Sensory Weighting in a Rhythmic Ball Bouncing Task

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Sensory Weighting in a Rhythmic Ball Bouncing Task

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1 Introduction

The role of sensory information in walking remains unclear despite its relevance to understanding human locomotor deficits and as a source of insight for robotics. System identification experiments using sinusoidal perturbations of a visual scene have yielded insights into control of human standing posture [2]. We propose a framework through which similar techniques can be used to identify estimator and controller structures used by humans during rhythmic movement.

A key challenge in translating these techniques to human walking is the high number of degrees of freedom involved. To address this, we examine paddle juggling (Figure 1) as a useful starting point to study control of rhythmic movements. Paddle juggling is much simpler than behaviors such as walking and running [1, 3] and yet preserves much of the essential nature of locomotion, such as its hybrid dynamical structure.

2 Methods

We developed a hard real-time virtual reality juggling apparatus that allows the delivery of precise visual and timing perturbations and the measurement of kinematics. Participants are presented with a graphical representation of a ball and paddle on a monitor, and are tasked with bouncing the ball with the paddle by moving a control device (a "haptic paddle"). Figure 1C illustrates 10 s during a typical juggling experiment, and marks collision and ball apex events as the paddle moves in real time. Our system allows us to manipulate various task settings, including dynamic parameters, and also features two different control modes: *paddle unlocked*, where paddle kinematics are displayed directly to the monitor, and *paddle locked*, where the paddle position is kept constant at all times, but paddle velocity and acceleration are updated according to the user's hand movements. The paddle-locked configuration is extremely useful as it allows for the calculation of closed-form dynamics and real-time estimate of the phase because at the time of paddle–ball collision, the time of the next impact can be predicted exactly.

We postulate that, with practice, a paddle juggler's behavior converges to an isolated, stable limit cycle with a nominal limit-cycle trajectory defined by the goal height. In paddle-locked mode, the plant can be modeled via a 1D linear Poincaré map about the ball apex position. This map can be linearized about the nominal height, to yield the following discrete-time, linear, time-invariant (LTI) system:

$$\Delta x_{n+1} = A_n \Delta x_n + B_n \Delta u_n, \qquad (1)$$

where Δx_n is the deviation of the ball height from the goal height during the n^{th} cycle and Δu_n is the deviation of paddle velocity from the nominal velocity. The parameters A_n and B_n are derived based on assuming that the ball trajectory is governed by a known gravitational constant and that the ball–paddle impact respects a simple coefficient of restitution law.

Our present experiment aims to find stimulus regimes in which closed-loop juggling is approximately linear, and to identify the human estimator and controller in these linear regimes. To identify the role of visual information, we apply perturbations to the displayed ball position and assess the juggler's response. The ball that is displayed on the screen is equal to the simulated ball height plus an input perturbation that varies from cycle to cycle. The output is taken as the actual (rather than displayed) ball height at each cycle.

3 Preliminary Results and Discussion

We hypothesize that participants will adjust their motor output in response to the visual perturbations, exhibiting a frequency-dependent "gain" to the visual perturbation. Specifically, we expect visuomotor gain to be lowpass, and phase to be uniformly 180°, as subjects will consistently react to visual perturbations by juggling "lower" or "higher" in the opposite direction of errors. At low frequencies we expect to see a 0 dB gain, corresponding to perfectly canceling out the perturbation at DC. As perturbation frequencies increase, we expect gain to decrease. Although we expect subjects will still attempt to cancel out perturbations, amount of compensation will be capped because cycle-by-cycle errors will fluctuate more rapidly, in addition to being higher magnitude.

Our data thus far shows that a skilled participant juggles sinusoidally in response to sinusoidal visual perturbations (Figure 2), in agreement with our general hypothesis. Sinusoidal magnitude of 1 cm was sufficient to induce this behavior, as shown for a perturbation of frequency $f_v = 17$ perturbation cycles per 40 juggling cycles (Figure 2A). Surprisingly, the skilled juggler is high-pass (Figure 2B), and tends to *overcompensate* for larger errors.

Pilot experiments with other participants indicate that duration of juggling experience is an important factor, so we are currently training subjects during multiple sessions. We will extend our analysis to perturbations in the timing of a haptic impulse provided to the hand at ball–paddle collision to assess the weight of haptic cues, another sensory modality that is important for stability in this task [1].

