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A method for measuring manual position control

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ABSTRACT

There is no generally accepted method for measuring manual position control. We developed a method for doing so. We asked university students to hold a handle that had one rotational degree of freedom. The angular position of the handle depended on the degree of pronation-supination of the forearm. The subjects' task was to hold the handle as steadily as possible to keep a needle positioned in a pie-shaped target zone on a computer screen. If the needle remained in the zone for 0.5 s, the gain of the feedback loop increased; otherwise the gain decreased or remained at the starting value of 1. Through this adaptive procedure, we estimated the maximum gain that could be achieved at each of the four pronation-supination angles we tested (thumb up, thumb down, thumb in, and thumb out) for each hand. Consistent with previous research on manual control, and so validating our measure, we found that our participants, all of whom were right-handed, were better able to maintain the needle in the target zone when they used the right hand than when they used the left hand and when they used midrange wrist postures (thumb up or in) rather than extreme wrist postures (thumb down or out). The method provides a valid test of manual position control and holds promise for addressing basic-research and practical questions.

1. Introduction

In many everyday tasks, it is important to hold one's hands steady. Think of a surgeon carrying out a delicate procedure, a welder striking and maintaining an arc on a precision machine, or a member of a bomb squad preparing to defuse a bomb. Given how important it is to maintain steady hand positions, it is surprising that there is no established method for determining how well hand positions can be maintained.

We pursued such a method here, focusing on the method's ability to pick up differences in manual positioning control for the two hands at different postures (at different pronation-supination angles). We were motivated to develop the method for applied as well as basic-science reasons. On the applied-science side, we thought such a measure could be used to indicate progress or lack thereof following stroke or injury given various drugs or rehabilitation regimens. We also thought the method might be useful in human-factors contexts such as tool design or personnel selection (e.g., who would make a good surgeon or bomb squad member). On the basic-science side, we thought the method could provide information about the degree of precision that is possible for different limb configurations and about the relative importance of visual feedback in judging and maintaining positions. The ensuing data could constrain future theorizing about motor control. For example, a theory like the one developed by the last author and others, which focuses on goal positions of the body and their suitability for different tasks (Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Engelbrecht, 1995; Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001), could benefit from benchmark data about the stability of the postures that are proposed (cf. Solnik et al., 2013).

It was important to validate our method, so we focused on an aspect of position control that has been thoroughly studied before, namely, the degree of position control that can be achieved with the two hands and by each hand in different forearm pronation and supination positions. Previous knowledge about both of these aspects of manual control let us judge the validity of the measure obtained with our procedure.

With respect to the two hands, all of our subjects were right-handed, so we expected them to do better when using the right hand than the left. Obtaining that result would, in our view, constitute prima facie evidence that our method was valid.

With respect to pronation and supination, we expected our participants to do better if they had their thumbs facing up or inward (toward the midsagittal plane) than if they had their thumbs facing down

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or outward (away from the midsagittal plane). We based this expectation on several sources of evidence. First, the time to carry out aiming movements is shorter when the hand is in intermediate pronation-supination angles than when the hand is in extreme pronation-supination angles (Coelho, Studenka, & Rosenbaum, 2014; Hughes, Seegelke, & Schack, 2012; Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012; Short & Cauraugh, 1999). Second, mechanical power is higher at intermediate pronation-supination angles than at extreme pronation-supination angles (Winters & Kleweno, 1993). Third, oscillation rates are higher at intermediate pronation-supination angles than at extreme pronation-supination angles (Rosenbaum, van Heugten, & Caldwell, 1996). Fourth and finally, hand positions are judged more comfortable at intermediate pronation-supination angles than at extreme pronation-supination angles (Rosenbaum et al., 2012; Rossetti, Meckler, & Prablanc, 1994; Solnik et al., 2013). Given these findings, we assumed that if we obtained evidence for better control at intermediate forearm angles, that would constitute further evidence for the validity of our approach.

2. Method

We asked our participants to grasp and hold a handle using their left or right hand in a range of orientations. The handle's orientation was reflected in the angular position of a needle appearing on a computer screen. The participant's task was to keep the needle within a narrow target range. Participants were asked to hold the handle as steadily as possible.

To probe the degree of control afforded by each manual posture, we dynamically altered the visuo-motor gain (i.e., the ratio of virtual object motion to actual object motion). If participants successfully maintained the needle within the target for 0.5 s, the gain increased and the needle became more sensitive to the handle's position. If participants were unable to maintain the needle within the target, the gain decreased or remained at the starting value of 1 and the needle became less sensitive to, or remained at the state of least sensitivity to, the handle's position. By manipulating the gain, we could magnify or minify the naturally occurring noise of wrist position vis a vis its visual depiction on the screen without changing any physical properties of the apparatus or visual display. Our main question was how high a level of gain participants could achieve for a given hand and hand position. We were interested in estimating the maximum gain, G_{MAX}, per hand and hand position so we could make statements about the relative degree of control that could be achieved by the hands in the positions they occupied. Our aim was not to find the optimal levels of control that could be achieved, but just to express the maximum level of control that could be reached as indexed by our maximum gain measure.

