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TIME ESTIMATION PERFORMANCE BEFORE, DURING, AND FOLLOWING PHYSICAL ACTIVITY

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An experiment is reported which evaluated performance on a 10-sec unfilled time interval estimation task before, during, and after physical work on a cycle ergometer at relative intensities of 30 and 60% $\dot{V}O_2$max. Results from eleven healthy male subjects revealed a significant increase in time estimation variability and a decrease in the mean estimated time intervals during exercise compared to non-exercise phases. These findings are part of a growing body of evidence which indicates that exercise and its severity has a substantive impact on perceptual and cognitive performance, particularly the ability to synchronize and anticipate the timing of events.

There are many conditions which involve decision-making and problem-solving while an operator is performing demanding physical work. For example, during an engagement a fighter pilot has to make a series of accurate, crucial responses while performing repeated muscular contractions in an M1 maneuver to help counteract the effects of excessive gravitational (g) forces. In the field, a combat soldier has to decide between numerous courses of action while on the move. Examples of such combined physical and cognitive activities also abound in the civilian realm. Firefighters, paramedics, and other emergency-response personnel are all required to respond quickly and accurately to cognitive task demands while engaged in moderate to strenuous physical exercise (work). An intrinsic part of many cognitive tasks is the necessity to accurately time responses and to register the correct passage of time. Many accidents are associated with time-order errors (KANTOWITZ and SORKIN, 1983) in which the temporally sequenced events are incorrectly ordered. Therefore, time interval estimation is

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an important response capability and has also been shown to be an effective tool for monitoring subtle changes in the integrity of central nervous system functioning (DOOB, 1971) as well as perceptual and cognitive processing (FRAISSE, 1963, 1984). Thus, time interval estimation is an appropriate measure for quantifying the effects of physical work.. Furthermore, among of the basic techniques available for assessing time estimation (KIRKCALDY, 1984), the production method appeared most suitable for this research (see also CAHOON, 1969; CURTON and LORDHAL, 1974; LOEHLIN, 1959).

The overwhelming majority of research on operator decision and response capabilities has been conducted in a quiet, pleasant laboratory environment where any accompanying physical demands are virtually zero. It is acknowledged that energetic aspects of arousal and activation influence such response capabilities (HEEMSTRA, 1985; HOCKEY *et al.*, 1986; SANDERS, 1983; VERCRUYSSEN, 1989; WOODS *et al.*, 1989). However, the manner in which such interactions occur and the extent of such influences are not well understood. Current theoretical approaches to such questions are of doubtful value and the ability to predict operator response under the combined influence of physical and cognitive stresses is essentially non-existent (HANCOCK, 1987). The present experiment is part of a series of such investigations, (*e.g.*, MIHALY, 1988a, b; MIHALY and VERCRUYSSEN, 1990; VERCRUYSSEN, 1990; VERCRUYSSEN *et al.*, 1990; WOODS *et al.*, 1990) which sought to distinguish the nature and extent of these influences. These studies include numerous measures of performance proficiency, but the present paper focuses on the effects of physical work level and practice on the ability to estimate a 10-sec interval. The purpose of this paper is to report the findings of an experiment conducted to determine the effects of physical work on time estimation performance sampled before, during, and following work bouts (30 and 60% of $\dot{V}O_2$max) on a cycle ergometer.

METHOD

Subjects. On 2 separate testing days, eleven healthy, non-smoking, unpaid, recruited male volunteers performed speed of response and time estimation measures before, during, and after exercise. Table 1 summarizes the subject demographics, including age, height, body mass, estimated percent body fat, estimated $\dot{V}O_2$max, and baseline response on a serial four-choice reaction time (SCRT) task.

Apparatus. The different exercise states were achieved by manipulating resistance to pedaling on a cycle ergometer. Before experimentation commenced, the maximal aerobic capacity ($\dot{V}O_2$max) and heart rates corresponding to 30 and 60% $\dot{V}O_2$max were estimated for each participant. Then, during testing, the experimenter adjusted the pedaling resistance (in watts) to keep heart rate at the predetermined, target levels during each work phase. In this study, a

Table 1. Subject demographics.

