

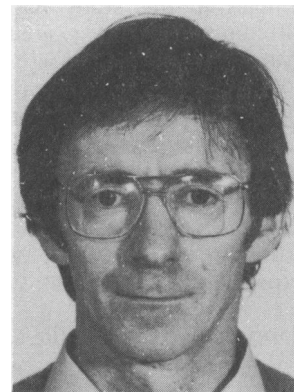


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INFLUENCE OF TIME OF DAY ON ALL-OUT SWIMMING

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ABSTRACT

The effect of time of day on all-out swim performances was examined. Fourteen subjects performed maximal front crawl swim tests on separate days over 100 m. and 400 m. at 5 different times of day between 06.30 h. and 22.00 h. Performance showed a significant linear trend with time of day in close though not exact association with the circadian rhythm in oral temperature: a goodness of fit test confirmed that the values predicted from linear trend analysis coincided with the measured values ($p < 0.05$). The steady improvement throughout the day was 3.5% for 100 m. and 2.5% for 400 m. swims. Trunk flexibility displayed a time of day variation with a trough in the morning and a peak in the afternoon. No significant rhythm was observed in ankle and shoulder flexibility, grip strength or peak expiratory flow rate ($p > 0.05$). It was concluded that maximal swimming trials are best scheduled for the evening and worst in the early morning. Specific fitness factors cannot clearly account for the higher exercise capability in the evening which is strongly related to the circadian curve in body temperature.

INTRODUCTION

Many measures of human efficiency change rhythmically in association with the circadian curve of body temperature (Rutenfranz and Colquhoun, 1979). Though much attention has centred on laboratory predictors of neuromotor (Colquhoun, 1972), cognitive (Folkard, 1975; England, 1979) and physical working capacity (Klein et al, 1968; Wahlberg and Åstrand, 1973), there is comparatively scant data on circadian variation in maximal performance or its components in field conditions. As competitive sport normally makes selective maximal demands on individual capacities, the study of strenuous exercise can enhance understanding of performance changes with time of day that might obtain at more moderate work levels.

In one of the few investigations of all-out athletic performance at different times of day, Conroy and O'Brien (1973) reported no significant difference in swimming 100 m. between morning (07.00-08.00

hours) and evening (17.00-19.00 hours) of the same day, though improvement in the evening was noted for 6 runners, 3 weight throwers and 3 oarsmen. Data demonstrating a circadian rhythm in a 5 min. run presented, but not yet published, by Stockton et al (1978) replicated the running results while Rodahl et al (1976) found that swimmers produced faster times over 100 m. at 17.00 hours compared with 07.00 hours in 3 out of 4 strokes studied. As performance rhythms vary between individuals according to circadian phase type (Horne and Ostberg, 1977), more than two data points throughout the day are needed for definitive location of daytime peaks and troughs.

Muscular strength (Reilly and Walsh, 1981), lung function (Reinberg and Gervais, 1972) and flexibility (Wright et al, 1969) — all major physical fitness components — have been reported to vary closely with nycthemeral body temperature oscillations. However, the existence of rhythmic fluctuations in aerobic power as represented by the maximal oxygen uptake ($\text{VO}_2 \text{ max}$) is questionable (Reilly and Brooks, 1982), though exercise can produce greatest discomfort at the trough phase of body temperature (Faria and Drummond, 1982). To what extent the discomfort is due to metabolic acidosis, shifts in neural sensitivity or related factors is unknown.

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This study attempted to determine the trough and peak time of physical performance through the normal hours of wakefulness. Swimming was chosen as the exercise mode in order to clarify questions arising from previous investigations (Conroy and O'Brien, 1973; Rodahl et al, 1976). Grip strength, peak expiratory flow (PEF) and flexibility were chosen as gross indicants of specific fitness components to supplement the performance measures. It was hypothesised that performance would follow the curve of body temperature, achieving a minimum in early morning and a maximum in the evening.

