COMPTRACK
A Compensatory Tracking Task for Monitoring Alertness

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Summary

Problem

A compensatory tracking task is needed to run on an IBM-compatible personal computer.

Objectives

The task required must satisfy four criteria:

1. To distinguish it from an auditory detection task used in previous research, the task should not involve auditory stimuli.
2. To allow study of vigilance decrements, the task should be monotonous enough to produce deficits associated with underarousal and loss of vigilance.
3. To allow study of rapid (20 sec) fluctuations in vigilance, the task should require continuous user input at near-one second intervals
4. The task program should allow msec-scale synchronization with external psychophysiological or other data collection processes.

Approach

The program required was programmed to run on a 386 IBM-compatible personal computer. The parallel output port was used to send synchronization signals to other data recording systems. An ascii output file records target position and user input at a sampling rate of 11 Hz.

Results

Two control experiments demonstrate that:

1. Alert task performance (mean distance < 3 d.r., see Figure H) requires the user to make appropriate trackball movements on average at least once per second.
2. The unseen mound or hill generating the surface force keeps the disk from remaining within 3 d.r. of the target bullseye for 95% of the time when no user input is being generated.
3. Adequate differentiation between alert and drowsy (or absent) performance can be achieved by distinguishing between times during an experiment when the target "escapes" beyond ~3 d.r., versus times when the subject is able to keep the target near to his or her best training performance level (see Figure F below).

A pilot training study demonstrates that adult subjects require ten minutes or less to learn the task. Pilot experiments show that the task is suitable for recording extreme performance fluctuations due to drowsiness or loss of alertness.

Conclusions

COMPTRACK is a compensatory tracking task that can be performed comfortably at a reasonable performance level by all or most subjects. The task takes 10 minutes or less to learn, and can be performed continuously for an hour or more. Alert subjects give graded responses using a trackball at a rate of nearly 2 per second, allowing second-by-second analyses of response behavior. COMPTRACK appears suitable for studying the dynamics of alertness under various task conditions, as well as for testing individual subject differences in vigilance behavior. The sync signal output allows for precise synchronization of performance data with concurrently-collected psychophysiological or other data. Data on the electroencephalographic (EEG) concomitants of fluctuations in COMPTRACK task performance will be reported elsewhere.

Introduction

A compensatory visual tracking task (COMPTRACK) has been programmed to operate on an IBM-compatible computer for use in vigilance research. The task meets four goals established in the course of previous research to develop an objective alertness monitoring system based on EEG and other psychophysiological data (Makeig & Inlow, 1993; Makeig et al., 1994).

1. To distinguish it from an auditory detection task used in previous research, the task should not involve auditory stimuli.

2. To allow study of vigilance decrements, the task should be monotonous enough to produce deficits associated with underarousal and loss of vigilance.

3. To allow study of rapid (20 sec) fluctuations in vigilance, the task should require continuous user input at near-one second intervals

4. The task program should allow msec-scale synchronization with external psychophysiological or other data collection processes.

This report describes the COMPTRACK task in detail, and presents control, training, and pilot data supporting the conclusion that the task is suitable for further use in vigilance research.

Resources Required

The COMPTRACK task requires a 386 IBM-compatible computer with a VGA color monitor and a Microsoft-compatible trackball or other input device. The program is coded in C and has been compiled for an IBM-compatible 386 PC using Borland C++ v3.1. (No C++ code is used in the program). Source code is available for use by other laboratories, and can be easily modified by C programmers to vary task difficulty or other task characteristics.

