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Habit outweighs planning in grasp selection for object manipulation

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ABSTRACT

Object-directed grasping movements are adapted to intended interactions with an object. We address whether adjusting the grasp for object manipulation is controlled habitually, based on past experiences, or by goal-directed planning, based on an evaluation of the expected action outcomes. Therefore, we asked participants to grasp and rotate a dial. In such tasks, participants typically grasp the dial with an excursed, uncomfortable arm posture, which then allows to complete the dial rotation in a comfortable end-state. We extended this task by manipulating the contingency between the orientation of the grasp and the resulting end-state of the arm. A one-step (control) group rotated the dial to a single target. A two-step group rotated the dial to an initial target and then in the opposite direction. A three-step group rotated the dial to the initial target, then in the opposite direction, and then back to the initial target. During practice, the two-step and three-step groups reduced the excursion of their grasps, thus avoiding overly excursed arm postures after the second rotation. When the two-step and three-step groups were asked to execute one-step rotations, their grasps resembled those that were acquired during the two-step and three-step rotations, respectively. However, the carry-over was not complete. This suggests that adjusting grasps for forthcoming object manipulations is controlled by a mixture of habitual and goal-directed processes. In the present experiment, the former contributed approximately twice as much to grasp selection than the latter.

1. Introduction

When we plan an action, we often have subsequent actions in mind. This becomes evident as the way we execute initial actions depends on the actions that follow (Ansuini, Santello, Massaccesi, & Castiello, 2006; Cohen & Rosenbaum, 2004; Gentilucci, Negrotti, & Gangitano, 1997; Marteniuk, Mackenzie, Jeannerod, Athenes, & Dugas, 1987; Rosenbaum et al., 1990; Sartori, Straulino, & Castiello, 2011). Such anticipatory behavior is particularly important for grasping a to-be-manipulated object because most object manipulations are best executed with a particular grasp. For example, a person who wants to rotate a door-knob in a clockwise direction will rotate the arm counterclockwise before grasping it and vice versa. This maintains the arm posture in a neutral medial range during the object manipulation and increases its' speed and accuracy (Herbort, 2015; Rosenbaum, van Heugten, & Caldwell, 1996; Short & Cauraugh, 1999).

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Before an object can be grasped, the grasping movement must be planned. This process includes several aspects, such as specifying the direction of the movement, shaping the fingers, or determining the force with which the object will be grasped. Here, we focus on the following specific – but central – aspect of this planning process: selecting how to place the fingers on an object based on the intended object manipulation ("grasp selection for object manipulation"). Although grasp selection for object manipulation has extensively been studied (for recent reviews, see Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012; Wunsch, Henning, Aschersleben, & Weigelt, 2013), little is known about the underlying mechanisms. There are two different perspectives that correspond to a dichotomy between goal-directed and habitual action selection (Dickinson, 1985; Dolan & Dayan, 2013). According to one approach, grasp selection for object manipulation is primarily a goal-directed planning process that is based on the anticipated action outcomes (Cohen & Rosenbaum, 2004; Johnson, 2000; Wunsch & Weigelt, 2016). This notion is goal-directed as grasp selection depends on the expected consequences of a grasp (e.g., the resulting arm posture) and matching these consequences to an individual's motivations (e.g., assuming a comfortable posture). According to the other approach, grasp selection is primarily habitual and is based on learned object manipulation task – grasp associations (Herbort, Butz, & Kunde, 2014; van Swieten et al., 2010). This is habitual because it assumes that grasps are selected because they proved useful in the past for manipulating objects in comparable ways, regardless of the expected requirements for the upcoming task. However, there is no compelling evidence for either perspective. In the remainder of the introduction, we present arguments for both views and outline the experimental procedure used to test between them.

1.1. Arguments in favor of the goal-directed view

According to the *goal-directed view* of grasp selection, anticipating the arm movement that is necessary to manipulate an object is used to select a grasp that allows for fast, accurate, or comfortable object manipulations (Cohen & Rosenbaum, 2004; Johnson, 2000; Stöckel, Hughes, & Schack, 2012; Wunsch & Weigelt, 2016). Thereby, the arm posture at the end of the object manipulation (end posture) and the arm posture when the object is grasped (initial posture) seem to play a pivotal role. Notably, this view includes the possibility that planning may only be necessary when a grasp is selected for a specific task for the first time. When a task is repeated, grasp selections may rely on recalling previous instances (Cohen & Rosenbaum, 2004; Weigelt, Cohen, & Rosenbaum, 2007).

There are mainly two observations that support the goal-directed view; however, they are not conclusive per se. First, at least some of the cognitive requisites for selecting grasps based on anticipated end postures are met. For example, to plan grasps that are based on the resulting end-states, it is necessary to prospectively predict and evaluate the possible end-states. Indeed, participants can mentally simulate object manipulations (Seegelke & Hughes, 2015). Likewise, participants can predict the subjective "awkwardness" of the arm postures (Johnson, 2000), which are a key determinant of grasp selection (Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992). Moreover, movement end postures appear to be represented prior to the onset of movement. For example, prospective judgments of how an object could be grasped for rotation were faster when the participant's actual arm posture was congruent to the arm posture at the end of the object manipulation (Zimmermann, Meulenbroek, & de Lange, 2012). Finally, the ability to discriminate between visual images of comfortable and awkward postures is correlated with the ability to adapt grasps for different object manipulations (Stöckel et al., 2012). However, the representation of the end postures does not imply that this information is processed during planning or that planning occurs at all (Johnson, 2000). These representations could be the result, rather than the cause, of action selection (Blakemore, Wolpert, & Frith, 2002; Ziessler & Nattkemper, 2011).

Second, grasp selection often depends on the intended object manipulation from the very first trial on which the task is performed (e.g., Cohen & Rosenbaum, 2004; Rosenbaum et al., 1990). As there is no opportunity for learning, these experiment suggests that grasps are planned in goal-directed fashion (Cohen & Rosenbaum, 2004). However, because most experimental tasks are inspired by everyday actions (Rosenbaum et al., 2012), participants may have reused the task-grasp associations that were learned during daily object manipulations. In fact, in less common tasks, participants made little to no grasp adjustments for different object manipulations on the very first trial(s) and only adjusted their grasps after gaining some experience with the task (Herbort, 2012; Künzell et al., 2013).

1.2. Arguments in favor of the habitual view

There are (at least) two ways that grasp selection could depend on habitual processes. First, specific grasps may be associated with different objects, regardless of the task. As such, specific grasps may not reflect the currently intended interaction with that object. For example, humans who are asked to manipulate everyday objects tend to select grasp points or grasp orientations that correspond to the object's prevailing use, regardless of their current object manipulation goals (Creem & Proffitt, 2001; Herbort & Butz, 2011). Likewise, grasps tend to be conserved during repeated (identical) interaction with objects (Glover & Dixon, 2013; Rosenbaum & Jorgensen, 1992). In this case, habitual processing thwarts adjusting grasps to object manipulations to some extent.

Second, specific grasps may be associated with *specific* object manipulations (i.e., a combination of object and intended object manipulations). The present article focuses on this aspect, which we refer to as the *habitual view*. This view suggests that specific grasps are selected for specific object manipulations because they have previously been used successfully for similar object manipulations (Herbort et al., 2014; van Swieten et al., 2010). Hence, grasp selections may depend on intended