METHODS

Fourteen competitive swimmers, four male and ten female, mean age 14.7 years, each volunteered to undertake work tests at five different times of day: 06.30 h, 09.00 h, 13.30 h, 17.00 h, and 22.00 h. All subjects habitually trained for between 90-120 min. both in the morning and in the evening, so presented no difficulties associated with morning and evening phase types or lack of familiarisation with the timing protocol. Tests included all-out 100 m. and 400 m. front crawl swim trials, these distances predominantly stressing anaerobic endurance and aerobic power mechanisms respectively. Subjects were arranged in five groups according to their best 100 m. front crawl competitive times. The order of test administration for time of day was balanced and tests were carried out over four consecutive weekends involving 8 separate days of testing. Subjects swam in pairs in the trials.

The last meal before a work test was a light snack taken at least 3 hours beforehand. Only a cool drink of water was taken for breakfast prior to the 06.30 hours test. The 100 m. swim trial was preceded by a standard warm-up of 500 m. intermittent swimming and a 2 min. preparatory period. The 400 m. trial followed after an intermission of 15 min. Water temperature was 28.5°C

(\pm S.D. = 1) °C and air temperature 19.5 (\pm S.D. = 2) °C. The pool length was 25 m.

Body weight was determined prior to the warm-up and grip strength was measured with a Takeikiki Kogyo dynamometer. Pre-swim oral temperature was obtained with a mercury thermometer positioned sub-lingually for 3 min. Peak expiratory flow rate (PEF) was measured with a Wright flow meter, the best of 3 trials being recorded. Four flexibility measurements were made in the interval between swim trials according to the procedures of Counsilman (1977). These included horizontal and vertical shoulder flexibility, trunk flexion range and ankle flexibility. Post-swim oral temperature was obtained after the 400 m. trial.

Data were analysed by means of a two-way ANOVA, times of day and subjects accounting for the two factors. Fisher's LSD test was used for a posteriori comparisons (Kirk, 1969). Correlation analysis between variables was pursued using the Pearson Product Moment method. Orthogonal polynomial equations were derived using the procedures outlined by Kirk (1969) for analysis of trends in the data with time of day. Linear equations were evaluated for dependent variables that demonstrated significant F results for time of day. Where significant trends in mean values departed from linearity a quadratic or cubic fit was attempted using orthogonal polynomial equations according to Kirk (1969). A goodness of fit test was applied to the agreement between the predicted and the observed mean values for all significant trends observed. P values of 0.05 were taken to indicate statistical significance for all tests.

RESULTS

Mean (\pm S.D.) values are presented for all variables for the five times of day in Table I. The subjects effect was significant for all variables except the oral temperatures. The oral temperature showed the typical circadian varia-

TABLE I
Mean (\pm S.D.) values for all variables at the five times of day (n = 14)

Variable	06.30 h.	09.00 h.	13.30 h.	17.00 h.	22.00 h.
Body weight (kg)	52.6 \pm 10.7	52.4 \pm 10.8	52.7 \pm 10.7	52.5 \pm 10.7	52.7 \pm 10.7
Pre-swim oral temperature (°C)	35.8 \pm 0.4	35.6 \pm 0.5	35.7 \pm 0.5	36.5 \pm 0.8	36.6 \pm 0.6
Post-swim oral temperature (°C)	36.2 \pm 0.4	36.1 \pm 0.6	36.2 \pm 0.7	37.0 \pm 0.7	37.1 \pm 0.5
PEF (l min ⁻¹ - BTPS)	414 \pm 115	400 \pm 85	420 \pm 113	426 \pm 114	421 \pm 117
Grip strength (kg)	30.7 \pm 9.7	32.0 \pm 9.2	31.3 \pm 9.4	32.1 \pm 9.6	31.4 \pm 9.2
100 m. swim time (s)	75.3 \pm 10.8	75.0 \pm 11.3	74.2 \pm 11.1	73.6 \pm 11.0	72.6 \pm 10.6
400 m. swim time (s)	337.7 \pm 24.2	334.6 \pm 23.6	334.2 \pm 24.4	332.0 \pm 24.1	329.1 \pm 23.8
Horizontal shoulder flexibility* (cm)	55.3 \pm 22.0	50.0 \pm 19.7	50.7 \pm 22.0	45.5 \pm 20.7	53.6 \pm 30.1
Vertical shoulder flexibility (cm)	32.1 \pm 13.0	33.0 \pm 12.1	33.2 \pm 12.4	32.3 \pm 13.5	32.7 \pm 12.3
Trunk flexion* (cm)	19.1 \pm 9.5	17.3 \pm 8.9	14.2 \pm 7.6	14.6 \pm 7.5	15.0 \pm 7.9
Ankle flexibility* (cm)	6.0 \pm 2.5	5.6 \pm 2.2	6.0 \pm 3.4	5.5 \pm 3.0	5.7 \pm 3.0

*The lower the score the better.

tion, the highest value being recorded at 22.00 hours in both conditions. The trend in the data conformed to a cubic function whose fit was significant. The temperature was significantly elevated post-exercise by 0.5°C over the pre-exercise level of 36.0°C (Fig. 1).