Task Description

The COMPTRACK task requires a subject use a trackball to keep a circular disk centered within a bullseye ring on a computer screen. The radius of the disk is ten pixels on the VGA monitor. The bullseye ring has an inner radius equal to the disk radius (1 d.r. = 10 screen pixels) and an outer radius twice the disk radius (2 d.r.). The screen background is black, the disk light grey, and the bullseye ring is dark grey. On a 386 PC, the program loops at a frequency of 22 Hz and writes the performance data at a sampling rate of 11 Hz. During the experiment, the position of the disk is a function of its previous position and velocity, plus the actions of three forces:

• The first force is a is a *buffeting* force which continuously changes in magnitude and direction. This force is the sum of six sine waves at different amplitudes, frequencies and phase angles. The components of this force are:

$$F_{B_x} = \sum_{n=0}^{5} c_x^{-n} \cos\left(c_x^n t + \phi_n\right), \; c_x = \left(\frac{1+\sqrt{5}}{2}\right)$$

$$F_{B_y} = \sum_{n=0}^{5} c_y^{-n} \sin\left(c_y^n t + \phi_n\right), \; c_y = \pi / 2$$

with a time (t) step of 0.015. The phase angles, ϕ_n, are random numbers generated for each frequency by the program at the start of each session. The equations above generate a sum of slowly precessing ellipses with cycle lengths near 1.9, 3.0, 4.7, 7.5, 12.0, and 19.0 seconds, respectively. The relative amplitudes of these components are proportional to their periods.

- The second force simulates action of the force of gravity causing the disk to slip on an unseen slippery *surface* shown in Fig. A below. This force is given as:

$$\begin{aligned} \vec{F}_S &= \tfrac{1}{2} r^2, && r \le 6 \\ \vec{F}_S &= \tfrac{3}{2}(r - 20\,diskRadius), && r > 6 \end{aligned}.$$

The surface force is always directed radially, a positive sign indicating an outward force. The unseen surface consists of a central circular mound with a base at 6 dr. (see Fig. B).

- The third force, $\vec{F}_U$, is the *user input*. It is proportional and oriented parallel to the vector representing the trackball's movement since the last time step.

These forces act on the disk through a spring-mass-dashpot system with a natural frequency of sqrt(5). The equation of motion giving the new position of the disk is:

$$\vec{x}_n = \vec{x}_{n-1} + a_1(\vec{x}_{n-1} - \vec{x}_{n-2}) + a_2\vec{x}_{n-2} + a_3\vec{F}_S + a_4(\vec{F}_B + \vec{F}_U)$$

$$where: \quad a_1 = 0.957, \; a_2 = 0.0003, \; a_3 = 0.05382, \; a_4 = 8.288e-5$$

This equation can be interpreted as follows. The new position of the disk is equal to its former position, plus the sum of:

- a slightly damped (.957) momentum term (simulating viscous drag)
- a small central repelling force proportional to the disk's two-back distance from the origin
- a weighted sum of the buffeting, surface, and user input forces.

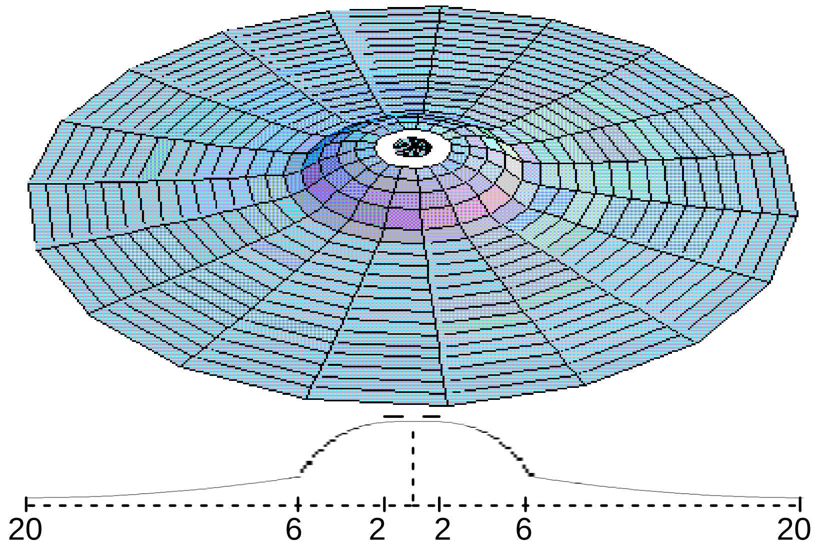


Figure A. The form of the (unseen) slippery surface giving rise to the *surface force* on the disk. The central bullseye ring is shown in white. The figure was generated by radially integrating the surface force equations given above.