Subject	Age (yrs.)	Ht (cm)	Mass (kg)	Estim. % fat	Estimated $\dot{V}O_2$ max	SCRT (msec)
1	24	188	72.6	10.7	45.3	428
2	20	180	63.5	12.0	47.2	307
3	26	175	74.8	18.7	37.4	343
4	26	183	88.4	18.2	40.7	393
5	23	168	59.0	12.5	50.0	367
6	25	168	68.0	18.0	52.2	343
7	28	175	70.3	14.5	42.2	357
8	24	188	79.4	15.0	38.4	310
9	23	178	72.6	10.0	40.2	308
10	30	183	74.8	16.2	44.6	369
11	26	170	73.5	10.0	55.8	348
Mean	25.0	177.8	72.5	14.2	44.9	352
S.D.	2.6	7.0	7.4	3.3	5.6	36

$\dot{V}O_2$ max recorded in $ml \cdot kg^{-1} \cdot min^{-1}$. S.D., standard deviation; SCRT, serial visual four-choice reaction time at rest on Day 2. Corrective lenses were worn by subjects 1, 4, 5, and 8. All subjects were right-handed except subject 8.

Cal-Med variable watt paramagnetic cycle ergometer (Model CM-RH 400) was used because it is capable of producing a constant workload (accuracy 1%) throughout a range of 0 to 450 W. As a result, the apparatus resists alterations in workload due to inadvertent fluctuations in pedaling speed. The ergometer included an analog sweep display for gauging pedaling speed in revolutions per minute (rpm). In addition, a metronome with a red flashing LED and a beeping tone was used to assist the subjects in maintaining the target cadence of 72 rpm. The metronome was turned off during the time estimation task.

Procedure. Subjects participated in 3 days of activities: an orientation day and 2 days of testing. Prior to the first testing session, subjects performed 25 practice trials on the unfilled time estimation task, with knowledge of results (KR) given after each trial. Next, the submaximal aerobic capacity test was administered. This test involved pedaling on a cycle ergometer at 70 W (60 rpm) for 3 min, followed by a 5-min cycling period with the physical workload at 150 W according to ASTRAND and RODAHL (1977). $\dot{V}O_2$max was extrapolated from the Astrand-Astrand Nomogram (ASTRAND, 1960) and reported in $ml \cdot kg^{-1} \cdot min^{-1}$. Four skinfold measurements (biceps, triceps, subscapular, and suprailiac), obtained with Lange skinfold calipers, were summed and percent body fat calculated according to the method developed by DURNIN and WOMERSLEY (1974).

Following the initial orientation day, subjects completed 2 days of experimental testing, each lasting approximately 90 min. Upon entering the laboratory, the subjects performed 25 practice trials while seated at a desk. The participants were asked to estimate a 10-sec time interval (BINDRA and WAKSBERG, 1956; McConchie and Rutschmann, 1971; Montare, 1985) by starting and stopping a clock timer. This dependent measure was selected because of its known reliability and history of successful applications (also see Bakan and Kleba, 1957; Clausen, 1950; Danzinger and DuPreez, 1963; Gilliland, 1940; Gilliland *et al.*, 1946; Guay and Hall, 1977; Hornstein and Rotter, 1969; McCauley *et al.*, 1980). Subjects were instructed to depress the start/stop button and count to themselves until they reached the estimated time interval of 10 sec at which time they depressed the start/stop button and observed their estimated interval on a digital display with 0.01 sec resolution. Following practice, the subjects were fitted with an Exersentry heart rate monitor and then asked to sit on the cycle ergometer.