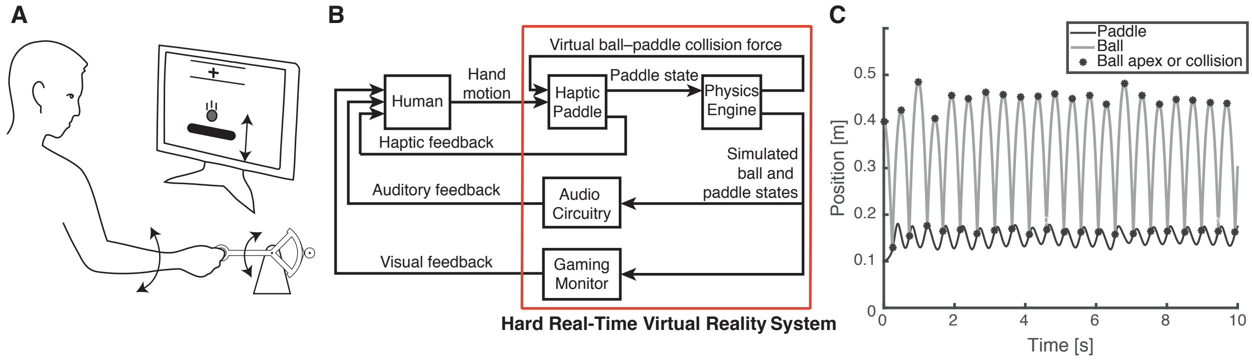

Figure 1: (**A**): The virtual paddle juggling task. (**B**): Block diagram of hard RT system with human user in loop. (**C**) Data from typical juggling session.

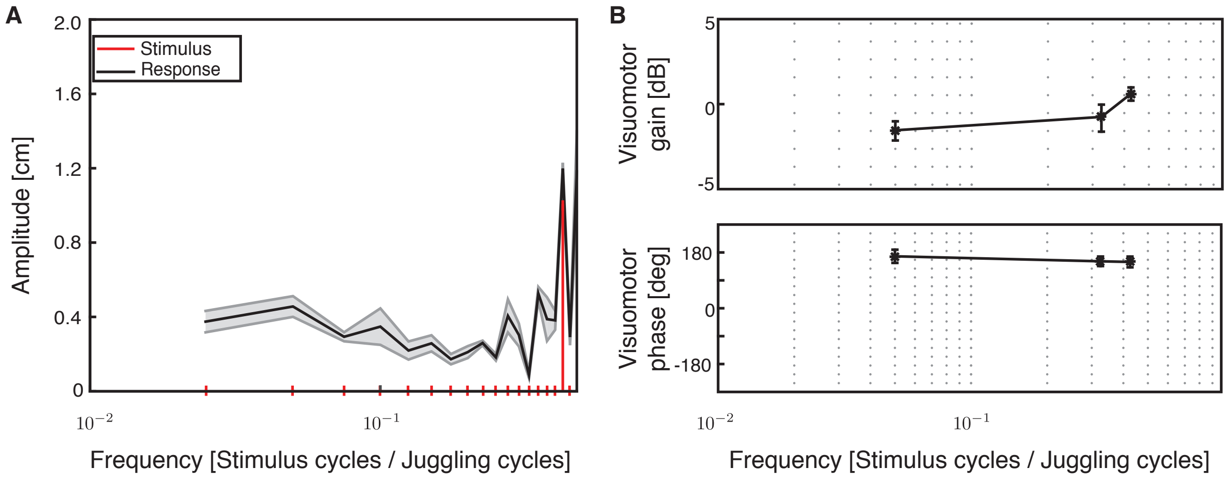

Figure 2: Responses of skilled juggler to visual perturbations. **(A)** Fourier transforms of ball apex perturbation at a frequency of 17 stimulus cycles per 40 juggling cycles (red). The corresponding neuromechanical response translates to a change in the actual ball apex position (black) due to the effect of the perturbation on the user's paddle control. **(B)** Estimated frequency response function (gain and phase) for the juggling task for the same participant. The inputs were perturbations to the displayed ball apex, and the outputs were the actual ball apex positions. Three stimulus frequencies were tested: $f_v = 2/40, 13/40, 17/40$, in units of stimulus cycles per juggling cycles.

References

[1] M. M. Ankarali and N. J. Cowan. System identification of rhythmic hybrid dynamical systems via discrete time harmonic transfer functions. In *Proc IEEE Int Conf on Decision Control*, Los Angeles, CA, USA, December 2014.

[2] K. S. Oie, T. Kiemel, and J. J. Jeka. Multisensory fusion: simultaneous re-weighting of vision and touch for the control of human posture. *Cog Brain Res*, 14(1):164–176, June 2002.

[3] S. Schaal, C. G. Atkeson, and D. Sternad. One-handed juggling: A dynamical approach to a rhythmic movement task. *J Motor Behav*, 28(2):165–183, 1996.