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Perceptual feeling and time-of-day effects on high intensity exercise performance

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ABSTRACT

The present study was designed to investigate the effect of time of day and perceptual feeling on high intensity cycle ergometry and related performance during 'normal working hours'. Eleven male participants (22.9 ± 2.6yrs; 182 ± 0.06cm; 80.43 ± 14.39kg) were tested over a 12 h period (08:00-20:00 h). Every hour, on the hour, participants performed a 10s maximal leg cycle ergometry test and completed an Exercise-Induced Feeling Inventory (EFI); every hour, on the half hour, they performed a standing broad jump (SBJ), hand grip test (HG) and vertical jump (VJ). Participants were instructed that each test required maximum effort. The main results show that there were no significant differences during the 12h experimental period in any of the performance variables ($P > 0.05$). However, peak power output during the high intensity cycle ergometry and distance and height achieved during the SBJ and VJ test along with positive engagement all peaked at 19:00h. The results show that high intensity cycle ergometry and related physiological measures are not affected by the time of day during 'normal working hours'. However, the data suggests that maximal performance is moderately affected by motivational levels of participants and therefore when using maximal exercise tests investigators should ensure that participants are highly motivated.

KEY WORDS: *Cycle ergometry; power output, feeling scale, diurnal*

INTRODUCTION

Virtually all physiological and behavioural processes are influenced by circadian rhythmicity (25). Diurnal variations are generated endogenously by the internal body clockwhich is synchronised to the 24h day and mainly controlled by the light dark cycle (18). The master body clock consists of a pair of suprachiasmatic nuclei (SCN) at the base of the hypothalamus (10). The SCN have receptors for melatonin which is suppressed by light and responds to darkness by preparing the body for sleep (26). It is now known that other brain regions and most peripheral tissues contain circadian clocks and are dependant in some way on the SCN for sustaining rhythmicity (11). Rhythms are also influenced by exogenous cues such as social interaction, timing of meals and sense of occasion (12).

The effects of circadian rhythms on anaerobic performance have been widely reported, however, results of these studies have been inconsistent. When significant patterns of diurnal variation have been found, values for peak power output (PPO) and mean power output(MPO) have tended to be higher in the afternoon/early evening compared to early morning values (17, 29). It is unclear what cause these fluctuations, however one suggestion is that the changes in performance may be related to an increased body temperature later in the day (22). To our knowledge, there have been no studies investigating physical performance every hour on the hour during a 12 hour period comprising normal 'working hours', while observing perceptual feeling states. Therefore the aims of this study were to assess the effect of the time of day on high intensity cycle ergometer performance test (CET), hand grip strength (HG), vertical jump height (VJ), standing broad jump (SBJ), in respect to perceptual feeling and patterns of diurnal variation.

SBJ and VJ performance were measured as they are tests of lower limb explosive power, an important contributor to sport and work performance in general and specifically to cycle ergometer performance. HG was measured as Baker and colleagues (3) have highlighted the importance of handgrip during high intensity cycle ergometry. They found PPO to be significantly higher when a standard handle bar grip was in place compared to no grip on the handlebar. An Exercise-Induced Feeling Inventory (EFI) was used to measure perceptual feeling state as it has been validated to assess feeling states which occur in conjunction with acute bouts of physical activity (13).

METHODS

Experimental approach to the problem

This investigation used a repeated measures design and required participants to perform a 10s maximal cycle ergometer test every hour on the hour. Every hour, on the half hour, they performed 3 x SBJ, 3 x maximal HG and 3 x VJ. Tympanic temperature (TT), blood pressure (BP) were measured and Exercise-Induced Feeling Inventory scores (EFI) were recorded on the hour before any exercise began. Heart rate (HR) was recorded pre and post all physical activity.

Within 5 days prior to the testing, all participants were briefed on all experimental procedures and fully familiarised with the CET, SBJ, HG and VJ tests. This normalized the experimental conditions for the effects of learning a novel task and to ensure reliability of the results (9, 21). Following familiarisation procedures (experimental design and equipment), each participant was tested over a 12 h period from 08:00 h to 20:00 h during a single day.

Participants were instructed to maintain a typical diet during the days leading up to the experiment. They were also directed to avoid caffeine and alcohol during the 24hpreceding the testing day. During the testing period, standardised meals were administered; water was drunk *ad libitum.* To ensure no external perceptual reference, all potential environmental light sources were blocked and no sunlight entered the laboratory.

Participants

Eleven healthy, physically active males (22.9 ± 2.6 yrs, 182 ± 0.06 cm, 80.43 ± 14.39 kg, mean ± SD) volunteered to participate in the study. All participants completed a consent form and a medical history questionnaire. Procedures were approved by the university ethical committee. Participants were volunteers and were instructed that they were free to withdraw from the experiment at any time. Body mass and stature were measured prior to testing and recorded to the nearest 0.1 kg and 0.1cm respectively.

