Effects of Force and Displacement Cues while Adapting in a Rhythmic Motor Task

Article · January 2009

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Effects of Force and Displacement Cues while Adapting in a Rhythmic Motor Task

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Abstract— This paper explores the effects of magnitude and phase cues on human motor adaptation. Participants were asked to excite virtual second-order systems at their resonance frequencies via a two-degree of freedom haptic interface, with visual and visual plus haptic feedback conditions. Their motor adaptations were studied through catch trials. The results indicate that, i) humans adapt to a nominal virtual system resonant frequency, ii) humans shift to higher and lower natural frequencies during catch trials regardless of feedback modality and force cues, iii) humans can detect changes in natural frequency when gain, magnitude, and phase cues are manipulated independently, and iv) humans are able to detect changes in natural frequency when the feedback (visual or visual plus haptic) is delayed such that the phase shift between the nominal system and catch trial system is zero.

I. INTRODUCTION

Haptic guidance schemes are incorporated in virtual environments to improve performance and to reduce training duration and user workload. Virtual fixtures, record-and-play, shared control, and error-based guidance schemes have shown potential to improve user performance during task completion and to accelerate learning rates, by guiding the user to perform the task in a preferred manner (see [1] and the references therein). Our prior works have focused on the effects of various forms of haptic assistance on both performance enhancement and training for manual control tasks and we have proposed shared control as the most general active haptic guidance scheme [1,2]. Our results indicate that the performance of manual control tasks is influenced by the user's ability to identify the dynamic parameters of the manipulated system [1]. Hence, it is suggested that a better understanding of human response and adaptation to varying system dynamics can enable improved design of haptic guidance schemes [2].

In the literature, it has been shown that humans can adapt their feed-forward control commands over time [3,4]. This adaptation can be viewed as successful training of a new skill. Control parameter adaptation during object manipulation was observed by Huang *et al.* [5] in a recent study of online control during object manipulation. They investigated a simple rhythmic object manipulation task in a virtual environment and determined that participants could identify and excite distinct virtual system natural frequencies with visual only, haptic only, or combined visual and haptic feedback. They also observed that participants appeared to tune control parameters of a general feedback strategy.

We hypothesize that the ability to learn new motor skills depends on the ability to form a control model, and to tune control parameters. The objective of this work is to determine which cues (displacements or forces) are primary for identification of a controlled system's dynamic behavior. To this end, we explore the ability of humans to resonate second-order virtual mechanical systems with the same or distinct natural frequencies. We investigate the effects of magnitude and phase cues, and feedback modality, on the human's ability to maintain or adapt their control commands for such a manually excited resonance task.

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II. METHODS

Participants sat in front of the monitor screen that displayed two rectangular masses and held a force feedback joystick (IE2000, Immersion Corp.) with their dominant hand (Fig. 1). The motion of one mass, m_1, was directly coupled with the joystick motion. The second mass, m_2, was connected to m_1 by a virtual spring (k) and damper (b), thus indirectly controlling the motion of m_2 with the joystick motion. The displacement transfer function (the mapping between the displacement of m_2 and the displacement of m_1) and the impedance TF (the mapping between the force applied by the motors and the displacement of m_1) were derived and used for haptic rendering. The visual cues were updated at a rate of 60 Hz on the computer screen while the haptic rate was set at a typical 1000 Hz. Force and displacement data of m_1 and m_2 were collected at a rate of 50 Hz.

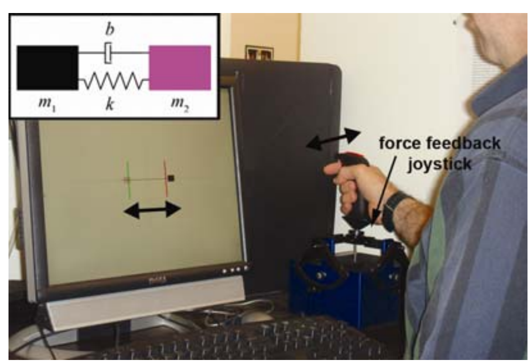

Fig. 1. A pictorial explanation of the dynamical task.