Five time estimation trials were performed under three exercise states: before exercise, between the 30 and 60% $\dot{V}O_2$max work bouts, and post-exercise. Before engaging in exercise, subjects performed five time estimation trials as part of a battery of performance tests (serial visual 4-choice reaction time, discrete visual 4-choice reaction time, simple index finger tapping, and response latency to unexpected stimuli). Mean heart rate for the subjects ranged from 70–80 bpm in this condition. Data collection progressed through the second work phase (either 30 or 60% $\dot{V}O_2$max depending on the schedule for counterbalancing), as participants completed the speed of response measures. Between the second and third work phase, five more time estimation trials were performed. During this transition phase between work bouts, HR ranged from 109–119 bpm, six subjects had completed work at 30% $\dot{V}O_2$max and five had just done a work bout at 60% $\dot{V}O_2$max. No differences in time estimation were found due to order of work bouts so data from all 11 subjects were collapsed and reported as a during-exercise condition. In the post-exercise recovery period following the two work bouts (30 and 60% $\dot{V}O_2$max), the final five time estimation trials were collected. Post-exercise heart rates ranged from 80–90 beats per min. Subjects pedaled during the exercise condition, but not the pre- and post-exercise phases.

An inherent limitation of all exercise studies is that rest and recovery phases cannot be counterbalanced. However, in this study, the exercise conditions were partially counterbalanced, six subjects performed the 30% $\dot{V}O_2$max work bout followed by 60% work bout and the other five subjects engaged in exercise in the opposite order. For further details on the procedure, see Mihaly (1988a, b) and Mihaly and Vercruyssen (1990).

Treatment of data. For each of the 11 subjects, the following descriptive statistics were calculated for the six experimental conditions (three work levels on two testing days), based on the five time estimation trials completed per work phase: (1) average time interval produced per condition (the time estimation mean), (2) average within-subject standard deviation of the time estimation mean, (3) average within-subject variance about the time estimation mean, and (4) average absolute error. Inferential statistics were calculated for these four measures;

the two practice levels (Day 1 and Day 2) and three work levels (pre-exercise, during exercise, and post-exercise) were the basis of a 2×3 (days×work) repeated measures analysis of variance (ANOVA) design. All *post-hoc* analyses were done using the Tukey *WSD* Method (see VERCRUYSSEN and HENDRICK, 1990). To determine trial effects, if any, the raw time estimation data were analyzed according to a 2×3×5 (days×work×trials) repeated measures ANOVA design. All analyses were conducted using an IBM 3081 mainframe computer and an analysis of variance for repeated measures (ANOVR) program developed by Games that generates both conventional and conservative probabilities (GAMES, 1981; GAMES *et al.*, 1980). Conservative probabilities were computed using the conservative Box *d.f.* adjustment (BOX, 1954; MEYERS, 1979; STOLOFF, 1966). All statistical contrasts were at the 0.05 level of significance.

RESULTS

Listed in Table 2 are the time estimation means and within-subject standard deviations for the six experimental conditions (2 days×3 work levels). Although there were no differences between days for these measures, the 2×3 analysis of variance revealed noteworthy findings with respect to the work factor (see Table 3). First, a main effect for work ($F_{2,20}=3.736$, $p=0.042$, conservative $p=0.082$) was seen in the time estimation means for the exercise versus non-exercise phases. As shown in Fig. 1, accuracy was higher and the absolute value of the estimate

Table 2. Work level means per day in seconds.

Work	Day 1		Day 2		Average*	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Before	10.07	0.45	9.85	0.39	9.96	0.42
During	9.58	0.55	9.67	0.53	9.62	0.54
After	10.10	0.44	9.90	0.36	10.00	0.40
Average*	9.92	0.48	9.80	0.43	9.86	0.45

*, Marginal average; $\bar{X}$, average time interval produced, based on 5 trials per work phase per day (11 subjects); S.D., average within-subject standard deviation for 5 trials.

Table 3. Day×work ANOVA results*.

Factor	*d.f.*	Mean		S.D.		Variance	
		F ratio	*p*	*F* ratio	*p*	*F* ratio	*p*
Day	1, 10	0.947	0.353	1.178	0.303	0.532	0.483
Work	2, 20	3.736	0.082	2.218	0.167	6.922	0.025
Day×work	2, 20	1.378	0.268	0.139	0.717	2.363	0.155

*, Data analyzed according to a 2×3 repeated measures design; S.D., within-subject standard deviation; variance, within-subject variance; *p*, conservative probability generated by the ANOVR program. An × denotes an interaction.

