Human Movement Science 48 (2016) 161–170

Contents lists available at ScienceDirect

Human Movement Science

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

Full Length Article

Task difficulty and inertial properties of hand-held tools: An assessment of their concurrent effects on precision aiming

Paula L. Silva [a,b,*], Reinoud J. Bootsma [c], Priscilla Rezende Pereira Figueiredo [d], Bruna Silva Avelar [d], André Gustavo Pereira de Andrade [e], Sérgio T. Fonseca [d], Marisa Cotta Mancini [d]

[a] *Graduate Program in Rehabilitation Science, School of Physical Education, Physical Therapy and Occupational Therapy, Universidade Federal de Minas Gerais, Av. Antonio Carlos 6627, Campus Pampulha, Belo Horizonte, MG 31270-010, Brazil*

[b] *Department of Psychology, University of Cincinnati, 4150N Edwards 1 Bldg, P.O. Box 210376, Cincinnati, OH 45221-0376, United States*

[c] *Institut des Sciences du Mouvement - UMR 7287, Aix-Marseille Université, Marseille, France*

[d] *Graduate Program in Rehabilitation Science, School of Physical Education, Physical Therapy and Occupational Therapy, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil*

[e] *Graduate Program in Sports Science, School of Physical Education, Physical Therapy and Occupational Therapy, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil*

ARTICLE INFO

Article history:
Received 26 November 2015
Revised 11 March 2016
Accepted 6 May 2016
Available online 21 May 2016

Keywords:
Reciprocal aiming
Fitts' task
Long-shafted probe
Mass distribution
Kinematics

ABSTRACT

Aiming hand-held tools at targets in space entails adjustments in the dynamical organization of aiming patterns according to the required precision. We asked whether and how these adjustments are modified by the tool's mass distribution. Twelve participants performed reciprocal aiming movements with a 50-cm long wooden probe. Kinematic patterns of probe movements were used as a window into the behavioral dynamic underlying performance of a reciprocal aiming task. We crossed three levels of task difficulty (IDs 2.8, 4.5 and 6.1) with two types of probe varying in their mass distribution (proximal *vs* distal loading). Movement duration was affected by task difficulty and probe loading (shorter for larger targets and proximal probe loading). Progressive deviations from a sinusoidal movement pattern were observed as task difficulty increased. Such deviations were more pronounced with proximal probe loading. Results point to a higher degree of non-linearity in aiming dynamics when the probe was loaded proximally, which might reflect employment of additional perceptual-motor processes to control the position of its less stable tip at the vicinity of the targets. More generally, the effects of probe loading on aiming pattern and dynamics suggest that perceptual-motor processes responding to task level constraints are sensitive to, and not independent from, biomechanical, end-effector constraints.

1. Introduction

Numerous daily and sports activities involve aiming the distal end of a hand-held tool or implement to targets in space. Driving a nail into the wall with a hammer or placing a screwdriver onto a screw head are but two representative examples.

* Corresponding author. Present address: Department of Psychology, University of Cincinnati, 4150N Edwards 1 Bldg, P.O. Box 210376, Cincinnati, OH 45221-0376, United States.

E-mail address: paula.silva@uc.edu (P.L. Silva).

http://dx.doi.org/10.1016/j.humov.2016.05.003
0167-9457/© 2016 Published by Elsevier B.V.

When performing any of these activities, a skillful actor patterns his or her muscular forces to control the motions of the end-effector (here the hand-held object) so as to achieve the intended target-object relation. Task-specific use of hand-held tools and implements therefore requires sensitivity to constraints at the level of the task (e.g., accuracy requirements) and constraints at the level of the end-effector (e.g., mechanical properties of the tool or implement being used). In the present contribution, we examined the concurrent influences of both types of constraints on the performance and kinematics of precision aiming, which is a fundamental component of the functional use of hand-held objects.

Inspired by the seminal work of Woodworth (1899) and Fitts (1954), Fitts and Peterson (1964), the effects of task constraints have been extensively explored in goal-directed aiming (see Plamondon & Alimi, 1997, and Elliot, Helsen, & Chua, 2001 for reviews). Both the duration and the kinematic pattern of a successful aiming movement have been demonstrated to vary as a function of a task index of difficulty (ID) combining the distance D to be covered and the tolerance for terminal spatial variability delimited by target width W. The relation between task difficulty – with $ID = \log_2(2D/W)$ being the most commonly used form – and movement time (MT) is in fact so robust, in both the discrete and reciprocal versions of Fitts' paradigmatic aiming task, that it has come to be known as Fitts' law.

