



Effect of handle design on movement dynamics and muscle co-activation in a wrist flexion task



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ARTICLE INFO

Article history:

Received 6 May 2016

Received in revised form

25 July 2016

Accepted 14 October 2016

Available online 2 November 2016

ABSTRACT

Arm and wrist manipulanda are commonly used as input devices in teleoperation and gaming applications, establish a physical interface to patients in several rehabilitation robots, and are applied as advanced research tools in biomechanics and neuroscience. Despite the fact that the physical interface, i.e. the handle through which the wrist/hand is attached to the manipulator, may influence interaction and movement behavior, the effects of handle design on these parameters has received little attention. Yet, a poor handle design might lead to overexertion and altered movement dynamics, or result in misinterpretation of results in research studies. In this study, twelve healthy subjects performed repetitions of a wrist flexion task against a dynamic load generated by a 1-DOF robotic wrist manipulandum. Three different handle designs were qualitatively and quantitatively evaluated based on wrist movement kinematics and dynamics, patterns of finger and wrist muscle activity, and ergonomics criteria such as perceived comfort and fatigue. The three proposed designs were further compared to a conventional joystick-like handle. Task performance as well as kinematic and kinetic parameters were found to be unaffected by handle design. Nevertheless, differences were found in perceived task difficulty, comfort and levels of muscle activation of wrist and finger muscles, with significantly higher muscle activation when using a joystick-like design, where the handle is completely enclosed by the hand. Comfort was rated high for the flat handle, adapted to the natural curvature of the hand with the fingers extended. These results may inform for the design of handles serving as physical interface in teleoperation applications, robot-assisted rehabilitation and biomechanics/neuroscience research.

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1. Introduction

Physical human-machine interaction is a field of growing importance, with applications in teleoperation, gaming, robot-assisted rehabilitation and sensorimotor control research. With the ability to precisely track movement trajectories and render virtual dynamics in well-controlled and reproducible conditions, robotic devices are well-suited for the investigation of the mechanisms underlying human sensorimotor learning and control, or

(neuro)mechanical joint properties (Wolpert and Flanagan, 2010) and find application as therapeutic tools in neurorehabilitation. In research, single-degree-of-freedom (DOF) manipulanda have been widely used to evaluate passive and active joint properties, typically at the level of the wrist, by applying external, well-controlled perturbations to the joint (Milner and Cloutier, 1993, 1998). More complex planar robotic manipulanda have allowed new insights into learning and adaptation processes of the central nervous system during reaching movements in stable or unstable force fields generated by the robot (Shadmehr and Mussa-Ivaldi, 1994; Burdet et al., 2001). Although there have been approaches to quantify hand-handle interaction forces (Kalra et al., 2015), other aspects such as handle ergonomics are also important as it has been shown that handle design can strongly influence performance as well as movement dynamics and kinematics during manipulation tasks (Dong et al., 2007; Herring et al., 2011; Horsfall et al., 2005; Kong et al., 2008; Santos-Carreras et al., 2012). Motivated by the

Abbreviations: DOF, degrees-of-freedom; EMG, electromyography; FCR, M. Flexor Carpi Radialis; ECR, M. Extensor Carpi Radialis; FDS, M. Flexor Digitorum Superficialis; EDC, M. Extensor Digitorum Communis; CI, co-activation index; MVC, maximal voluntary contraction.

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ergonomics of hand-held machine tools, several studies have looked into optimizing cylindrically shaped handles, and found that the handle diameter influences forearm muscle activity, force generation capabilities, as well as perceived comfort during power grip tasks (Ayoub and Presti, 1971; Grant et al., 1992; Kong and Lowe, 2005; Gonzalez et al., 2015). However, in the case of isolated wrist tasks, there is less information on how handles should be designed and how the finger placement and guidance imposed by the handle might influence subjects' performance as well as affect comfort and fatigue. Yet, the wrist joint is ideally suited for motor learning experiments as, through an appropriate fixation, it can be reduced to a mostly 1-DOF joint with a large range of motion (up to 95°/98° [male/female] flexion), capable of generating high torques (around 8.6 Nm for males and 5.2 Nm for females in isokinetic contraction (Morse et al., 2006),) during dynamic interactions.

Most of the existing wrist robots used in motor learning research or in neurorehabilitation were designed with joystick-like handles (Masia et al., 2009; Suminski et al., 2007; Kadivar et al., 2012), in which the subject holds a cylinder-shaped handle using a power grasp, and the hand can enclose the entire handle surface. Pilot data previously collected by our group during dynamic wrist flexion tasks with a joystick-like handle mounted on a robotic wrist manipulandum (ReFlex, Chapuis et al., 2010) illustrated that such a handle may lead to high co-contraction levels between wrist flexor and extensor and between finger flexor and extensor muscle groups, which might affect the observation of adaptation mechanisms during motor learning experiments, and increase muscle fatigue or muscular pain during successive task repetitions. This might be an undesired side effect, especially in tasks involving intensive interaction with a robotic manipulandum, such as during robot-assisted rehabilitation.