Program Output

The COMPTRACK program raises a signal on its parallel port each time it collects data, and lowers the signal when the data is written to disk. This allows accurate synchronization of EEG and visual task data. In our experiments, the 386 computer is connected via its parallel port (lines 2, 3, and 7) to a signal amplifier which connects to one channel of a 32 channel A/D collecting simultaneous EEG data. On exit, the program also saves an ascii file to disk consisting of lines recording, for each loop in which it raises the parallel port signal, six fields:

trackball_velocity_[xy]   *disk_position_[xy]*   *total_forcing_[xy]*

The first and second fields report the current trackball velocity vector (in pixels). The second two fields report the current disk screen position, relative to screen center (in pixels).The third pairs of fields report the total of the buffeting and surface forces acting on the disk (in relative units).

Data Analysis

Figure B gives a schematic of the screen display, and shows various vector quantities which can be computed from data stored in the ascii output file. In the figure, the target disk and the bullseye ring are shown in solid lines. The inner dashed circle shows the foot of the (unseen) central mound or hill, at 6 d.r., generating the surface force component of the forcing function. The outer dashed circle shows the position of a shallow trough in the surface function, at 20 d.r..

This circle represents the practical excursion limit of the disk trajectory when no user input is present (cf. Fig. C).The vectors shown in the figure represent:

Dr	=	the current radial distance of the target disk from screen center
Ft	=	the total force acting on the disk at each update
Fr	=	the radial projection of Ft on the current disk position vector
Vm	=	the current trackball (or mouse) velocity
Vmr	=	the current radial trackball (or mouse) velocity
Vt	=	the current velocity of the disk
Vtr	=	the current radial velocity of the disk
Tt	=	the (projected) target disk trajectory

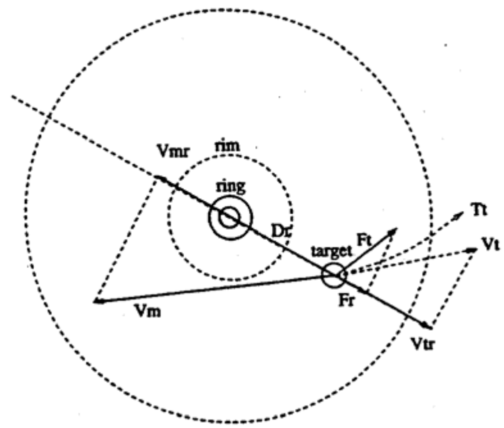


Figure B. Schematic diagram showing the target disk and bullseye ring visible on the terminal screen,. The inner dashed circle represent the edge of the 'slippery mound or hill' (cf. Fig. A), the outer dashed circle the practical limit of excursion of the disk if no user input is present. The vector quantities listed are useful for data analysis

These vectors can be used to analyze the motion of the disk and the dynamics of the subject's response to movements of the disk away from the screen center.

Control Experiments

Two control sessions were run to document the behavior of the target disk, (1) in the absence of user input, and (2) immediately after user inputs cease. Figure C shows the path of the target disk during several minutes when no user input is present. The path of the disk normally avoids the central mound of the virtual surface (Fig. A) and remains within 20 d.r. of the screen center.

