Human Response Delay in Balancing Virtual Pendulums with Overdamped Dynamics

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ABSTRACT

The results of our experiments aimed at estimating the distribution of the response delay time in human intermittent control over unstable mechanical systems are presented. A novel experimental paradigm: balancing an overdamped inverted pendulum was used. The created simulator of balancing a virtual pendulum makes the pendulum invisible when the angle between it and the upward position is less than 5°, which enabled us to measure directly the delay time. It is demonstrated, in particular, that (i) the response delay time may be treated as a random variable distributed within a wide interval and (ii) the response delay in human intermittent control may be determined by cumulative actions of two distinct mechanisms, automatic and international, endowing it with complex nonlinear properties.

Categories and Subject Descriptors

J.4 [**Social and Behavioral Sciences**]: psychology; H.1.2 [**User/Machine Systems**]: human factors

General Terms

Experiment

Keywords

Human intermittent control, response delay, pendulum balancing

1. INTRODUCTION

According to the modern paradigm, human control over unstable mechanical systems can be categorized as intermittent and this type of control being rather efficient on its own is a natural consequence of human physiology (see., e.g., [1]). With respect to human behavior the notion of intermittency implies that actions of a human operator in controlling a mechanical system form a sequence of alternate fragments of passive and active phases, with transitions between them being event-driven. The latter means that the control is activated or halted when the discrepancy between the goal and the actual system state exceeds a certain threshold or falls behind it, respectively. Recently, we developed a concept of noise-driven control activation as a more advanced alternative to the conventional threshold-driven activation [2]. In this concept the transition from passive to active phases is probabilistic and reflects human perception and fuzzy evaluation of the current system state before making decision concerning the necessity of correcting the system dynamics. Broadly speaking, during the passive phase the operator accumulates the information about the system state, naturally, this process is not instantaneous but requires some time in addition to the physiological delay in human response. The cumulative effect of the two mechanisms, the accumulation of information about the system state and the physiological delay, can be described by some delay time τ_d. The found stochasticity of human intermittent control in experiments on balancing virtual stick [2] prompts us to expect that this delay time is not a fixed value but a random variable with a relatively wide distribution; this feature is crucial for modeling human intermittent control. To elucidate the probabilistic properties of this cumulative delay in human reactions in controlling unstable mechanical system we have conducted some experiments and the purpose of present work is to report the obtained results.

However, before discussing our results, some comments concerning the research of human response delay are worthwhile. Investigations of response delay in human reactions to various stimuli including visual ones has a relative long history (see, e.g., [3]). Usually in experiments on human visual perception the values of delay time $\tau_d \gtrsim 100$ ms are detected and they are unimodally distributed within a wide interval; the gamma or Weibull fits are often used to characterize the found results (see, e.g., [4]). During the last decade there has been accumulated some evidence that mental processes contribute substantially to the response delay and such factors as memory load and required attention are essential in this case (see, e.g., [5, 6] and references therein). Taking into account this fact and the possible existence of two mental systems of information processing (see a review [7]) we may expect the response delay time distribution to exhibit complex behavior especially in cases when it is related to decision-making in multifactorial processes like human intermittent control.

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2. EXPERIMENTAL SETUP

As previously [2], in our investigations, we used a novel

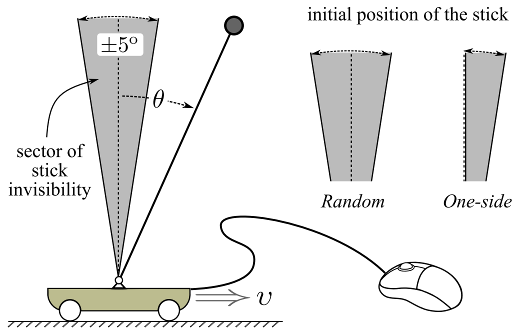

Figure 1: The used simulator of balancing a one-degree-of-freedom overdamped inverted pendulum (stick) with a region of invisibility.