Table 4. Days × work × trials ANOVA results*.

Factor	*d.f.*	*F* ratio	*p*
Day	1, 10	0.956	0.351
Work	2, 20	3.733	0.082
Day × work	2, 20	1.385	0.266
Trial	4, 40	5.480	0.041
Day × trial	4, 40	0.345	0.570
Work × trial	8, 80	2.274	0.162
Day × work × trial	8, 80	0.813	0.389

*, Analyzed according to a 2×3×5 repeated measures design; *p*, conservative probability generated by the ANOVR program. An × denotes an interaction.

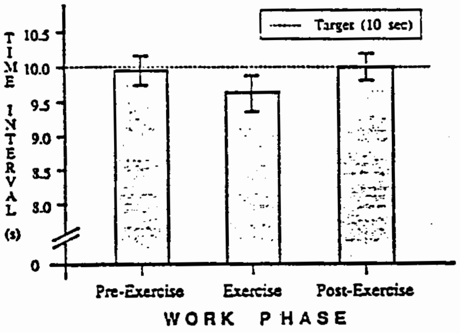

Fig. 1. Mean time interval estimated per work level, averaged over subjects and two testing days ($n=110$ points per mean; 11 subjects × 2 days × 5 trials). Error bars represent plus and minus one standard deviation.

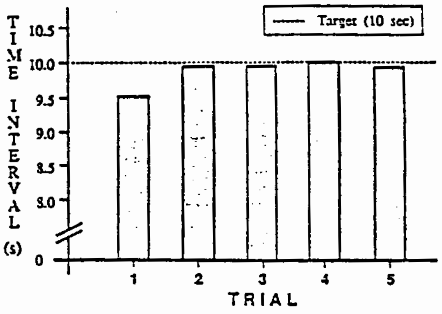

Fig. 2. Mean time interval estimate collapsed over work levels and days as a function of trials per condition ($n=66$ points per mean; 11 subjects × 2 days × 3 work levels). Trial 1 was without feedback, whereas trials 2–5 were with feedback (knowledge of results: KR).

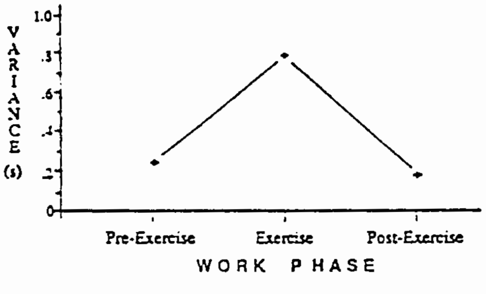

Fig. 3. Mean within-subject variance when estimating a 10-sec time interval as a function of work level ($n=110$ points per mean; 11 subjects × 2 days × 5 trials).

was lower during exercise (9.62±0.54 sec) compared with pre- and post-exercise means (9.96±0.50 and 10.00±0.40 sec, respectively). For time estimation means, there was a significant effect of trials (see Table 4). *Post-hoc* analysis distinguished trial 1 (Mean=9.53) as significantly lower than trials 2–5 (9.94, 9.92, 10.0, and 9.89, respectively), as illustrated in Fig. 2. Finally, as illustrated in Fig. 3, within-subject variance was significantly higher for the exercise compared to the non-exercise phases ($F_{2,20}=6.922$, $p=0.001$; conservative $p=0.025$).