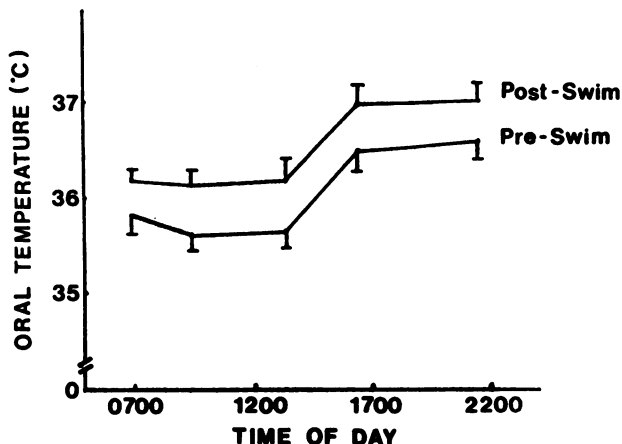


Fig. 1: Pre- and post-swim oral temperatures (mean ± S.E.) at the five times of day (n = 14).

A time of day effect was evident in both 100 m. and 400 m. swim trials according to ANOVA. For the two swims the steady improvement during the day conformed to a significant linear trend. The subsequent goodness of fit test established that the predicted values provided a satisfactory fit to the data (Fig. 2). Performances at the different distances were highly correlated (r = 0.80) as illustrated in Fig. 3. The 100 m. times correlated significantly with grip strength (r = -0.60), body weight (r = -0.62), horizontal shoulder flexibility (r = 0.59), vertical shoulder flexibility (r = -0.59) and age (r = -0.54). The 400 m. times were significantly correlated with grip strength (r = -0.54), PEF (r = -0.62), body weight (r = -0.57) and horizontal shoulder flexibility (r = 0.59).

A time of day effect was significant for the trunk flexibility test but for none of the remaining three flexibility measures. The best trunk flexibility score was observed at 13.30 hours, the poorest at 06.30 hours. Results obtained at 13.30 hours did not differ significantly from those at the two later times of day. Scores attained at 17.00 hours and 22.00 hours did not differ from that at 09.00 hours, though the mean score at 09.00 hours was significantly poorer than that at 13.30 hours. The form of the curve was not satisfactorily clarified by any orthogonal polynomial equation. The curve shown in Fig. 4 suggests part of a sine wave: cosinor analysis was not pursued because of the large

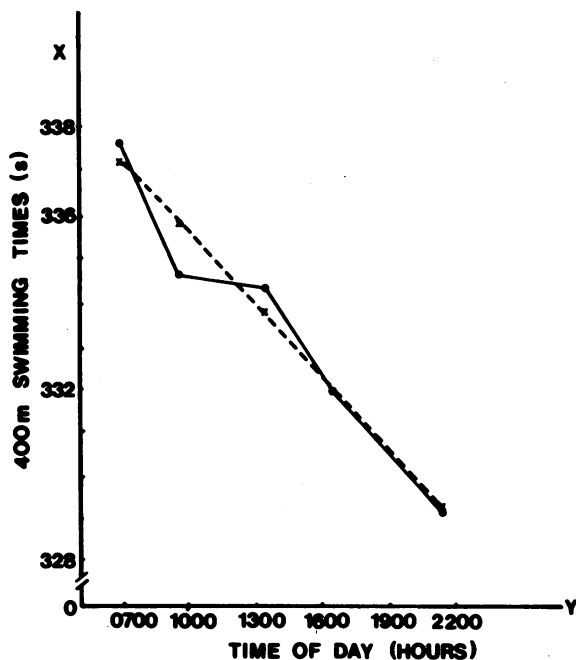
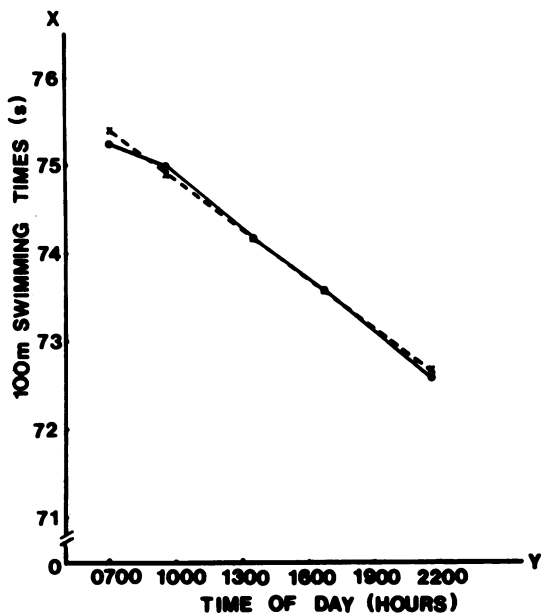