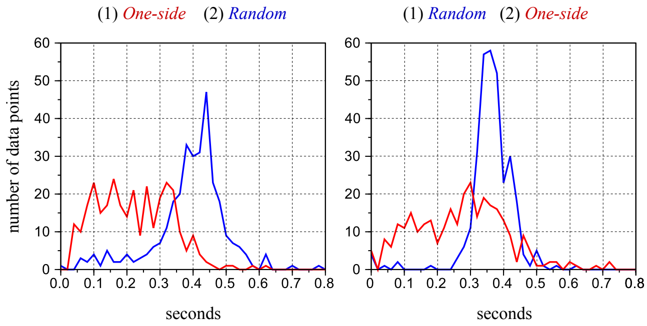

Figure 2: Two histograms of response delay time obtained based on the conducted experiments for different subjects within the *Random* and *One-side* stick appearance setup.

experimental paradigm: balancing an overdamped inverted stick (Fig. 1) whose dynamics is governed by the equation

$$\tau\frac{d\theta}{dt} = \sin\theta - \frac{\tau}{l}\vartheta\cos\theta\,,$$

where the cart velocity ϑ is determined by operator actions, τ is the timescale of the stick motion, l is the stick length. The overdamping eliminates the effects of inertia, and therefore reduces the dimensionality of the system. The new feature of this balancing simulator is that the stick becomes invisible within the sector $\pm5^{\circ}$ (Fig. 1).

Twelve subjects were instructed to maintain the upright position of the stick on the computer screen by moving the platform horizontally via the computer mouse. When the stick leaves this sector and becomes visible, a subject tries to restore its upright position. If, nevertheless, the stick falls it is returned immediately by computer into the invisibility sector and the balancing experiment is resumed. Two types of experimental set-up were studied, in the first case after falling, the stick is placed randomly inside the invisibility sector such that from which side the stick will appear is not predictable. In the second case the stick appears from one side only. The time span τ_d between the moments when the stick leaves the invisibility sector becoming visible and when a subjects starts cart (mouse) motion was fixed and regarded as the current value of the response delay time.

3. RESULTS AND DISCUSSION

The statistical data collected in this way are illustrated in Fig. 2. Their analysis enables us to draw the following conclusion.

- The response delay time characterizing the transition from passive to active phases in human intermittent control is a random variables changing in a wide interval from the lower value less than 100 ms up to upper value about 600 ms. It should be noted that the lower and upper values are typical delay times of human response to predictable and unpredictable events, respectively [1].

- The found distributions of response delay time for many subjects contain at least two different fragments represented individually in Fig. 2 by *Random* and *One-side* data, which argues for the hypothesis about the existence of two mental systems affecting together human decision-making.

- The individual difference in the response delay time distribution found for several subjects in experiments with predictable and unpredictable stick appearance demonstrates the substantial role of mental processes in evaluating the current state of system dynamics by human operators.

The found results are essential for constructing mathematical models of human intermittent control that operate directly with the human delay.

4. REFERENCES

[1] Ian D. Loram, Henrik Gollee, Martin Lakie, and Peter J. Gawthrop. Human control of an inverted pendulum: is continuous control necessary? Is intermittent control effective? Is intermittent control physiological? *The Journal of Physiology*, 589(2):307–324, 2011.

[2] Arkady Zgonnikov, Ihor Lubashevsky, Shigeru Kanemoto, Toru Miyazawa, and Takashi Suzuki. To react or not to react? Intrinsic stochasticity of human control in virtual stick balancing. *Journal of The Royal Society Interface*, 11:20140636, 2014.

[3] Trisha Van Zandt. Analysis of Response Time Distributions. In Hal Pashle and John Wixted, editors, *Stevens' Handbook of Experimental Psychology, Volume 4, Methodology in Experimental Psychology*, pages 461–516. John Wiley & Sons, New York, 3rd ed., 2002.

[4] Evan M, Palmer, Todd S. Horowitz, Antonio Torralba, and Jeremy M. Wolfe. What are the shapes of response time distributions in visual search? *Journal of Experimental Psychology: Human Perception and Performance*, 37(1):58–71, 2011.

[5] Edward F Ester, Tiffany C Ho, Scott D Brown, and John T Serences. Variability in visual working memory ability limits the efficiency of perceptual decision making. *Journal of vision*, 14(4):2(1–12), 2014.

[6] Benjamin Pearson, Julius Raškevičius, Paul M Bays, Yoni Pertzov, and Masud Husain. Working memory retrieval as a decision process. *Journal of Vision*, 14(2):2(1–15), 2014.

[7] Jonathan St BT Evans. Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology*, 59:255–278, 2008.