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Changing difficulty level in a one-dimensional tracking task and corresponding heart rate changes

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Abstract. Subjects were required to track a target consisting of two vertical bars moving with either a constant or a sinusoidally modulated speed across an oscilloscope screen with a joystick-controlled light-spot. Either target size (distance between bars - size guided tasks) or velocity of the target movement (velocity guided tasks), varied throughout different tasks determined by subject's performance. The target's initial movement period was either 2 or 3 seconds. The following parameters were studied: time on-target intervals, time off-target intervals, number of tracking errors, heart rate and tracking error incidence over the cardiac cycle. Time on-target intervals were longer for the velocity guided tasks than for the size guided ones. The same was true for time off-target intervals. Values for both types of intervals decreased gradually over the fixed sequence of tasks for velocity but not for size guided tasks. Heart rate was higher in the size guided task. Tracking error incidence did not depend on the phase of cardiac cycle.

Key words: heart rate, eye-hand tracking, target size guided performance, velocity guided performance

INTRODUCTION

Behaviourally challenging tasks are often able to evoke substantial responses of the autonomic nervous system, cardiovascular activity being the most widely tested. The magnitude or pattern of reactivity varies not only according to the type of problem (mathematical, perceptual etc.), but also between various groups of subjects (i.e. adults vs. children). Marked, metabolically supported, cardiovascular changes are reported as a response to psychosocial stress, where actual physical effort in responses generation is very small and practically identical for both conditions. In general, heart rate (HR) deceleration is believed to be expected under situation, when subjects are required to pay attention to external stimuli, whereas the opposite reaction, HR acceleration, is more typical for mental elaboration, regardless of the degree of actual energy requirements (Lacey 1967).

Eye-hand tracking tasks are usually presented with unchanging parameters during their course (Poulton 1974). The role of the subjects could be relatively simple under these conditions as they have no chance to influence the task by their performance. Our previous results (Indra et al. 1987, Radil et al. 1987) showed that interactions between eye-hand tracking performance and the autonomic nervous system, represented by changes in heart rate and differences in error incidence phase-locked with respect to the cardiac cycle vary according to objective and subjective difficulty of the tasks. Thus we recorded heart rate changes and the incidence of tracking errors contingent upon the cardiac cycle as useful indicators of the subject's general performance ability and also as an expression of the individual amount of effort invested in different processing phases of the tasks (van der Molen et al. 1984).

In the present experiments a one-dimensional tracking task (Indra et al. 1987) was modified in such a way that either the target size or velocity varied depending on the subject's performance efficiency throughout tracking tasks. Tracking accuracy was examined under two different types of target movement (sinusoidal or linear) in both (target size or velocity) "feedback" conditions.

The aims of this study were:

1. to compare the effect of the target size and velocity upon tracking efficiency;

2. to investigate whether differences in cardiovascular responses exhibited during the above two tracking conditions are stable and characteristic for them and to test whether the incidence of tracking errors with respect to the phase of the cardiac cycle is similar or different under target size and velocity conditions.

METHODS

Subjects

Ten right-handed subjects (6 male, 4 female), aged 20-29 years (mean 25.5 years with corresponding SD 2.37), without any known neurological disorders participated. All were naive about the purpose of the experiment and had normal or corrected-to-normal vision.

Procedure

The subject sat in a semi-dark chamber in front of a cathode ray tube (CRT) monitor on which the tracking tasks were presented. Prior to data collection each subject was allowed to become familiar with the task for several minutes. Then, after a five minute period of relaxation, data collection was started. All tasks were completed by each subject within approximately 30-35 min. Rest periods, lasting 2-3 min, were given between tasks to minimize fatigue.