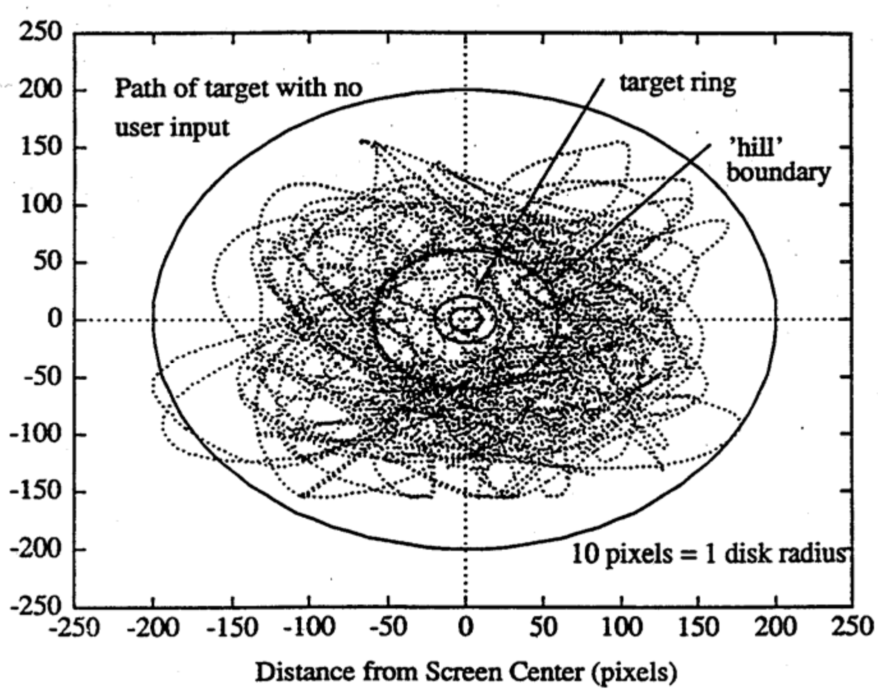


Figure C. The 'free' path of the target disk during a 5-minute control run in which no user input was provided.

Figure D is a histogram of the data in Fig. C. The median distance to the screen center during sustained periods of no user input is 9.4 d.r..

```
22        0  |
21       16  |
20       37  |
19       41  |*
18      141  |***
17       91  |**
16      283  |*******
15      582  |***************
14      597  |***************
13      852  |**********************
12     1018  |**************************
11     1148  |******************************
10     1162  |******************************
 9     1180  |*******************************  <- median = 9.4
 8     1200  |*******************************
 7     1102  |****************************
 6     1521  |****************************************
 5      864  |**********************
 4      636  |****************
 3      426  |***********
 2      213  |*****
 1       90  |**
```

Figure D. A histogram showing the distribution of distances from screen center in Fig. C above. Units in left column: disk radii.

Figure E shows the results of a control experiment in which a user controlling the position of the disk to within 2 d.r. of screen center several times suddenly ceased giving further trackball input. As the figure shows, the position of the disk moves out to 10 d.r. about 2 sec after user input ceases, reaching a maximum excursion near 20 d.r. at about 5 sec and thereafter returns to near its median no-input distance (9.4 d.r.).

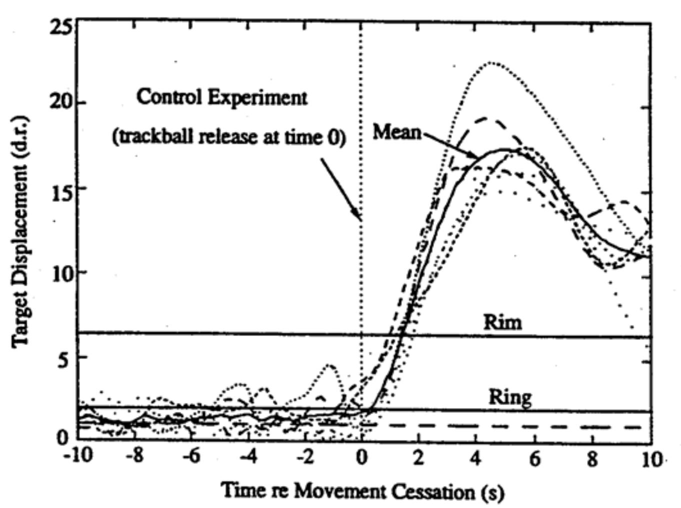


Figure E. Results of a control experiment in which the subject kept the target disk close to the screen center, then periodically stopped producing further trackball input (at time 0). The consistent 'escape' of the disk to 6 disk radii (d.r.) within 2 seconds is demonstrated.