Six healthy male students of Rice University (18-32 years old, avg. 22 years) participated in the study. They were asked to smoothly oscillate m_1 at the natural frequency of the virtual second-order dynamic system by moving the joystick along one of its axes in a sinusoidal manner throughout 10-second long trials. They were told that if the excitation was at the natural frequency of the virtual second-order system, the amplitude of oscillations of m_2 would grow largest for constant amplitude excitation of m_1. At the end of the trial, a message indicating if participant's hand oscillation was greater than, lower than or within 5 percent of the system natural frequency was displayed as performance feedback.

At the beginning of the experiment, participants were overtrained with a nominal system of 1 Hz natural frequency. Once they adapted to the dynamics of the nominal system then in random "catch trials" the parameters of the dynamical system were altered such that the resulting target systems had either the same or different natural frequency with altered magnitude and/or phase cues. The target systems were presented in three sets of test sessions, in which one out of ten trials was a catch trial. In the first set, the natural frequency of the system was same as that of the adapted nominal system and the magnitude cue was changed by either changing the damping ratio or the dc-gain. The phase cue was changed by incorporating the delay between the states of the two masses. In the second set, the natural frequency of the system was changed. The catch trial systems had either both magnitude and phase cues altered or one of the two cues altered. In the third set, the impedance magnitude function of the target and nominal systems were matched while keeping the same or different natural frequency. All target systems were tested six times in random order and with two type of sensory feedback, i.e., visual-alone (V) and visual combined with haptic (V+H) feedback.

The spectrogram (time-frequency trajectory) profiles of hand displacement data were obtained and the frequency with the largest intensity at each sample instant was extracted. A plot of the frequency as a function of the duration of a trial was termed as the hand motion frequency profile while controlling the nominal or the target system. *Frequency trajectory error* is introduced as a measure of performance, defined as the absolute difference between the hand frequency profile and the natural frequency of the target system accumulated across a 10 second trial, i.e., 500 samples. Statistical tests such as analysis of variance and Student's t-test were used to determine differences among systems, and sensory feedback at a 95% significance level (i.e., α=0.05).

III. Results

An exemplary time-frequency profile of the hand motion for the target systems with different natural frequency compared to the nominal system is shown in Fig. 2.

For target systems with the natural frequency same as that of the nominal system, participants in general did not diverge from the natural frequency when magnitude cue was altered, despite matching the impedance or displacement transfer function. Effects of feedback on frequency trajectory errors data failed to show significance. When both the magnitude and phase cues were changed for target systems of different natural frequency, the hand trajectory quickly adapted to the new dynamics and converged to the system's natural frequency. A repeated measure ANOVA showed that the frequency trajectory errors were significantly lower with the

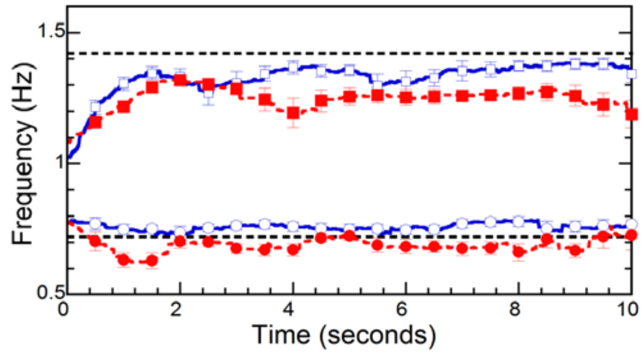

Fig. 2. Average time-frequency trajectory profiles of the target systems when both magnitude and phase cues were altered. The error bars show standard error of the mean. Open and filled symbols represent hand excitation profiles with V and V+H feedback, respectively.

nominal system and larger when exciting the systems of high natural frequency. Further analysis showed that the trajectory errors were affected by the feedback at the high natural frequency and were not affected at the low natural frequency. When either magnitude or phase cue was changed in target systems with different natural frequency, the errors substantially increased indicating inability of participants to quickly converge to the natural frequency. The errors were relatively higher when exciting the high natural frequency than when exciting the low natural frequency. An interesting observation was that for target systems with low natural frequency the effect of feedback failed to show significance on the trajectory error data, whereas, V feedback yielded significantly larger errors than V+H feedback when exciting the high natural frequency. This result indicates that when one cue was changed, a human ability to adapt to the low natural frequency was not affected by the feedback, and haptic cue help participants identify and converge to the high natural frequency.

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