Acta Psychologica 144 (2013) 298–307

Contents lists available at ScienceDirect

Acta Psychologica

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

Whole-body posture planning in anticipation of a manual prehension task: Prospective and retrospective effects

William M. Land [a,b,d,*], David A. Rosenbaum [c], Christian Seegelke [a,b,d], Thomas Schack [a,b,d]

[a] Department of Neurocognition and Action, Biomechanics, Bielefeld University, Germany
[b] Research Institute for Cognition and Robotics (CoR-Lab), Bielefeld University, Germany
[c] Department of Psychology, Pennsylvania State University, University Park, PA 16802, United States
[d] Cognitive Interaction Technology, Center of Excellence (CITEC), Bielefeld University, Germany

ARTICLE INFO

Article history:
Received 2 October 2012
Received in revised form 28 May 2013
Accepted 10 June 2013
Available online 7 August 2013

PsycINFO codes:
2340
2330

Keywords:
Anticipation
Posture planning
Prehension
Grasping
Motor hysteresis
Motor control

ABSTRACT

This study examined the extent to which the anticipation of a manual action task influences whole-body postural planning and orientation. Our participants walked up to a drawer, opened the drawer, then grasped and moved an object in the drawer to another location in the same drawer. The starting placement of the object within the drawer and the final placement of the object in the drawer were varied across trials in either a blocked design (i.e., in trials where the same start and end location were repeated consecutively) or in a mixed fashion. Of primary interest was the posture adopted at the moment of grasping the drawer handle before pulling it out prior to the object manipulation task. Of secondary interest was whether there were sequential effects such that postures adopted in preceding trials influenced postures in subsequent trials. The results indicated that the spatial properties of the forthcoming object manipulation influenced both the postures adopted by the participants and the degree to which the drawer was opened, suggesting a prospective effect. In addition, the adopted postures were more consistent in blocked trials than in mixed trials, suggesting an additional retrospective effect. Overall, our findings suggest that motor planning occurs at the level of the whole body, and reflects both prospective and retrospective influences.

1. Introduction

Understanding how movements are planned and controlled is a fundamental concern for the cognitive sciences, including robotics (Schack & Ritter, 2009). With an estimated 100 to 150 degrees of freedom in the human skeleton (van Ingen Shenau, van Soest, Gabreëls, & Horstink, 1995), a central problem is how the motor system selects and executes particular movement-elements when a physical goal can be achieved in infinitely many ways. This range of possibilities makes understanding movement control complicated for scientists, though it affords flexibility and richness for those carrying out movements in everyday life.

Given the wide range of ways in which motor tasks can be performed, observations of regularities in the way tasks are performed can provide insight into how movements are planned and controlled. To this end, research has shown that the way movements are planned and executed depends largely on the goal of the action (Fischer, Rosenbaum, & Vaughan, 1997; Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987; Rosenbaum et al., 1990). For example, it has been found that participants tend to grasp a horizontally placed bar differently depending on which end of the rod will be placed down (Rosenbaum et al., 1990). When the right end of the bar will be placed downward using the right hand, participants tend to adopt an initial overhand grasp. In contrast, when the left end of the bar will be placed downward, the same participants tend to adopt an initial underhand grasp. Thus, participants tend to select initial grasp postures that lead to a comfortable or easy-to-control thumb-up posture at the end of the movement, even if this means adopting initially uncomfortable (underhand) postures. The tendency to avoid awkward postures at the end of a movement has been called the *end-state comfort effect*. This effect has been taken to support the idea that individuals anticipate future goal-related postural states (e.g., Fischman, Stodden, & Lehman, 2003; Rosenbaum, Meulenbroek, & Vaughan, 2006, 2012; Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012; Rosenbaum, Cohen, Jax, Weiss, & van der Wel, 2007; Short & Cauraugh, 1999; Weigelt & Schack, 2010).

Within the research on anticipatory motor control, there has been a growing appreciation that the coordination and involvement of the entire body is vital to the understanding of action planning and object manipulation (Fischer, 2000; Lam, McFee, Chua, & Weeks, 2006; Marteniuk & Bertram, 2001; Rosenbaum, 2008; Rosenbaum, Brach, & Semenov, 2011; Studenka, Seegelke, Schütz, & Schack, 2012; van der Wel & Rosenbaum, 2007). For example, Marteniuk and Bertram (2001) showed that task-specific synergies form during locomotion

* Corresponding author at: Bielefeld University, Neurocognition and Action—Biomechanics, N3-111, 33501 Bielefeld, Germany. Tel.: +49 521 106 5132.
E-mail address: William.Land@uni-bielefeld.de (W.M. Land).

0001-6918/$ – see front matter
http://dx.doi.org/10.1016/j.actpsy.2013.06.002

and prehension tasks such that invariant spatial trajectories of the hand are achieved by coordination of arm and body movements. Similarly, Ma and Feldman (1995) showed that when subjects were asked to lean their torsos either forward or back during a reach, the trajectories of their hands were practically identical to when they performed the reach using only their arms. Ma and Feldman suggested that the consistent endpoint position of the hand was achieved by a synergy between the trunk and arm, which was organized and controlled in an integrated manner. Similar results were also reported by Saling, Stelmach, Mescheriakov, and Berger (1996).

In related research, Fischer et al. (1997) showed that the anticipation of future task demands can influence preceding postural coordination. Specifically, these authors examined the relative contributions of the hip, shoulder, and elbow in a sequential sagittal-plane reaching task. While seated, participants in a control group reached from a start position to a first target and back. Meanwhile, other identically-seated participants in an experimental group reached from the same start position to the first target and then to an additional second target and back. The results indicated that the posture adopted at the first target was influenced by the location of the second target. Thus, the participants anticipated the demands of the final reaching task while reaching to the first target. The postures adopted at the intermediate target reflected a minimization of travel costs between the start and final target positions.