Discussion

The two control experiments demonstrate that:

- Alert task performance (mean distance < 3 d.r.) requires the user to make appropriate trackball movements on average at least once per second (Fig. E).
- The unseen mound or hill generating the surface force keeps the disk from remaining within 3 d.r. of the target bullseye for 95% of the time when no user input is being generated.
- Adequate differentiation between alert and drowsy (or absent) performance can be achieved by distinguishing between times during an experiment when the target "escapes" beyond ~3 d.r., versus times when the subject is able to keep the target near to his or her best training performance level (see Fig. F below).

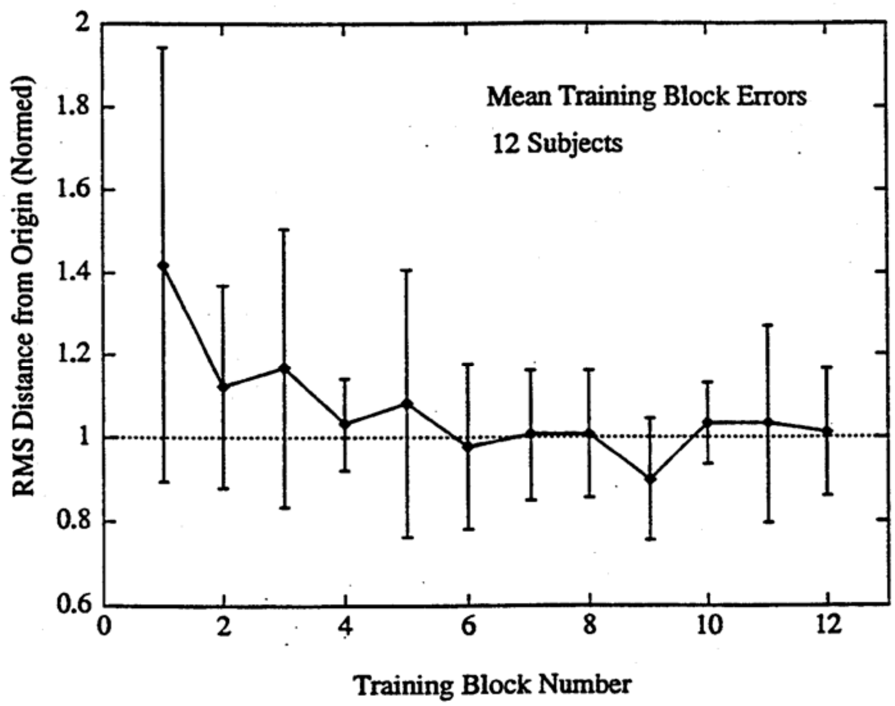


Figure F. Root-mean square (rms) distance from the origin in 12 consecutive 2-minute training blocks. Means and standard deviations of 12 subjects. Training stabilizes by the 6th training block. Ordinate normalized by dividing each subject's data by their mean distance in the last 5 training blocks before averaging.

Training Data

Twelve subjects trained on the task for an hour in twelve 2-minute blocks separated by 2-minute relaxation periods included to promote optimum learning performance. Root-mean square (rms) distance of the target from screen center during each of these runs is shown in Figure F below.

Two of the subjects performed relatively poorly during the first 5 blocks, whereas the performance of the other 10 subjects was nearly constant after the first block. Analysis of variance showed that performance in the final 5 blocks did not vary over blocks, but varied between subjects ($p<.05$). Apparently, further improvements in performance would be slow or non-existent under similar training conditions.

Figure G shows a histogram of the rms distance of the target disk from screen center during the last 5 training blocks for the 12 subjects. Nine of the 12 were able to keep the disk within 2 d.r.; all were able to keep the target within 3 d.r. of screen center. The figure also labels the gender of each of the subjects. No consistent gender difference is seen in the 12 (6 female, 6 male) subjects. The best performers in the group reported prior training in other skills involving hand-eye coordination (music, riflery, etc.).