The target was represented by two vertical bars (9 mm long), moving periodically in a horizontal direction across the CRT screen. The subject was instructed to follow the target as accurately as possible by keeping a light-spot, operated by a one-dimensional joystick, within the bars of the target. At the beginning the target was presented at the left side of the CRT, while the light-spot was positioned in the center. One movement period (MP) was defined as time for the target to move from the left side of the screen to the right side and back. Two different MPs were used: 2,000 ms (fast) and 3,000 ms (slow). One trial was comprised of 90 or 60 MPs, respectively, and was thus completed within 180 s during size guided tasks. During velocity guided tasks this time was shortened accordingly. The eye--screen distance (120 cm) corresponded to 5 deg of full target displacement, i.e. 10 cm, achieved by 60 deg of joystick lever angular displacement. Time intervals during which the light-spot moved outside the target were considered as off-target, or tracking error intervals. On-target, or successful tracking intervals were defined in a complementary way. The moment when the light-spot left the target was defined as the tracking error instant. The period's total time of on- and off-target intervals during one MP served as a basis for the calculation of the next period's parameters. The averaged values of on- and off-target intervals during the whole session were used for final off-line statistical evaluation.

The principal experimental parameters were either the width of the target which varied in size guided tasks or the velocity of target movement across the CRT screen which varied in velocity guided tasks. Tracking was considered successful in any MP when the light-spot was kept within the target more than 80% of the MP time. Success within one MP led to decreasing the distance between the two bars of the target in the size guided tasks, or to increasing the target movement velocity in the velocity guided tasks. On the other hand, when the subject failed within a given MP to reach the preset 80% level, that led to a one step decrease in difficulty for the next period. In the velocity tasks this parameter changed in 50 ms steps. In the size tasks the distance between two bars changed in 0.5 mm steps. All these values were set on the basis of pilot testing and previous experiments. Thus the tracking difficulty never stayed the same. The range of the steps varied individually, depending on the subject and task performed and generally covered no more than five or six steps. Initial values for the two parameters were as follows: target width of 16 mm and initial MPs of 2,000 or 3,000 ms; the tasks with the latter period were considered to represent a preparatory phase. Two different types of movement were chosen: linear (regular) and sinusoidally modulated. No attempt was made to score subjective difficulty of the trials or to indicate to him/her the number of successful intervals.

The subject's ECG was recorded using two active and one grounding electrodes. One recording electrode was placed on the upper sternum, the other was fastened to the processus xiphoides. The ground electrode was attached to the lower right rib cage. The ECG signal was amplified by a SAN-EI 1205 Bioamplifier and the instances of R-waves, as the most prominent component of the ECG complex. The correct detection of the R-waves was secured by a manual setting of the amplitude threshold. The accuracy of the R - R interval measurement was 1 ms. Target movement, time of occurrence of R-waves and tracking error instants (beginning of a tracking error interval as well as its end) were recorded and stored for off-line evaluation by a SM 4/20 computer (DEC 11 type).

The incidence of tracking errors with respect to the R - R intervals was also tested using a special computer program. Due to the variation of R - R interval length the intervals were divided into 10 sections and all errors occurring during an R - R interval were located in one of these sections.

The paradigm adopted can be characterized by the following two main factors: subjects (10) x tasks (8) which cover different levels: initial speed, type of target change throughout the particular task (size or velocity), type of target movement. The sequence of all 8 tasks is presented in Table I. To ensure the identical tracking conditions to all participants the slower (easier) tasks were always presented in the first half of the experiment.

RESULTS

A two-way analysis of variance was applied to the mean values of on-target intervals calculated for each task over all subjects ($F_{1,79}$=43.403; P<0.001. As the main effect there was a significant difference between the size guided tasks (1,3,5,7) (with mean

TABLE I

Description of the tasks

Task	Movement period	Type of movement	Mode of target change
1	3000	ramp	size
2	3000	sinusoidal	velocity
3	3000	sinusoidal	size
4	3000	ramp	velocity
5	2000	ramp	size
6	2000	sinusoidal	velocity
7	2000	sinusoidal	size
8	2000	ramp	velocity