Fig. 2: Comparison of predicted linear trends and observed performance data for 100 m. and 400 m. front crawl swims during the solar day.

x ----- x denotes predicted values
o ————— o denotes observed values

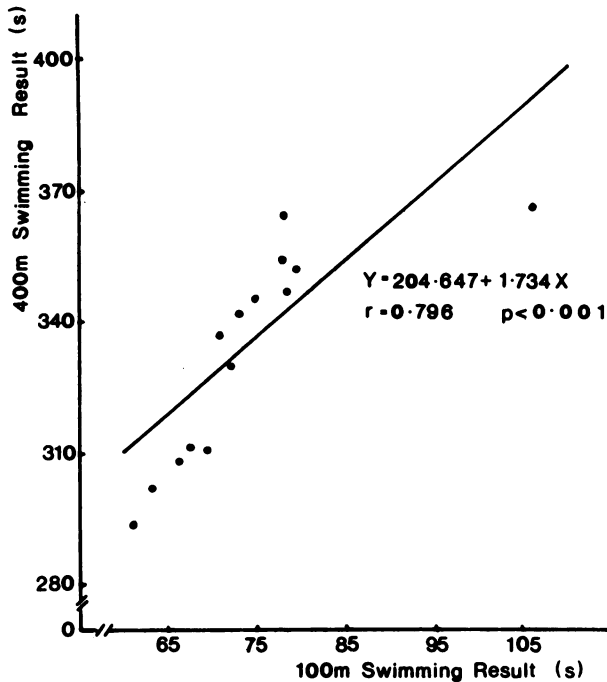


Fig. 3: Relationship between 100 m. and 400 m. front crawl performance ($n = 14$).

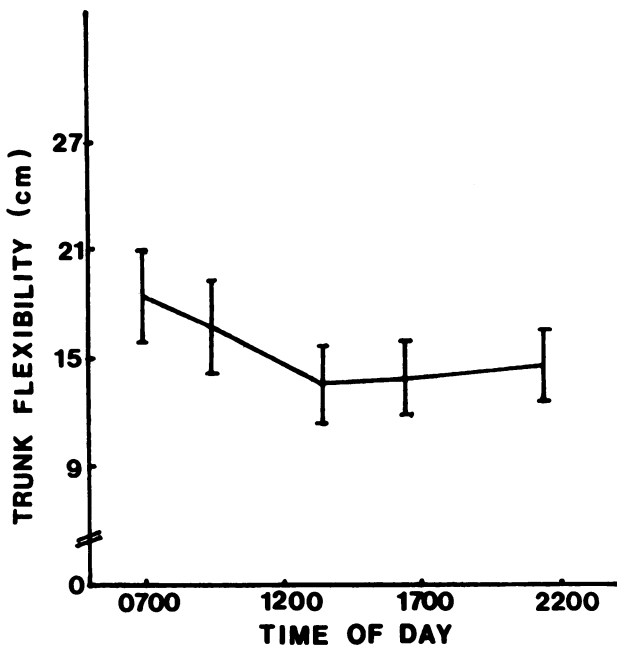


Fig. 4: Trunk flexibility during the solar day (mean \pm S.E.): the lower the values the better.

gap for sleeping which would require completion for a 24-hour periodicity to be delineated. The variations with time of day for PEF and grip strength were non-significant.