Behind the method were two main ideas. First, when visual feedback gain increases, greater control is needed to keep a visible cursor within a target of fixed width. By increasing the visual feedback gain and by identifying G_{MAX} for a given hand and hand-position, we could characterize the relative level of control that could be achieved as indexed by that variable. As stated before, but not expressed in terms of in G_{MAX} in particular, we now reiterate our prediction in terms of that variable. We predicted that G_{MAX} would be greater for the right hand than for the left hand and would be greater at midrange forearm orientations (up and in) than at extreme forearm orientations (down and out).

The second idea behind our method was to maximize sensitivity and minimize bias. If we had simply asked participants to do as well as possible at keeping the cursor in the target zone though the gain had a single unchanging value, our measure of performance might have been insensitive if the single gain were either too low or too high to differentially tax the neuromotor control system for the two hands and four hand positions. Regarding bias, participants might have entered the task biased by their beliefs or expectations and, with a single gain, their performance could have reflected those expectations or beliefs. We wanted to avoid a possible motivational confound of this kind. By dynamically changing the gain and by making the gain changes unobtrusive (another feature of our method, because nothing happened when the gain changed except for the relation between the handle's position and the needle's position on the screen), we could further reduce the chance that bias affected our results.

2.1. Subjects

Sixteen Penn State undergraduates (ten female, six male) participated in exchange for course credit. The subjects' ages ranged from 19 to 25 years (mean = 19.73 years, SD = 1.67 years). The subjects' mean height was 1.73 m (SD = 0.11 m) and their mean weight was 71.08 kg (SD = 22.82 kg). All participants reported preferring their right hand, as indicated in their responses to the short form of the Edinburgh Handedness Inventory (Oldfield, 1971). Their mean number of right-hand-preferred items out of 11 was 10.25. The study was approved by the Penn State Institutional Review Board.

2.2. Experimental setup and procedure

As shown in Fig. 1, the handle stood beneath a 95 cm high table on which rested a 48.3 cm diagonal screen with a resolution of

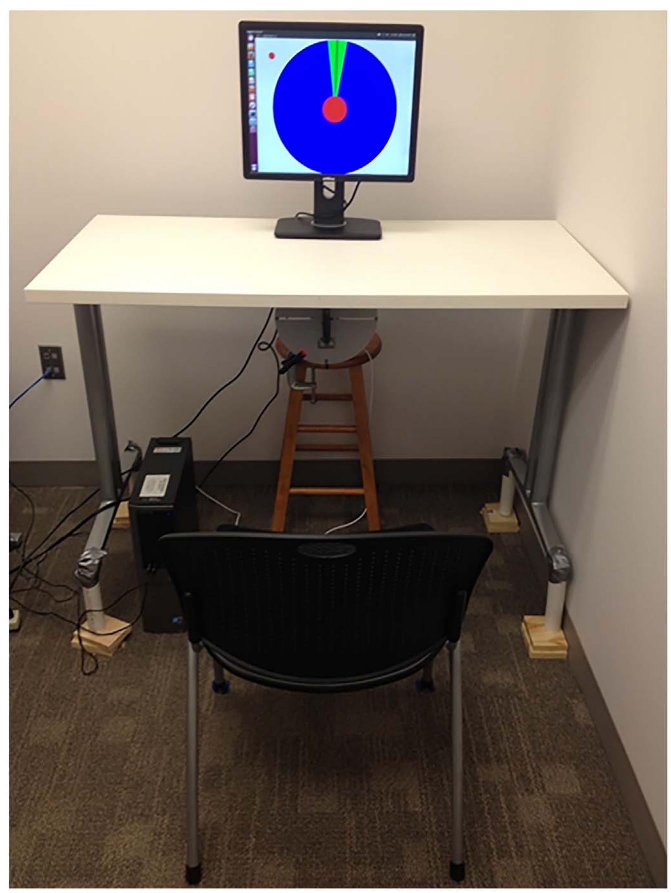

Fig. 1. Setup used in the experiment. Participants sat facing a computer screen. Here the needle (the black line extending from the central red dot) points straight up, indicating that the handle is at the middle of its acceptable range of motion. The red dot appearing in the upper left corner of the display indicates that the trial has not yet begun. The handle held by the participant is shown below the table. A clamp (bottom left) is affixed to the wheel on which the handle is mounted. The clamp was removed at the start of the trial. Here the handle is shown oriented vertically, allowing for “up” and “down” grasps. The handle could have also been oriented horizontally for “in” and “out” grasps. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)