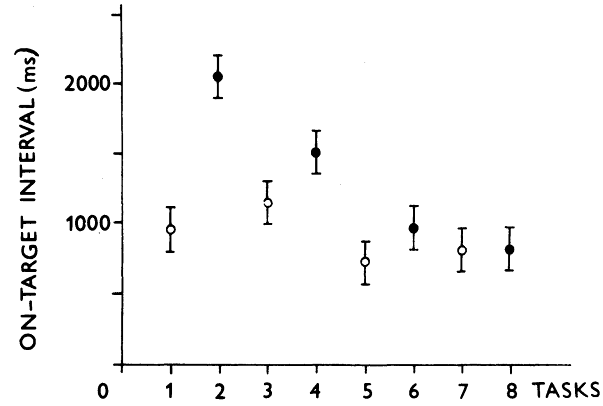

Fig. 1. Mean on-target intervals across subjects, plotted for the tasks adopted (see also Table I). The velocity guided situation is indicated by filled circles and size guided tasks by empty circles. Means and corresponding SD are given.

value 917 ms) and the velocity guided tasks (2,4,6,8) (mean value 1,342 ms) ($F_{1,79}$=19.007; $P<0.001$). The analogous values for time off-target intervals, i.e. tracking errors were 250 ms and 347 ms, respectively ($F_{1,79}$=43.015; $P<0.001$). The results of post-hoc interactions evaluation of on- and off-target intervals for all eight tasks are presented in Table II. (just significantly different tasks are displayed). Additional view on these results with separation of each task and variable is shown on Figs. 1. and 2, respectively. No significant differences were found for both types of target movement (linear *versus* sinusoidal). The group of velocity guided tasks yielded (applying a linear regression analysis to check any possible trend throughout the task) a significant decrease for lengths of on-target intervals ($F_{1.39}$=55.0; $P<0.001$) as well as for off-target intervals ($F_{1.39}$=8.6; $P<0.01$) in contradistinction to the size guided tasks. The values of the total on-target time (Fig. 3) show a characteristic and significant decrease for velocity guided tasks ($F_{1.39}$=54.160;

TABLE II

Post-hoc analysis of interactions of on and out intervals

	Task 1	2	3	4	5	6	7	8
1		+		+				
2	o		+	+	+	+	+	+
3		o			+			
4	o				+	+	+	+
5		o		o				
6		o			o			
7		o		o				
8		o						

Explanation of signs: +, indicates that compared tasks (on-target intervals) are significantly different; o, indicates that compared tasks (off-target intervals) are significantly different

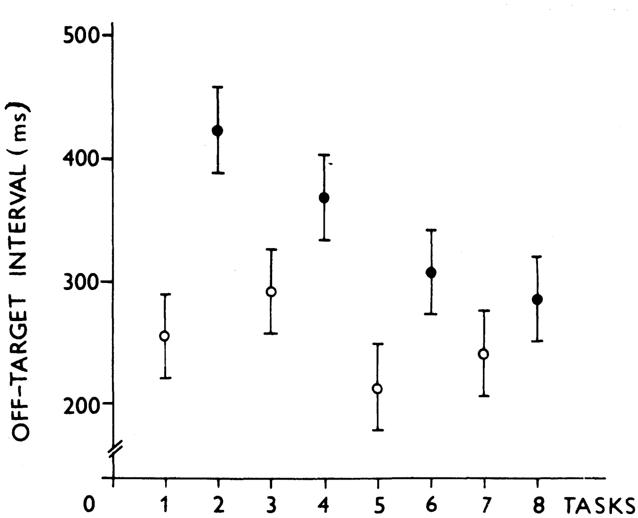

Fig. 2. Mean off-target intervals across all subjects for different tasks and for both types of target changes (see also Table I).

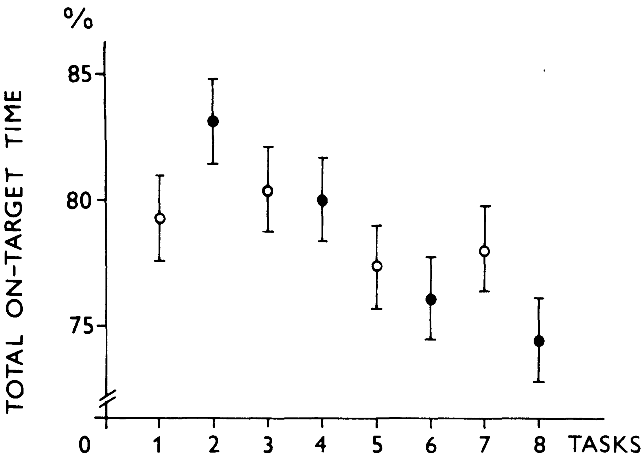

Fig. 3. Mean total on-target time (expressed as percentage of task duration) across all subjects for different tasks for both types of target changes (see also Table I).

