Human Movement Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Second-order grasp planning reflects sensitivity to inertial factors

Jeffrey B. Wagman[a,*], Drew H. Abney[b], David A. Rosenbaum[c]

[a] Department of Psychology, Illinois State University, Normal, IL, USA
[b] Department of Psychology, Indiana University, Bloomington, IN, USA
[c] Department of Psychology, University of California, Riverside, CA, USA

ARTICLE INFO

Keywords:
Grasping
First order planning
Second order planning
Inertia

ABSTRACT

Previous studies have shown that people's grasps of objects are tuned to the objects' inertial properties. In most of those studies, information obtained about the attunement of the grasps to the objects' inertial properties was limited to *first-order* grasp planning (i.e., planning of grasps based on immediate task demands). We investigated attunement of grasps to an object's inertial properties in the context of *second-order* grasp planning (i.e., planning of grasps based on subsequent task demands). In Experiment 1, participants grasped a horizontal rod whose right or left end would be brought down onto a target. Consistent with previous findings, participants grasped the rod so as to complete the movement with a thumb-up posture, using an overhand grasp when the right end of the rod was to be brought to the target and an underhand grasp when the left end was to be brought to the target. They also grasped the rod to the right of center, but more so when doing this with an underhand than when with an overhand grasp. In Experiment 2, participants performed the same task with an asymmetrically weighted rod. Changes in subjects' grasps in Experiment 2 compared to Experiment 1 suggested that participants grasped the rod based on the inertial properties of the rod in a way that took advantage of the pendular properties of the hand-plus-object.

1. Introduction

Consider someone grasping a hammer to pound a nail. The person will likely pick up the hammer by its handle with the radial (thumb) side of the hand toward the head, and s/he will grasp the handle closer to the bottom than the top. But if the same person picks up the same hammer not to pound a nail but instead to pull a nail out of a board with the hammer's claw, then s/he will pick up the hammer with the ulnar (little-finger) side of the hand toward the head and grasp it closer to the claw. If the hammer's appearance is identical in the two cases, the difference in behavior indicates that the manipulation does not just depend on how the hammer looks – an example of *first-order* grasp planning – but also on the actor's plan for what s/he intends to do with the hammer *after* it is picked up – an example of *second-order* grasp planning (Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012; see Wagman & Carello, 2003).

The choice of how and where to grasp an object affects how the mass of the object is distributed relative to the wrist and thus alters the mass distribution of the hand-object system. Such choices alter how easily the object can be controlled, and depend on the sensitivity of the actor to the inertial properties of the object and body (see Carello & Turvey, 2017). Insofar as grasping an object is an act that transforms a detached object into a hand-held tool (Gibson, 2014/1979), choosing how and where to grasp an object reflects sensitivity to the functionality of the ensemble of elements involved in the act (Wagman & Carello, 2003; Wagman & Taylor, 2004).

* Corresponding author.
E-mail address: jeffreywagman@illinoisstate.edu (J.B. Wagman).

http://dx.doi.org/10.1016/j.humov.2017.10.009
Received 31 January 2017; Received in revised form 16 October 2017; Accepted 18 October 2017

Here, we investigated the extent to which participants are sensitive to the way grasp types and grasp locations alter the functionality of a hand-held object for a task in which the act of grasping the object had implications for the final position of the body well after initial contact with the object. We asked how grasp type and grasp location depended not just on the immediate lift of an object but also on the final position to which the object would be brought. Previous studies have looked at this question (Cohen & Rosenbaum, 2004; Rosenbaum, Marchak, Barnes, Vaughan, Slotta, & Jorgensen, 1990; Rosenbaum et al., 2012), but they have paid scant attention to the inertial properties of the object being grasped. What work has been done on the influence of inertial properties on grasps have concerned first-order grasp planning in relatively simple, "single-act" maneuvers like lifting an object with as little rotation as possible and putting the object back down again. Under such circumstances, participants show sensitivity to the inertial properties of the grasped object and the associated controllability of the hand-object system. For example, when attempting to minimize object rotations, people grasp objects with appropriate force and in appropriate locations on the object (Bingham & Muchisky, 1993; Bingham & Muchisky, 1995; Lederman & Wing, 2003; Wing & Lederman, 1998). Under similar task instructions, participants tend to grasp objects with greater variability of finger placement when they are more uncertain about the mass distribution of the object (Lukos, Ansuini, & Santello, 2007). Finally, people prospectively adjust fingertip forces based on experience lifting the objects or based on expectations about the objects' inertial properties (Gordon, Westling, Cole, & Johansson, 1993).

