS)-studies show that the preservation of a left hemisphere network including frontal, parietal and temporal areas seems to be crucial for tool use (Buxbaum and Saffran, 2002; Goldenberg and Spatt, 2009; Hodges et al., 2000; Ishibashi et al., 2011). The left temporo-parieto-frontal network is not only responsible for planning the use action of a specific tool, but also for planning the preceding grasping action. When attempting to use a single tool, some left brain damaged patients with apraxia show errors in the preceding grasping movement by omitting a rotation of the hand (Randerath et al., 2010, 2009; Sunderland et al., 2011).

A number of studies with healthy participants support the idea that objects automatically activate components of the action they afford even in the absence of an explicit intention to act upon them. functional Magnetic Resonance Imaging (fMRI) studies have shown that merely observing (Creem-Regehr and Lee, 2005) or observing and making decisions regarding different qualities of objects (Bach et al., 2010) activate left fronto-parietal regions that usually can be seen in object related action execution (Frey, 2007). Converging evidence suggests that automatic processing of action affording components might introduce conflicts in action planning. A phenomenon found in several behavioral studies is a "stroop-like" effect, reflecting longer response-times (RTs) when manual responses are incompatible with the grip one usually would produce for grasping a presented object. The incompatibility sources are based on the perception of particular tool attributes relevant for typical grasping. In the literature two different tool attributes have been mentioned and discussed to explain this stroop-like effect. One explanation stresses the tool's spatial alignment (Daprati et al., 2010; Vingerhoets et al., 2009), meaning the handle's orientation toward the hand, arguing that RTs are prolonged when the handle is oriented away from the responding hand instead of toward. For example in the classic study by Tucker and Ellis (1998) participants had to judge whether drawn objects with handles (e.g., teapot) were presented upright or inverted by responding with either a right-hand or left-hand key press. All objects were presented in such a way that handles in half of the trials were aligned with the responding hand and in the other trials handles were oriented toward the opposite side. RTs were significantly faster when the handle's direction was congruent with the side of the responding hand. The authors propose that the task elicited some form of motor activity directed toward the handles, even though participants did not act on the objects. The other incompatibility source is a tool's function, resulting in slower RTs when intending to grasp objects in a manner that is incompatible with how the object is normally used (Bub and Masson, 2010; Bub et al., 2008; Jax and Buxbaum, 2010). Other findings seem to support this influence of tool semantics. For example grasps appropriate for use (although to a lesser extent) may occur even when the task is simply to transport an object (Creem and Proffitt, 2001; Randerath et al., 2009). In this simple grasping to transport task the instructions deliver no cues that could define a grasp, accordingly the extent of functional grasping varies between individuals (0–100%) (Randerath et al., 2009). One can only speculate why there is such behavioral variability between and within individuals. Potentially due to instructions lacking constraints, some subjects (at times) appear to associate an object's identity and typical subsequent use, whereas others do not. In line with this, Creem and Proffitt (2001) found the frequency of functional grasps to be reduced in a group solving a secondary word-association task while grasping to transport. Thus a semantic component seems to influence the production of functional grasping. When perceiving a familiar object, processing affordances might contribute to both, information about tool orientation and tool function. Amongst others, Gibson (1986) described the term affordances in relation to possible actions as what "the environment offers an animal". On the one hand, this includes object features such as material, size and structure that offer visual cues for a possible visuomotor action with an object, and on the other hand the perception of affordances also is influenced by the actors previous knowledge about that object. Both attributes – tool function and tool orientation – have in common that the tool's structural properties need to be perceived. However, whether compatibility effects are predominantly driven by the tool's typical function or simply the tool's orientation is unclear.

In contrast to the above mentioned and often proposed automaticity it has been argued that the way we perceive affordances depends on the actor's intention and the relative importance of the affordances for the specific action task (Buxbaum and Kalénine, 2010; Osiurak et al., 2010, 2011; Shaw et al., 1982; Valyear et al., 2011). Following this notion, affordance perception could be influenced by the situational context the action is performed in. Recent findings support this idea. The situational context in which we plan actions (for instance whether we just did or did not use an object according to its typical function) seems to matter when processing affordances of a visually presented object. When tool use precedes or is intermixed with a transport task it can influence the planning of the grasping movement for the