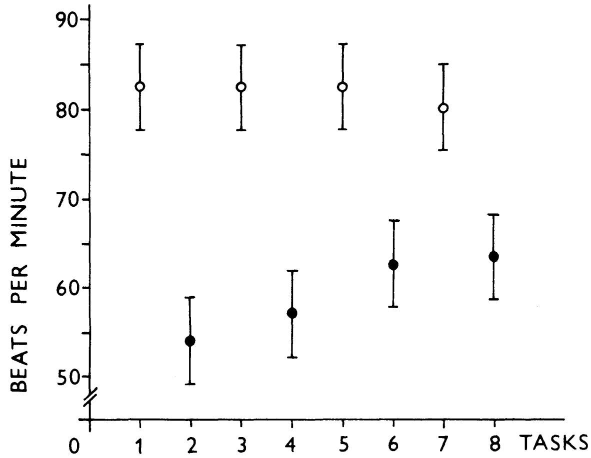

Fig. 5. Mean heart rate across all subjects plotted for different tasks and both types of target changes (see also Table I).

$P<0.001$) only with no such effect in the size guided tasks.

Tracking error incidence is shown in Fig. 4. This variable was obviously higher for the fast MPs in comparison with the slow (preparatory) ones and for size guided tasks in comparison with velocity guided ones ($F_{1,79}=16.63$; $P<0.001$). Regression analysis of the results from consecutive velocity guided tasks yielded a significant increase of tracking error incidence ($F_{1,39}=20.58$; $P<0.001$), mirroring the decrease of on-target intervals described above.

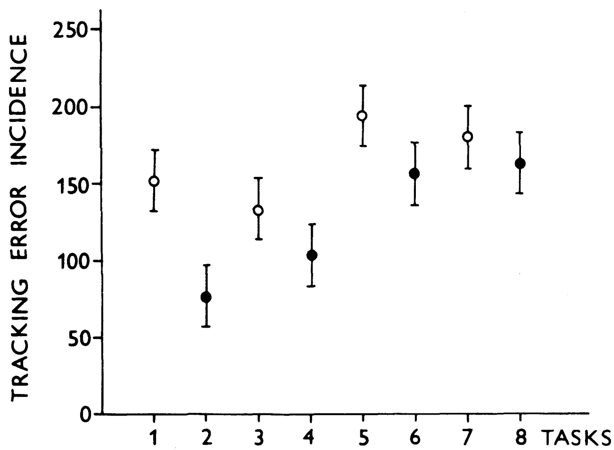

Fig. 4. Mean tracking error incidence across all subjects for different tasks for both types of target changes (see also Table I).

Highly significant differences in heart rate (measured over the whole session and expressed as beats per minute) were found between the trials with different types of the target change throughout the task. Mean values of heart rates for all 8 tasks are shown in Fig. 5. Size guided and velocity guided tasks show significant differences in heart rate ($F_{1,79}=81.713$; $P<0.001$). The mean heart rates for size and velocity guided tasks were 82.00 beats/min and 59.35 beats/min, respectively. Regression analysis showed a significant increase for consecutive velocity guided tasks during the session ($F_{1.39}=5.020$; $P<0.05$). No significant differences in heart rate were found with respect to the type of target movement (sine, linear) or initial MP (2,000, 3,000 ms).

Histograms of incidence of tracking error instants within the "normalized" inter R - R intervals divided into 10 equal bins showed no relationship between tracking error incidence and the cardiac cycle.

