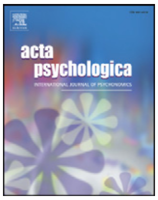
Acta Psychologica 138 (2011) 126–134

Contents lists available at ScienceDirect

Acta Psychologica

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



Comparison of grasping movements made by healthy subjects in a 3-dimensional immersive virtual versus physical environment[☆,☆☆]

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ARTICLE INFO

Article history:
Received 13 August 2010
Received in revised form 21 May 2011
Accepted 23 May 2011

PsycINFO classification:
2330 Motor processes
2323 Visual perception
3380 Rehabilitation

Keywords:
Virtual reality
Kinematics
Reach to grasp
Visual perception
Haptics
Motor process

ABSTRACT

Virtual reality (VR) technology is being used with increasing frequency as a training medium for motor rehabilitation. However, before addressing training effectiveness in virtual environments (VEs), it is necessary to identify if movements made in such environments are kinematically similar to those made in physical environments (PEs) and the effect of provision of haptic feedback on these movement patterns. These questions are important since reach-to-grasp movements may be inaccurate when visual or haptic feedback is altered or absent. Our goal was to compare kinematics of reaching and grasping movements to three objects performed in an immersive three-dimensional (3D) VE with haptic feedback (cyberglove/grasp system) viewed through a head-mounted display to those made in an equivalent physical environment (PE). We also compared movements in PE made with and without wearing the cyberglove/grasp haptic feedback system. Ten healthy subjects (8 women, 62.1 ± 8.8 years) reached and grasped objects requiring 3 different grasp types (*can*, diameter 65.6 mm, cylindrical grasp; *screwdriver*, diameter 31.6 mm, power grasp; *pen*, diameter 7.5 mm, precision grasp) in PE and visually similar virtual objects in VE. Temporal and spatial arm and trunk kinematics were analyzed. Movements were slower and grip apertures were wider when wearing the glove in both the PE and the VE compared to movements made in the PE without the glove. When wearing the glove, subjects used similar reaching trajectories in both environments, preserved the coordination between reaching and grasping and scaled grip aperture to object size for the larger object (cylindrical grasp). However, in VE compared to PE, movements were slower and had longer deceleration times, elbow extension was greater when reaching to the smallest object and apertures were wider for the power and precision grip tasks. Overall, the differences in spatial and temporal kinematics of movements between environments were greater than those due only to wearing the cyberglove/grasp system. Differences in movement kinematics due to the viewing environment were likely due to a lack of prior experience with the virtual environment, an uncertainty of object location and the restricted field-of-view when wearing the head-mounted display. The results can be used to inform the design and disposition of objects within 3D VEs for the study of the control of prehension and for upper limb rehabilitation.

Virtual reality (VR) technology is increasingly being used to create environments for motor rehabilitation (Rose et al., 2000; Saposnik & Levin, 2011). One advantage of this technology is the ability to manipulate sensory attributes of training environments such as object properties and user feedback. For example, VR technology makes it possible to create tasks that can be controlled, programmed and modified according to user abilities while allowing them to interact with objects in an environment that is potentially more motivating than traditional rehabilitation settings (Broeren, Rydmark, & Sunnerhagen, 2007; Jack et al., 2001; Knaut, Subramanian, McFadyen, Bourbonnais, & Levin 2009; Lourenço, Azeff, Sveistrup, & Levin 2008; Sveistrup, 2004). However, before being adopted as an exercise environment for rehabilitation, it is necessary to determine the kinematic equivalence of movements made in virtual environments (VE) by comparing them to similar movements made in physical environments (PE). This is especially important for reach-to-grasp movements which largely

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[☆] Part of the material in the manuscript was presented in abstract form at the Canadian Physiotherapy Association National Congress, Ottawa, ON, Canada, May 29–June 1, 2008 (Poster #011.43) and at Virtual Rehabilitation 2008, Vancouver, CANADA, August 25–27, 2008.

[☆☆] Supported by the Canadian Foundation for Innovation (CFI) infrastructure grant to MFL. MFL holds a Tier 1 Canada Research Chair in Motor Recovery and Rehabilitation. ECM is with the State University of Campinas, Brazil and was supported by CAPES — Brazil.

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doi:10.1016/j.actpsy.2011.05.015

depend on veridical information about the object to be grasped in order to plan reaching paths and grip types (Jeannerod, 1999; Smeets & Brenner, 1999). Specifically, previous studies have found that grasping in VEs is inaccurate in the absence of haptic feedback (Hibbard & Bradshaw, 2003) but that parameters of grasping are improved when continuous or intermittent haptic calibration is provided (Bingham, Coats, & Mon-Williams, 2007; Cuijpers, Brenner, & Smeets, 2008). Most of the previous studies describing grasping in VEs have used physical objects (augmented reality) or fixed devices (i.e., joysticks) to provide haptic feedback instead of tactile or force feedback delivered directly to the hand and/or fingers.

Using a handheld haptic stylus and two different grip types in a VE, Broeren et al. (2007) reported consistent performance of reaching movements in terms of movement time, hand path ratio and peak velocities in healthy adults but parameters were not compared with those from similar reaching movements in a PE. Viau, Feldman, McFadyen, and Levin (2004) compared reaching and grasping made in a VE displayed on a computer screen with no visual depth cues to a PE of equivalent dimensions in healthy subjects. A virtual hand representation was obtained with a glove equipped with strain-gauge sensors (Cyberglove, Immersion Corp.) and haptic information was delivered via a prehension force-feedback device (Cybergrasp, Immersion Corp.). Arm kinematic data were recorded with an optical motion analysis system (Optotrak, NDI Inc.) as participants reached to physical or virtual targets. Movements involving reaching, grasping, transporting and placing a ball, were similar in terms of spatial and temporal kinematics in both environments. However, subjects used more elbow extension and less wrist extension in the VE, which was attributed to the absence of depth perception and tactile feedback in the VE at the end of the reach.