DISCUSSION

Findings from this experiment show that during work, subjects consistently underestimated 10 sec by about 3.8%, with significantly higher intra- and inter-subject variability than during rest and recovery. From this one might predict that, during physical work, individuals perceived that they have less time in which to respond or to perform a maneuver than they actually do. Such phenomenon could have important implications in situations where accuracy in anticipation timing of events determines the success or failure of particular goal-directed actions (also see RUTHERFORD and WILSON, 1988). Careful examination of accident data often shows that not only are quick responses necessary to prevent accidents, but the timing of such rapid responses is crucial. If the underestimation effect is relatively constant across time, it would yield an exercise-induced underestimation of approximately 2.3 min per hour. Or stated another way, subjects would describe an hour of real time to have taken more than 62 min. The relevance of this effect depends on the consequences of such errors in real-world settings. Nevertheless, this research points to the fact that an elevated metabolic level produces an acceleration of our internal clock, thereby distorting our perception of exogenous real time. As such, these findings invite replication as well as continued investigation of this exercise-induced temporal distortion to determine its impact on longer and shorter target intervals. Plotting the discrepancy caused by exercise between duration estimate and target duration, both with and without feedback, as a function of various interval durations would aid our understanding of the factors influencing endogenous timing. Individual differences such as age and gender plus chronobiological factors such as time-of-day circadian rhythm effects are also important considerations in this quest (see CARLSON and FEINBERG, 1970; KIRKCALDY, 1984; GILLILAND and HUMPHREYS, 1943; HANCOCK and VERCRUYSSEN, 1990).

From the 2×3×5 (days×work×trials) analysis, it was determined that the time estimation mean for the first trial (without KR) was less accurate than trials 2–5 (with KR). This effect was expected since knowledge of results has repeatedly been shown to facilitate human learning and performance (BILODEAU and BILODEAU, 1961; LOCKE *et al.*, 1968; MONTARE, 1988) and to decrease variance in a time estimation task (MONTARE, 1985, 1988).

Although present findings indicate this covariation between physiological change and perceived duration, numerous investigators (*e.g.*, FRANCOIS, 1927a, b; HETSCHEL, 1979) have indicated that this is not a causal relationship. Thus, we feel it is important to dispel the simplistic and fallacious argument that heart rate controls perceived duration. There are a number of possible explanations for the pattern of results observed, but three seem most noteworthy. One explanation comes in a global argument made by TREISMAN (1963), who forwarded a time perception model where the basic frequency of internal "beats" was sensitive to non-specific arousal effects. It could be argued that exercise-induced arousal produced the significant differences in duration estimates. Another explanation is based on work by HANCOCK (1984) and the close coupling of body temperature with duration estimation (see also BELL, 1966; HOAGLAND, 1933). Thus, it is possible that the present effect of exercise is one mediated through a body temperature influence on a collection of timing mechanisms in the central nervous system (see HANCOCK, 1983). A final explanation might be described as biomechanical interference. Intentionally confounded in this design was exercise and pedaling, leading to difficulty in differentiating the effects of exercise-induced arousal and mechanical interference produced during the leg movements of pedaling. Presumably it is possible that the effects obtained may be due simply to movement of the lower limbs. MIHALY and VERCRUYSSEN (1990) report a method which separates the effects of exercise into those caused by movement and those caused by elevated metabolic processes, but they applied this procedure to speed-of-response measures and not time estimation. While we are reluctant to speculate on which of these explanations is most accurate without additional data, we are inclined to support the latter two more than the first.

While much attention has been focused on human navigation in spatial dimensions, relatively little work has been directed to the equivalent understanding of human time perception. This is somewhat disturbing as we clearly recognize that the contents of a task affect its perceived duration and in a similar manner the percept of time available to complete a task has a significant impact on efficiency.

In summary, the results of this study suggest that people become unreliable, underestimators of fixed time intervals when arousal is increased by concurrent physical work, compared to pre- and post-work states. It was also shown that individuals were better estimators of a 10-sec interval when given knowledge of results on the previous trial as compared to when subjects did not receive KR. The findings of the present study have implications in instances where accurate anticipation or coincidence timing is important for safety or when subjective states are affected by the discrepancy between endogenous and exogenous time.

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Institute of Technology) assisted in writing FORTRAN programs for data analysis. Computational support was provided by the Caltech Concurrent Supercomputing Facility. An earlier version of this paper was presented at the 1988 Annual Meeting of the Human Factors Society (Mihaly, Hancock, Vercruyssen, and Rahimi, 1988a).

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