An ergonomic interface between a robotic manipulandum and the wrist should in general consider several biomechanical and physiological factors. For example for the investigation of wrist joint control, it is desirable that movements are controlled mainly by wrist muscles and the contribution of extrinsic finger muscles is minimized. Mechanically unstable loading – e.g., caused by awkward postures due to ergonomically inadequate devices – may restrain or alter the formation of optimized patterns of muscle activity that occur during motor adaptation (Osui et al., 2002;

Hermesdörfer et al., 1999), leading to increased co-activation or co-contraction (i.e. co-activation of an agonist-antagonist muscle pair) of the forearm muscles (Milner and Cloutier, 1993). High rates of co-contraction and co-activation affect joint impedance (Hogan, 1984a) and may result in higher rates of fatigue, possible over-exertion and development of muscle pain (Tomatis et al., 2009; Zennaro et al., 2003). As subjects are typically required to perform many movement repetitions during motor learning tasks involving novel dynamics or in rehabilitation applications, the development of muscle fatigue or muscular pain should be avoided. It is thus important to reduce excessive muscle activation through an ergonomic design.

In this study, we present the qualitative and quantitative evaluation of three handle designs, evaluated on a 1-DOF robotic wrist manipulandum during repeated dynamic wrist flexion movements against a load generated by the robotic manipulandum. Handles are compared using ergonomics criteria such as comfort, fatigue and pain evaluated through questionnaires, as well as an analysis of muscle activity patterns in wrist and hand muscle groups measured with surface electromyography (EMG). We further compare patterns of muscle activity for a joystick-like handle used in previous measurements with the manipulandum. In addition, wrist dynamics and performance in a target reaching wrist flexion task are analyzed. We hypothesized that handle design and finger position on the handle would influence the way subjects perform fast wrist flexion movements, generate wrist flexion torque, and modulate wrist impedance.

2. Materials and methods

2.1. Subjects

Twelve healthy subjects (age 27.8 ± 10.7 years, 7 males) were recruited for this study. Participants came to the Rehabilitation Engineering Laboratory at ETH Zurich for a 1-h session with the robotic manipulandum (ReFlex, Chapuis et al., 2010). As inclusion criteria, subjects had to be over 18 years old and right handed. Exclusion criteria were any neurological disorders, functional deficits of the wrist/hand as well as any history of wrist injury, or presence of any dermatological diseases.

Prior to the experiment, each participant was informed about

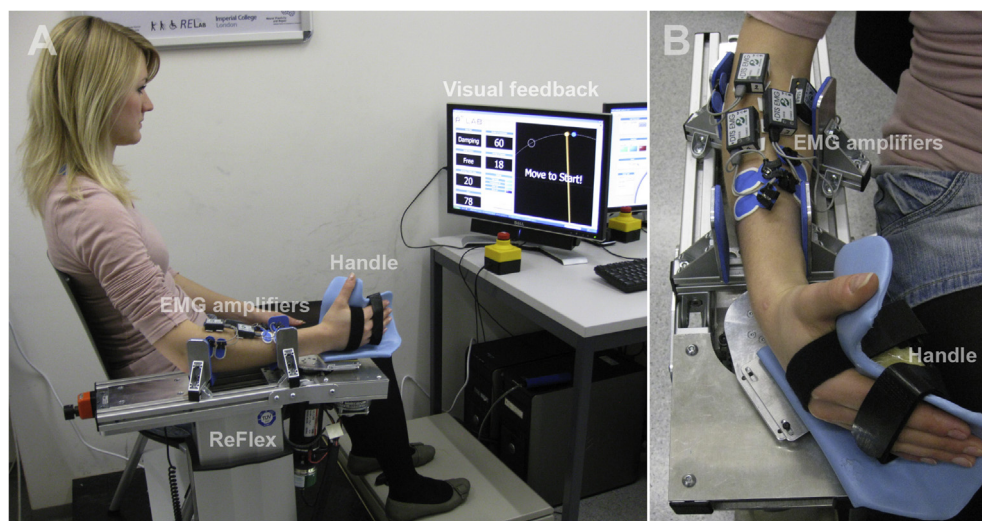


Fig. 1. Haptic wrist interface ReFlex. Experimental setup during a measurement session including the visual feedback presented to the subject (A). Front view of the adjustable arm support with a curved handle (B).

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