DISCUSSION

The results demonstrated longer average on-target intervals which might be considered a relevant parameter of tracking accuracy for velocity guided tasks in comparison with size guided tasks, although this was caused by differences for slow target movements only. The subjects were able to anticipate the centre position of the moving target more exactly and to control their movement more adequately under velocity guided conditions. Sinusoidally controlled target speed seemed to be easily predictable in spite of the fact that the absolute speed changed due to the velocity guided design (see below). Thus subjects were more able to adopt the target speed changes than self-controlled changes of target size. The probable cause was that target speed in general was a more important factor (Lisberger et al. 1987, Morrice et al. 1990). This conclusion is supported by the results showing that different recorded parameters of tracking accuracy were better for slow target movements. Target size increase was inefficient for preventing off-target tracking errors, as the amplitude of the corresponding hand movements was too high to be compensated in this way. So an important factor codetermining higher tracking accuracy for velocity guided tasks was related to the fact that fewer errors were triggered under this condition. Unfortunately due to the technique available we were unable to measure the detailed trajectory of the hand movements.

The relatively high efficiency of our velocity guided design may be surprising when considering its design in detail. Whenever the subject was on target above 80% of the MP time interval the target speed increased for the next MP by 2%. That meant that the task became more difficult. However, even when the subject would have spent under higher speed equal absolute time on target, this would represent a higher proportion of the new MP as tracking becomes even more accurate. This could mean that under certain conditions target speed should be even further increased in the next MP. As a result it might become higher than anticipated by the subject. Whenever the subject spent less than 80% of MP duration on-target, the target speed decreased by 2%. The task became easier. However, even equal absolute on-target time could have been interpreted then as if tracking became less accurate than before, i.e. often target speed might have been decreased more than anticipated. It follows that the type of automatic regulation used for instant target velocity guided conditions, based upon adopting the proportional principle with respect to time, tended to more extreme values than expected. In spite of this circumstance subjects apparently took advantage of the fact that they could influence target speed.

A surprising finding was that the increase of on-target intervals was paralleled by an increase in off--target intervals during velocity guided tracking. One might assume on the basis of simultaneous reduction of tracking error incidence that the speed of error correction was not optimized under the above condition, the critical factor of better tracking performance being the lower error rate.

As stated, the sequence of 8 tasks was fixed and the easier slow initial target speed experiments, considered as preparatory, have been performed first. It remains unclear therefore whether the decrease of on- and off- target intervals, total on-target time and parallel increase of tracking error incidence over consecutive velocity guided tasks is being codetermined by the above circumstance or is a sign of some sort of gradual adaptation to the experimental conditions or of fatigue. The latter explanations seem to be improbable due to the alternating non-fitting values characterizing all followed parameters during target size and velocity controlled tasks. Adaptation to requirements of the experiment would have caused an improvement of performance, probably. Although not investigated in a formal way, the subjects did not report a marked fatigue during the session which was interrupted between trials by sufficient resting periods. Thus it seems that the changes in the tracking parameters described appearing over trials were determined mostly by the way of ranking them during the experimental sessions.

Our present results concerning heart rate during tracking are partially congruent with previous reports of higher heart rate when tracking was more difficult (Indra et al. 1987). Tracking under velocity guided conditions was performed in general more efficiently and heart rate was considerably lower in comparison with the size guided task. Lower performance efficiency developing over the trials was paralleled by a corresponding increase in heart rate. However, the surprisingly large difference in heart rate between size and velocity guided tasks was not accompanied by differences of corresponding magnitude in parameters characterizing tracking accuracy. Moreover the values of heart rate changes reflecting the individual task difficulties and/or task presentation sequence were strictly separated for both types of conditions. Subjects were thus able, regardless of the fixed sequence of the tasks, to distinguish perfectly between two types of tasks presented in alternate succession. Thus heart rate was reflecting both the stimulus conditions and situational factor (Barry 1984). Under the conditions described possible relationship of heart rate changes to error commission and correction (van der Molen et al.1984, 1985) were impossible to detect due to fast alternation of these processes.

In contradistinction to our earlier findings on error incidence contingent upon the phase of cardiac cycle during simple (not "feedback" controlled) one-dimensional tracking (Indra et al.1987) no such dependence could be detected in the present experiments. Neither could we confirm the presence of such a phasic modulation of error incidence over the cardiac cycle during the two--dimensional tracking (Mates and Radil 1992). It seems probable, therefore, that the above phenomenon is linked to stereotyped and fully automatized tracking performance only.

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