The lengthening of MT observed when the aiming task becomes more difficult has been related to systematic changes in the kinematic pattern of aiming movements, in both the discrete (e.g., Beggs & Howarth, 1970; Elliott, Helsen, & Chua, 2001; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987) and reciprocal (e.g., Guiard, 1993; Huys, Fernandez, Bootsma, & Jirsa, 2010; Mottet & Bootsma, 1999) versions of the task. When task difficulty is low (i.e., when aiming for relatively large targets) movement patterns demonstrate symmetrically-shaped velocity profiles. Movements performed under higher levels of task difficulty are characterized by a progressive asymmetry in the velocity profile, mainly due to a lengthening (both in absolute and relative terms) of the duration of the deceleration phase. The window into the perceptual-motor processes underlying task execution offered by analysis of the characteristics of the kinematic patterns is perhaps richest for Fitts's (1954) reciprocal version of the aiming task, as portraying the to-and-fro movements into phase and Hooke spaces provides insight into the underlying dynamics (Bongers, Fernandez, & Bootsma, 2009; Bootsma, Fernandez, & Mottet, 2004; Bootsma & Mottet, 2004; Bootsma, Mottet, & Zaal, 1998; Buchanan, Park, & Shea, 2004; Buchanan, Park, & Shea, 2006; Fernandez & Bootsma, 2004; Fernandez & Bootsma, 2008; Guiard, 1993; Mottet & Bootsma, 1999; Mottet, Guiard, Ferrand, & Bootsma, 2001).

Geometrical and mechanical characteristics of the end-effector have also been demonstrated to affect the time required to perform an aiming movement. For a given level of task difficulty, increasing the length of a hand-held probe (Baird, Hoffmann, & Drury, 2002) and increasing the mass transported (Fernandez & Bootsma, 2004; Fitts, 1954; Hoffmann, 1995; Hoffmann & Hui, 2010; Konz & Rode, 1972; Langolf, Chaffin, & Foulke, 1976) both give rise to a lengthening of MT. Most of these studies focused exclusively on MT and did not address the kinematic patterning of the aiming movements. One exception is the study performed by Fernandez and Bootsma (2004). These authors exploited the anisotropy of the arm's workspace to investigate the effect of total transported mass through manipulations of the direction of end-effector motion during a reciprocal aiming task. Results showed that, at each level of task difficulty (IDs of 3, 4, and 5), the duration of movement increased when participants moved in directions associated with higher magnitudes of transported mass. For example, movement time was longer when transport of the entire upper limb was required to move between targets than when only transport of the less massive forearm was required. Importantly, manipulations of total transported mass did not provoke changes in the movement's kinematic patterns. In particular, no changes in the harmonicity of aiming patterns or in the underlying dynamical organization were observed. From these results they concluded that while (informational) constraints at the level of the task affected the processes underlying movement organization, (biomechanical) constraints at the level of the effector did not.

In the present study, we explored the effects of mass distribution along a long-shafted probe on the duration and organization of reciprocal aiming movements. The mass distribution of a hand-held object can, in principle, affect its appropriateness for performing manual tasks, and hence, influence the organization of aiming movements. For example, by the laws of mechanics, a hammer (whose mass is concentrated far from the point of grasp) is effective for transferring momentum to an external target, minimizing the need for generating muscular torque. However, maneuvering the hammer to adjust the position of its weighted end is relatively hard, particularly when the task involves high accelerations. Designing hammers with large heads is a strategy to compensate for the low maneuverability of the hammer's end position when hitting the typically very small nail heads. In contrast, by virtue of its mass being concentrated closer to the point of grasp, a screwdriver is comparatively ineffective for transferring momentum, but less difficult to maneuver. Maneuverability would be particularly beneficial for precision tasks requiring high speeds and rapid adjustments in end-effector's acceleration pattern. Here we arrive at the main hypothesis of the present experiment: tools with their mass concentrated close to point of grasp are expected to allow adjustments in the underlying perceptual-motor organization that minimize declines in performance (speed) as precision demands increase. We therefore expect that, differently from manipulation of transported mass, manipulation of a probe's mass distribution will affect not only the duration of aiming movements but also their kinematic pattern, particularly when accuracy demands are more stringent. Confirmation of this hypothesis would push a reassessment of the current view that task level constraints are informational while biomechanical constraints are not.

Recently, Lin and Chen (2014) have studied the effect of mass distribution of long-shafted probes on the duration of aiming movements. No difference in movement time was observed when proximal and distal loading conditions were compared (though middle loading was associated with faster performance). The authors suggested that distal and proximal loading benefit different aspects of aiming movements, leading to a similar effects on global performance. However, these authors did not address the kinematic patterning of the aiming movements and, therefore, the effect of end-effector's mass