One study that did investigate the effect of inertial properties on second order grasp planning was by Wagman and Carello (2003). They found that participants chose to grasp an object closer to its center of mass when the participants were to perform a precision task (e.g., striking a small nail) than when the same participants were to perform a power task (e.g., pounding a large spike). Carrying forward the same general approach, in the two experiments reported here, rather than varying the nature of the grasp that was required (precision versus power), we focused only on the power grasp, asking how it would be oriented where it would be applied to a horizontal dowel that was lifted, rotated, and displaced so either its left or its right end would be brought down onto a target. We hypothesized that our university-student participants would be sensitive to how grasp choices (in terms of both grasp orientations and grasp location) would influence the mass distribution of the hand-object system and the subsequent functionality for completing the manipulation task.

In the first experiment, we investigated grasp choices for an object rotation and placement task when the object being lifted, rotated, and placed had an internally symmetric load (i.e., was of uniform density). In the second experiment, we investigated grasp choices for the same object rotation task when the object being lifted and turned had an internally asymmetric load, the side of which was externally (visibly) marked. We analyzed grasp type (overhand versus underhand grasps) and grasp locations in both experiments to quantify subjects' sensitivity to task constraints and the object's inertial properties.

We also analyzed grasp locations along the length of the rod to test an additional hypothesis about the grasps, namely, that our participants (all of whom used the right hand), would grasp the horizontal rod farther to the right when they used an underhand grasp than when they used an overhand grasp. The basis for this prediction was our expectation that our participants would grasp the rod so as to exploit its pendular properties. That is, they would grasp the rod so as to take advantage of the gravitational forces acting on it, thereby decreasing the muscular forces required to perform the rotation (cf. Bernstein, 1967; Rosenbaum, Chapman, Coelho, Gong, & Studenka, 2013). Grasping the rod more to the right when the rod was picked up with an underhand grasp meant that more of the rod's length (and therefore in this case, more of its mass) would fall below the axis of rotation at the grasp location. Similarly, grasping the rod more to the left (or less far to the right) when the rod was picked up with an *overhand* grasp meant again that more of the rod's length (and therefore in this case more of its mass) would fall below the axis of rotation at the grasp location. In short, grasping the rod to place more of the rods' length (and subsequently, mass) below the axis of rotation while the rod was being turned would make it easier to turn the rod. À la Bernstein (1967), who emphasized exploitation of, rather than opposition to, physical mechanics our participants would leverage gravitational forces during the rotation.

2. Experiment 1

In Experiment 1, our participants reached out and grasped a horizontal wooden rod (Fig. 1), rotated it 90°, and placed an end, specified before the reach, end down onto a target. The rod had a white end and a black end and was internally weighted such that the mass distribution was symmetric about the rod's center. Across trials, we varied the rod's initial orientation (i.e., which end was either to the participant's right or left at the start of the trial) and final orientation (i.e., which end of the rod was to be placed down onto the target at the end of the trial). The four possible pairs of initial and final object orientations were tested in a random order per participant.

We had four predictions. First, participants would show a strong preference for grasping the rod in such a way that they would exhibit a thumb-up orientation (Fig. 1A) rather than a thumb-down orientation (Fig. 1B) upon the completion of the rod transport. So we expected our participants to exhibit the so-called *end state* comfort effect (see Rosenbaum et al., 2012, for a review). This meant that when the right end of the rod would be placed down, the rod would be grasped with an overhand (palm facing down) grasp (assuming use of the right hand), but when the left end of the rod would be placed down, the rod would be grasped with an underhand (palm facing up) grasp (again assuming use of the right hand).

Our second prediction was that because the rod's center of mass was always at the rod's geometric center (30 cm from either end), the initial object orientation (i.e., which end was to the participant's right or left at the beginning of the trial) would not systematically influence the final grasp orientation. Therefore, participants would show strong preferences for the grasp choices described above regardless of how the rod was oriented in the cradle (i.e., which end was either to the participant's right or left at the start of the trial).