Procedures

Cycle ergometry

A calibrated Monark (894E, Monark, SE) cycle ergometer was used for each experimental protocol. For each participant the saddle height was adjusted so their knee remained slightly flexed after the completion of the power stroke (with final knee angle approximately 170-175°, where 180° is when the knee is fully extended). Toe clips were used to ensure that the participants' feet were held firmly in place and in contact with the pedals. All participants were instructed to remain seated for the duration of the test. All participants were given the same level of verbal encouragement. Prior to each of the trials, the participants completed a standardised warm-up, 3minat 60rpm with a resistance of 2.0kg.

Participants were given a rolling start of 60rpm for a 5s period prior to resistive force application. On the command 'go', participants began to pedal maximally. Each participant was required to pedal with maximum effort for a period of 10s against afixed resistive load of 75 grams per kilogram total body mass as recommended by Bar-Or (5). Peak power output (PPO), the highest value in watts, recorded over the 10s maximal exercise period, was captured using an inertia corrected computer programme (Cranlea, UK).

Participants completed three maximal SBJs, HGs and VJs, with 20s rest between each trial and 2min rest between each of the performance variables. Each time they were encouraged to produce a maximal effort; with the best attempt recorded as a performance measure.

Standing broad jump

Prior to each jump, participants stood behind a marked line with their feet slightly apart. A two-foot take-off and landing was used. Free arm movement was permitted to provide forward drive and to increase the height and velocity of the body's centre of gravity and take off (1); investigators ensured that technique remained consistent throughout the testing period. Distance was measured in cm from the marked line to the rearmost heel strike.

Maximal hand-grip strength

Each participant performed the test with their dominant hand using a hand dynamometer (Takei, JP). Participants performed this test with their elbow by their side, flexed to a right angle, with their wrist held in a neutral position (20). The highest output (kg) of three trials was recorded as their maximum handgrip strength.

Vertical jump

Participants stood side on to a wall and jumped vertically using both arms and legs (counter-movement) (16) to project their body upwards and touch the wall at the highest point possible. Jump height was measured in cm and standingreach was subtracted.

Psychological measurement

An Exercise-Induced Feeling Inventory (EFI) (13) was completed by each participant every hour prior to the cycle ergometer test. The EFI measures feeling states occurring in conjunction with acute bouts of physical activity (13). Twelve variables were measured on a scale of 0 to 4 (0 = do not feel; 4 = feel very strongly) and were grouped into four categories of positive engagement (enthusiastic; happy; upbeat), revitalisation (refreshed; energetic; revived), tranquillity (calm; relaxed; peaceful), or physical exhaustion (fatigued; tired; worn out).

Physiological measurements

Blood pressure was measured immediately prior and immediately after each cycle ergometer test using a digital blood pressure monitor (Ormon HEM-705C, GDR) applied to the upper arm while participants were in a seated position. Body temperature was measured prior to each cycle ergometer trial by a tympanic (ear) thermometer (Braun 4520 Thermoscan, GDR), and heart rate was monitored continuously throughout the testing period using telemetry (Polar, FIN).

Statistical analyses

Time of day effects on performance characteristics and temperature were evaluated using a repeated-measures analysis of variance (ANOVA), with subsequent Bonferroni post-hoc analysis. Similarly, psychological measures were investigated with a repeated measures design ANOVA and Bonferroni post-hoc analysis. Statistical significance was set a priori at $P < 0.05$.

RESULTS

Cycle ergometer test

No time-of-day effect was observed for PPO (W) over the 12h testing period ($P > 0.05$). The maximum value for PPO occurred at 19:00 (710.91 ± 72.43W) while the lowest PPO was recorded at 13:00h (678.00±77.40W).

Standing broad jump, handgrip, vertical jump

Similarly there was no significant time-of-day effect observed for the SBJ (cm), HG (kg) or VJ (cm) (W) over the 12h testing period ($P > 0.05$). SBJ and VJ performance peaked at 19:00 (209.77 ± 23.59; 53.45 ± 13.05cm) with minimum values occurring at 08:00 and 18:00 respectively (192.77 ± 22.49; 53.36 ± 13.06cm).

Temperature

Tympanic temperature was not affected by the time-of-day ($P > 0.05$). Temperature (˚C) ranged from 36.23 ± 0.18 at 11:00 to 36.51 ± 0.20 ˚C at 15:00.

Values for each of the variables recorded at 1hr intervals are displayed in table 1.