Use of a VE with better 3D rendering can overcome the problem of altered grasping kinematics due to problems in depth perception. Thus, we created a 3D VE with object locations calibrated to the subject's arm length and recorded reaching and grasping movements to three objects requiring different types of grasps. Since the provision of adequate haptic information is essential for grasping, we also used a cyberglove and cybergrasp system for this purpose and compared movements made with and without the glove in a PE. We hypothesized that reaching and grasping kinematics of movements made in the 3D VE when haptic feedback is provided would not be different from those made in a similarly-calibrated PE in healthy subjects. We also hypothesized that the haptic glove system itself might modify some parameters of grasping because of its weight and encumbering effect. Preliminary results have appeared in abstract form (Magdalon, Michaelsen, Quevado & Levin, 2008).

1. Methods

1.1. Study sample

A convenience sample of 10 healthy right-handed adults participated (eight women; mean (SD) 62.1 (8.8) yrs, range 49–74 yrs). Participants were excluded if they had neurological or orthopedic arm disorders or were previously exposed to a similar VE. Participants signed informed consent forms approved by the Ethics Committee of CRIR – Center for Interdisciplinary Research in Rehabilitation of Greater Montreal. Participants had no known visual or perceptual problems, movement impairments or other conditions that would interfere with reaching and grasping movements.

2. Experimental procedure

2.1. Reach-to-grasp task

Subjects reached and grasped 3 objects (can, screwdriver, and pen) with their dominant hand, presented in two environments. In PE, physical objects were manipulated directly with the subject's hand or while the subject wore a glove that provided haptic information about the object (see below). In the 3D immersive VE, subjects manipulated visually similar virtual objects of the same dimensions while wearing the haptic glove. Participants were comfortably seated in front of a table adjusted to elbow height. For all trials, the wrist initially rested on a foam support (120 mm × 70 mm × 25 mm) with the shoulder in ~0° extension and ~20° abduction (where 0° for each direction was defined as the arm alongside the body), the elbow flexed to ~90° (fully outstretched position was 180°), the forearm semi-pronated and the wrist in neutral between flexion and extension with the index and thumb in contact (Fig. 1). The contralateral arm rested alongside the body. At an auditory signal, participants reached, grasped and transported the object at a self-paced speed from midline to a position 31.5 cm ipsilateral to midline and then returned their arm to the initial posture.

Objects were placed in front of the participant in the trunk midline at 2/3 arm length (measured from the medial border of the axilla to the wrist crease). The objects had different orientations and afforded three different grasp types. The can (height 70 mm, diameter 65.6 mm) was oriented vertically and required a cylindrical grasp (circular palmar grasp). The screwdriver (height 280 mm, diameter 31.6 mm) was oriented horizontally and rotated 30° on the table requiring a power grasp (palmar grasp with abducted thumb). The pen (height 150 mm, diameter 7.5 mm) was oriented vertically and required a precision grasp between index and thumb. All three objects were of similar dimensions and occupied the same amount of the visual field in both environments. The objects rested (PE) or appeared to be resting (VE) on a horizontal surface and were all located at the same height in the visual field to avoid differences in distance perception (Cutting & Vishton, 1995; Mon-Williams & Bingham, 2008). To maximize recognition in the virtual environment and incorporate functional tasks we used three common objects that could be easily recognized in 3D environments and are commonly manipulated. Object presentation within each environment was randomized and the order of environments was balanced and randomized. Ten trials were recorded for each object and environment for a total of 60 trials, with rest periods of 1–5 min permitted between trial blocks and tasks. Participants were allowed to practice 5 trials prior to recording in order to become familiar with the VE.

2.2. Virtual environment

The VR system was created with the CAREN (Computer Assisted Rehabilitation Environment; Motek BV) VR simulation system running on an IBM compatible PC (Dual Xeon 3.06 GHz, 2 GB RAM, 160 GB hard drive and Windows XP). The system had a dual head Nvidia Quatro FX 3000 graphics card providing a stereoscopic visual representation of the environment with high frame rates (70 Hz). The system had a delay time of 16 ms. The VE was displayed in 3D via a head-mounted display (HMD) (Kaiser XL50, Rockwell Collins, UK[1]). The HMD had a FOV of 50° diagonal, 30° vertical and 40° horizontal, XGA resolution 1024 horizontal pixels × 768 vertical lines, frequency 60 Hz and weighed 1 kg. The HMD blocked all peripheral vision and only the VE was visible to the participants. The virtual representation of the subject's hand was obtained using a glove embedded with 22 strain-gauge sensors (Cyberglove, Immersion Corp.[2]) which provided range of motion and velocity information. To enable the subject to "feel" the virtual objects, a Cybergrasp device (Immersion Corp.[2]) was fitted to the dorsal surface of the gloved hand which delivered prehension feedback in the form of extension forces (up to 12 N per finger) to the distal phalanxes of each digit. The timing and magnitude of the force pulses stimulated low-threshold cutaneous mechanoreceptors when the hand contacted the virtual objects providing the subject with the sensation of touching a solid surface (Johansson &