The earliest and the latest times of testing were clearly the poorest and best respectively for both swim distances. No evidence was consistently presented for rhythmic variations in the individual fitness components.

DISCUSSION

The results of both swim tests conformed to a linear trend throughout the day closely in phase with the oral temperature variation. The peak values were found at 22.00 hours: this is slightly later than the acrophase usually reported for body temperature of between 19.00 and 20.00 hours (Reilly and Brooks, 1982a). The plateau apparent in the evening may be an artefact of the measurement schedule with a true peak about 20.00 hours being missed. Estimates based on the cubic trend equation confirmed that the predicted peak value for oral temperature occurred at approximately 20.00 hours. This suggests that the association between body temperature and the performances does not inextricably link both together to a common oscillator. Indeed body temperature has been found to be slightly out of phase with metabolic and circulatory variables that show sensitive responses to exercise (Reilly and Brooks, 1982a) and there is some evidence supporting the existence of two internal "master locks" (Minors and Waterhouse, 1981).

The optimal core temperature for exercise is about 38.3°C according to Åstrand and Rodahl (1977) and the oral temperature was closest to this value in the late evening. The close association between body temperature and motor performance that normally exists has been found to persist in shift workers during adaptation of both rhythms to a nocturnal work regime (Colquhoun, 1971). It is possible that the longer swim times observed in the morning contained a residual effect of prior sleep though the existence or the extent of this component cannot be established using our experimental paradigm. Present results indicate that the body temperature does contribute significantly towards the performance changes with time of day though the exact mechanisms involved remain to be uncovered.

It is unlikely that the timing of tests employed missed the true peak in swim performance since the linear trend in swim times continued throughout the day until 22.00 hours. This suggests that the performance curves lagged slightly behind the temperature rhythm late in the evening and that they are not necessarily locked to the same causal nexus. The implication for scheduling swimming competitions where absolute performance levels are important, such as attempts to attain qualify-

ing standards for major championships, is that these events should be fixed for evening rather than afternoon times. The poorest performances would be expected for a morning meeting and the earlier the competition time the poorer the performance. Such findings imply also that the highest training stimulus can be presented to the organism in the evening and lower intensity efforts can be concentrated in the morning session.

The inclusion of female subjects introduced a possibility of an interaction between menstrual and circadian rhythms but this does not seem to interfere with the establishment of a time of day effect. Stephenson et al (1982) have shown that important determinants of performance – including peak $\dot{V}O_2$, anaerobic threshold and rating of perceived exertion – do not vary during the different phases of the menstrual cycle. Body temperature does vary in relation to the menstrual cycle (Redgrove, 1971) but the distribution of experimental tests over 4 successive weekends is likely to have counter-balanced circa-mensal influences. Resting metabolic measures remain constant throughout the menstrual cycle as does exercise time to exhaustion on a cycle ergometer though the variation in core temperature is apparent during exercise as well as at rest (Stephenson et al, 1982a).

The specific fitness measures displayed relatively flat curves throughout the day except for the trend in trunk findings of Stockton et al in 1978 of rhythms in grip strength, lung function and whole body flexibility strength, lung function and whole body flexibility closely in phase with the variation in oral temperature. The warm-up routine probably mobilised the shoulder and ankle joints sufficiently to offset a circadian variation in joint stiffness usually associated with a 24 hour cycle in the temperature of tissues within and around these joints (Wright et al, 1969). This is consistent with the time of day effect observed for trunk flexibility since the trunk musculature was not dynamically mobilised by the swimming warm-up to the same extent as the shoulder and leg muscles. Similarly circadian variations in dynamic lung compliance (Gaultier et al, 1977) may have been swamped by the physical activity prior to testing peak expiratory flow rate.

In summary this experiment presented evidence of a time of day effect on swimming performance and on trunk flexibility, the most favourable time of day being late in the evening. The fundamental rhythm in body temperature seems to be an important concomitant of the performance though their phase relationships are not in perfect agreement.

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