In research that was likewise concerned with postural planning, Bongers, Michaels, and Smitsman (2004) investigated whether postures are influenced by the anticipation of upcoming task demands in tool use. In their two experiments, Bongers, Michaels, and Smitsman asked participants to hold a rod of varying lengths, walk toward a cube, and then displace the cube with the rod's tip. Of particular interest was the distance at which participants stood from the cube prior to displacement. It turned out that this dependent variable was influenced both by the length of the rod and the posture required for the upcoming displacement. Participants stood at greater distances from the cube when using a larger rod to displace the object. In addition and more importantly, when displacing a smaller cube, which required greater precision in the use of the rod, participants stood closer to the cube. This reduced distance was related to differences in adopted postures (less extension of the shoulder and arm when the rod required more control). These findings highlight the influence of anticipated task demands on anticipatory posture planning.

To extend this line of work, we sought to determine whether whole-body postures are influenced by the anticipation of a much more complicated physical action than has been studied previously. We explored motor planning when participants walked up to a drawer, opened the drawer, picked up a dowel from one of four starting locations in the drawer, and then placed the dowel at one of four ending locations in the same drawer. By studying this task, we sought to investigate a natural, complex task with few restrictions on movement range. In pursuing this task, we followed the recommendation of Marteniuk and Bertram (2001) in their pioneering study of whole-body coordination that avoiding artificial restrictions in movements may allow for the manifestation of motor control strategies.

The specific aims of the study were, twofold. First, we sought to determine the extent to which aspects of postural orientation (e.g., torso angle, hip angle, standing distance, etc.) are planned in advance of a prehension task. Specifically, we asked whether participants would adopt different body postures relative to the drawer when grasping the drawer handle prior to moving the object within the drawer from different starting positions to different ending positions. Based on previous research (e.g., Fischer et al., 1997; Haggard, 1998; Hesse & Deubel, 2010; Rosenbaum et al., 1990), we hypothesized that the postures adopted when the participants grasped the drawer handle would reflect a minimization of travel costs with respect to the location of the upcoming object manipulation. The dependent variables we focused on were: (1) the handle grasp position; (2) torso and hip angle; (3) the lateral position of standing in front of the drawer; (4) the distance participants stood from the drawer; (5) the degree of upper torso pitch, and (6) the distance the drawer was opened. We expected the first three dependent variables to depend on the lateral position of the object's starting and ending locations, and we expected the second three dependent variables to depend on the fore–aft position of the object's starting and ending locations. Finally, we predicted that the starting placement of the object, more than the ending placement of the object, would more strongly influence postures at the point of grasping the drawer handle grasp. This prediction was based on the findings of Haggard (1998), who found a gradient for advanced planning in that movement adjustments are generally more common for aspects of immediately forthcoming movements than for later forthcoming movements.

The second aim of the present study was to examine whether there are retrospective as well as prospective effects in whole-body posture planning. According to the computational model of motor planning developed by Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, and Engelbrecht (1995), as people repeatedly perform an action, they should "settle in" and exhibit a greater degree of stereotypy over repeated instances of the same movement. This increased postural consistency is predicted not only to result from the convergence toward less costly movements, but also from a more precise anticipation of the external task demands. The idea here is to reduce changes, not just with respect to what will happen, but also with respect to what already has.

To address this possibility, we had our participants perform the drawer opening and prehension task in both blocked orders (i.e., repeated instances of the same start and end location for the prehension task in successive trials) and random orders (i.e., unpredictable order of start and end placement locations in successive trials). We predicted that participants would show more consistency in postural parameters when performing the task in a blocked rather than in a random fashion. We further expected that in the blocked order condition participants would show more postural consistency during the later instances of a trial type than in the early instances, consistent with settling in.

2. Method

2.1. Participants

Twenty right-handed students (7 men, 13 women, mean age of 24.05 years) from Bielefeld University were recruited to take part in the study. Before starting the experiment, the participants completed an informed consent form as well as the Revised Edinburgh Handedness Inventory (Dragovic, 2004). The handedness inventory assesses hand preference on a battery of common tasks and provides a handedness score on a scale from -1.00 (*strongly left-handed*) to 1.00 (*strongly right-handed*). Based on the handedness inventory, all participants were considered right-handed ($M = 0.89$, $SD = 0.17$). The participants received either course credit or 5€ for participation. All participants were naïve as to the purpose of the study. The study was conducted in accordance with local ethical guidelines and conformed to the Declaration of Helsinki.

2.2. Apparatus and experimental setup

The experimental set-up consisted of a drawer, 80 cm wide × 50 cm deep × 15 cm high (see Fig. 1a) equipped with a horizontal handle that extended across the drawer face. To standardize the height of the drawer for each participant, the height of the drawer handle was set to the height of the participant's right anterior superior iliac spine. Inside the drawer were 4 circular holes (each 7 cm in diameter and 5 mm deep) designed to hold a dowel (8 cm in height, 6.5 cm in diameter, and 380 g in weight) (see Fig. 1b). The holes were located in the front left (FL), front right (FR), back left (BL), and back right (BR) of the drawer. The distance between the left and right grooves was 58 cm, and the distance between the front and back grooves was 13 cm. To grasp the dowel in the front of the drawer, the drawer had to be opened at least 13 cm to permit