Visuomotor Tracking on a Computer Screen – An Experimental Paradigm to Study the Dynamics of Motor Control

R. Bormann[1], J.-L. Cabrera[2], J. G. Milton[3] and C. W. Eurich[1]

[1]Institute for Theoretical Physics, University of Bremen, Germany
bormann@uni-bremen.de, eurich@physik.uni-bremen.de
[2]Laboratorio de Fisica Estadistica, IVIC, Venezuela
jlc@manare.ivic.ve
[3]Department of Neurology, The University of Chicago, USA
sp1ace@ace.bsd.uchicago.edu

Computational principles of motor control problems like motor planning, estimation, prediction and learning have recently attracted much attention (e. g. [1]). A particular class of problems, the ongoing feedback control, is especially suited to derive dynamical properties and mechanisms underlying the control of body movements. Examples for such feedback systems include the control of body posture [2] where noise-induced transitions between co-existing periodic orbits account for the dynamics of the body center-of-pressure [3]; and the problem of balancing a stick at the fingertip where the existence of parametric noise and on-off intermittency have been demonstrated [4]. These two systems, however, allow only for a limited manipulation of system parameters. In postural sway, body mass and height are basically fixed, in in stick balancing, only the mass and the geometry of the stick can be altered deliberately.

In this contribution, we describe a more flexible experimental paradigm for studying the dynamics of motor control in a visually guided feedback task.

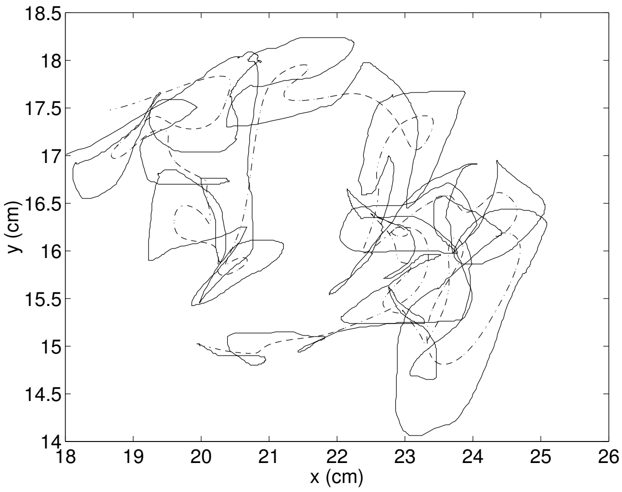

FIGURE 1: *Example of a tracking sequence of a 32-year-old male subject. Solid line: orbit of the mouse pointer showing the hand movements. Dashed line: orbit of the target. For the experiment, a computer screen with a resolution of 1200x1600 pixel is used. Length scales were converted to cm, whereby the conversion factor is 43 pixel/cm. The actual movement of the hand on the table covers* $1/4$ *of the screen area.* $k = 10$.

A subject is presented two dots on a computer screen. The first dot represents the position of the computer mouse and thus reflects the position of the subject's hand. The second dot is a target which has to be tracked. In a first series of experiments, the motion of the target was determined to be

$$\ddot{\vec{x}}_t(t) = k\left(\vec{x}_t(t) - \vec{x}_m(t)\right) , \tag{1}$$

where $\vec{x}_t$ and $\vec{x}_m$ are the positions of the target and the mouse pointer, respectively. The feedback enters through the distance-dependency of the "force" acting on the target. During a session, the subject is asked to "balance" the target by keeping the dots as closely together as possible while avoiding an escape of either point off the screen. The movement of both the mouse and the target is recorded with a sample rate of 100 Hz. Figure 1 shows a sample recording of such a session, covering about 30 s of tracking.

The equation of motion (1) is that of an harmonic oscillator and corresponds to the dynamics of a stick balanced at small angles. We investigated if the dynamics of the hand and forearm in our setup resembles the dynamics of the control movements during stick balancing. Figure 2 shows an example of a power spectrum of $|\vec{x}_t - \vec{x}_m|$. Two scaling regions are clearly visible, one with slope $-1/2$ and one with slope -2.6 (solid lines). This corresponds very well with the results on stick balancing [4] where exponents of $-1/2$ and -2.5 were found. The first scaling region was interpreted as a hallmark of on-off intermittency [4,5]. This interpretation is further corroborated in our tracking system by the statistics of the so-called laminar phases, i. e., those parts of the trajectory where the distance between mouse and target falls below a given threshold: the number of sequences scales with an exponent of $-3/2$ as a function of sequence length (data not shown). The on-off intermittency in connection with the existence of parametric noise results in a statistical stabilization of the target [4].

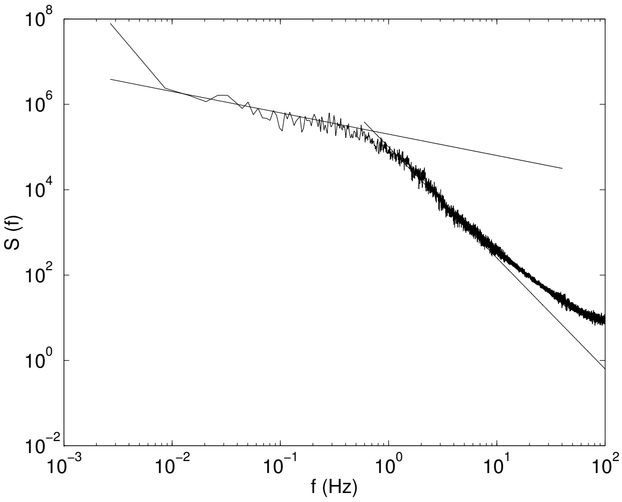

FIGURE 2: *Power spectrum of the tracking movement of a 64-year-old male subject for $k = 5$. Two trajectories were averaged.*

The tracking paradigm introduced here will allow for a thorough study of the properties of neural control. For example, the feedback law for the target may be altered deliberately. In particular, artificial delays – which will add to the delays of the subjects' sensorimotor loop – can be introduced and tested against predictions of dynamical models. Such models will be much easier than in other control problems, because the natural environment is in part replaced by an artificial environment on the computer screen.

[1] D. Wolpert and Z. Ghahramani, *Computational principles of movement neuroscience* Nature Neurosci. Suppl. **3** (2000) 1212–1217.

[2] J. J. Collins and C. J. De Luca CJ, *Open-loop and closed-loop control of posture: a random walk analysis of center-of-pressure trajectories*, Exp. Brain Res. **95** (1993) 308–318.

[3] C. W. Eurich CW and J. G. Milton, *Noise-induced transition in human postural sway*, Phys. Rev. E **54** (1996) 6681–6684.

[4] J. L. Cabrera and J. G. Milton, *On-off intermittency in a human balancing task*, Phys. Rev. Lett. **89** (2002) 158702.

[5] S. C. Venkataramani, T. M. Antonson Jr., E. Ott and J. C. Sommerer, *On-off intermittency: power spectrum and fractal properties of time series*, Physica D **96** (1996) 66–99.