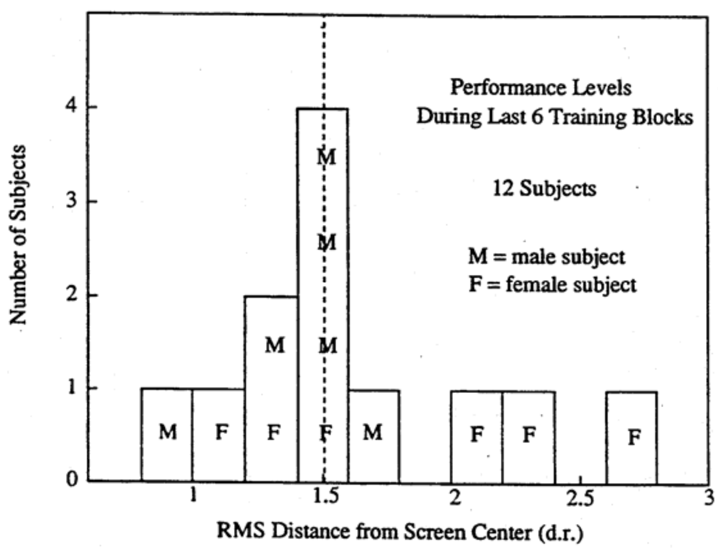
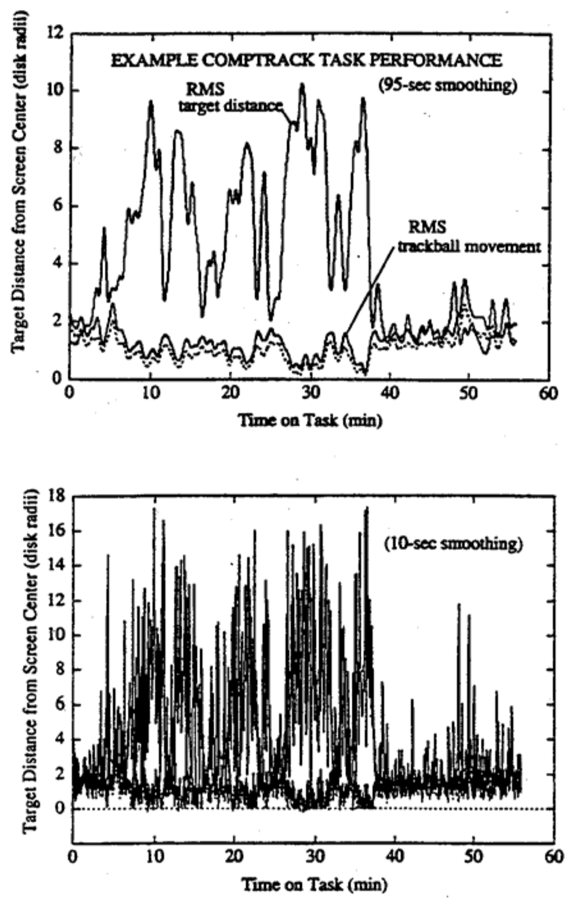


Figure G. Histogram showing mean absolute rms distance from screen center during the last 6 training blocks for 12 subjects.

Sample Data

Figure H shows root-mean square (rms) target distance from screen center (Dr in Fig. B), rms trackball velocity (Vm), and radial trackball velocity (Vmr) during a 56-minute session during which the subject became drowsy during several periods from minutes 3 to 39. In this figure, all three time series are smoothed using a moving 95-second bell-shaped (Papoulis) window. Figure I shows the same data superimposed on the same time series smoothed using a bell-shaped 10-second window. Of particular interest are the 'drowsy' periods in which mean level of subject input drops to near-zero. Even in these periods, the subject gives occasional responses, demonstrating the performance intermittency associated with drowsiness (Makeig and Jung, submitted). Before and after the drowsy period (minutes 1-3, 39-56), the subject responds to the random forcing function with a consistent level of input, and holds the target within 2 d.r. of screen center.



Figures H & I. Results of a 56-minute task session during which the subject experienced drowsiness and loss of vigilance. During this period (minutes 3-39), rms target distance from screen center increased, and rms level of trackball input declined. Same data are shown using two different smoothing lengths.

Figure J shows the mean frequency spectrum for changes in trackball speed, in the magnitude of the forcing function, and in target displacement from screen center averaged over seven 56-minute task sessions on 4 subjects. The forcing function spectrum shows the six sinusoidal components making up the buffeting force (slowed somewhat, probably because of an interaction with the surface force), while the trackball movement spectrum has peaks near 20 s and 600 ms per cycle. The first peak might be related to the recently-identified 20 sec cycles in EEG and performance on an auditory detection task during drowsiness (Makeig & Jung, submitted). The second most probably represents the tendency for alert subjects to produce input at roughly 600 ms intervals. The target displacement spectrum has a lowpass character, with its half-down point at about 6 sec per cycle.

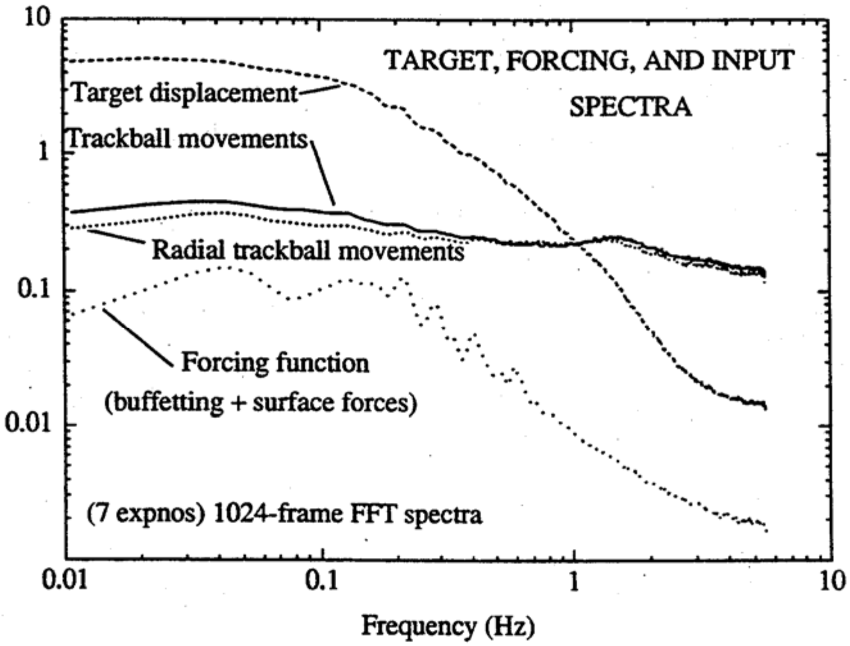


Figure J. Amplitude spectra, averaged over seven 56-minute task sessions, for target displacement, trackball movements, and the (unseen) target forcing function.

Conclusion

COMPTRACK is a compensatory tracking task that can be performed comfortably at a reasonable performance level by all or most subjects. The task takes 10 minutes or less to learn, and can be performed continuously for an hour or more. Alert subjects give graded responses using the trackball at a rate of nearly 2 per second, allowing second-by-second analyses of response behavior. While some subjects in our first experiments using the task maintain good performance for an hour or more, the monotony of the task, coupled with additional requirements of the experiment -- that subjects sit in a comfortable chair in a quiet, dimly-lit, warm chamber and refrain from making unnecessary movements -- have produced a tendency for some subjects to lose vigilance, producing sporadic dropoffs in task performance (see Figure H above). As in previous auditory detection experiments (Makeig & Inlow, 1993), these performance lapses can begin after as few as 2 minutes on task. Most often they involve intermittent failures or long delays in subjects' responding to target movements.

COMPTRACK therefore appears suitable for studying the dynamics of alertness under various task conditions, as well as for testing individual subject differences in vigilance behavior. The sync signal output allows for precise synchronization of performance data with concurrently-collected psychophysiological or other data. Data on the electroencephalographic (EEG) concomitants of fluctuations in COMPTRACK task performance will be reported elsewhere.

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