Table 1. *Values for measured variables.*

Variable	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Temp (˚C)	36.34 ±0.23	36.26 ±0.18	36.24 ±0.24	36.23 ±0.18	36.28 ±0.15	36.35 ±0.30	36.40 ±0.14	36.51 ±0.20	36.39 ±0.22	36.33 ±0.15	36.50 ±0.30	36.51 ±0.11
Wingate $_{(peak)}$(W)	686.82 ±71.68	686.36 ±98.24	696.55 ±67.21	700.91 ±67.88	694.18 ±59.78	678.00 ±77.40	681.27 ±75.48	694.91 ±72.59	684.70 ±72.76	694.91 ±66.37	700.91 ±68.42	710.91 ±72.43
SBJ (cm)	192.77 ±22.49	199.73 ±29.66	201.32 ±28.67	202.91 ±27.26	203.27 ±25.72	200.18 ±26.10	204.55 ±24.46	206.00 ±28.20	201.77 ±21.02	203.18 ±21.09	208.05 ±19.93	209.77 ±23.59
HG (kg)	43.95 ±6.70	44.82 ±7.89	42.86 ±7.06	43.91 ±6.49	43.86 ±6.73	42.00 ±7.40	42.64 ±6.99	42.09 ±6.32	42.27 ±6.10	42.45 ±6.13	41.91 ±6.01	42.77 ±6.51
VJ (cm)	52.59 ±12.04	53.09 ±11.82	52.55 ±12.57	52.23 ±13.18	52.32 ±12.81	52.00 ±12.71	52.14 ±11.97	51.18 ±12.73	52.45 ±12.62	51.05 ±13.22	53.36 ±13.06	53.45 ±13.05

Exercise-Induced Feeling Inventory

Post hoc analysis of EFI scores found the mean value for positive engagementto be significantly higher at 12:00 h than at 17:00 h ($P < 0.05$). Mean values for physical exhaustion were significantly higher at 16:00 h and 17:00 h than at 14:00 h and significantly higher at 17:00 h than at10:00 h ($P < 0.05$). Revitalisation was found to be significantly higher at 12:00 h than at 17:00 h ($P < 0.05$). The acrophase (peak) for positive engagement, revitalisation, tranquillity and physical exhaustion occurred at 19:00 h, 13:00 h, 11;00 h and 10:00 h respectively, with the bathyphase (trough) occurring at 17:00 h, 17:00 h, 18:00 h and 17:00 h respectively (Table 2).

Table 2. *Exercise-Induced Feeling Inventory Scores; (0 = do not feel; 4 = feel very strongly) (±SD) (n = 11)*

Variable	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Positive Engagement	2.61 ±0.71	2.70 ±0.60	2.64 ±0.48	2.46 ±0.88	2.79 ±0.78	2.52 ±0.90	2.67 ±0.56	2.45 ±0.62	2.39 ±0.80	2.30 ±0.77	2.33 ±0.87	2.97 ±0.90
Revitalization	2.15 ±0.62	2.00 ±0.82	2.33 ±0.49	2.24 ±0.58	2.42 ±0.90	2.06 ±0.71	2.42 ±0.50	1.85 ±0.75	1.88 ±0.89	1.70 ±0.85	1.94 ±0.94	2.18 ±1.01
Tranquillity	2.94 ±0.42	2.76 ±0.58	2.79 ±0.34	3.00 ±0.52	2.97 ±0.62	2.70 ±0.78	2.82 ±0.58	2.82 ±0.74	2.79 ±0.67	2.73 ±0.85	2.64 ±0.91	2.88 ±0.58
Physical Exhaustion	1.58 ±0.70	1.33 ±0.62	1.12 ±0.62	1.51 ±0.99	1.48 ±0.86	1.58 ±0.91	1.24 ±0.80	1.85 ±0.86	1.91 ±0.97	2.24 ±0.83	1.91 ±0.97	1.88 ±1.15

The acro phase and bathy phase for all measured variables are displayed in Table 3.

Table 3. *Acro phase and bathy phase for all measured variables during 12h testing period.*

Variable	Acrophase	Bathyphase
Body temp (˚C)	15:00 h	11:00 h
10s sprint (W)	19:00 h	13:00 h
SBJ (cm)	19:00 h	08:00 h
HG (kg)	09:00 h	18:00 h
VJ (cm)	19:00 h	17:00 h
HR B W/U	14:00 h	13:00 h
HR A W/U	14:00 h	09:00 h
HR A Sprint	18:00 h	10:00 h
HR B SBJ	19:00 h	10:00 h
HR A SBJ	19:00 h	13:00 h
HR B HG	14:00 h	10:00 h
HR A HG	19:00 h	13:00 h
HR B VJ	14:00 h	11:00 h
HR A VJ	19:00 h	12:00 h
Positive engagement	19:00 h	17:00 h
Revitalisation	13:00 h	17:00 h
Tranquillity	11:00 h	18:00 h
Physical Exhaustion	10:00 h	17:00 h

HR B W/U (HR before warm-up); HR A W/U (HR after warm-up); HR A Sprint (HR after cycle ergometer sprint); HR B SBJ (HR before SBJ); HR A SBJ (HR after SBJ); HR B HG (HR before HG); HR A HG (HR after HG); HR BVJ (HR before VJ); HR A VJ (HR after VJ).

DISCUSSION

This study was designed to investigate the time of day effect on high intensity exercise performance during 'normal working hours', to establish if physical performance is associated with diurnal variation and to assess potential influences ofmotivation and psychological drive.

The major finding of the present study is that the time of day had no significant effect on high intensity cycle ergometry performance or other measures during 'normal working hours'. However, the results suggest that performance is somewhat affected by subject motivation, as evidenced by peak EFI values for positive engagement coinciding with peaks observed for the maximal cycle ergometry, SBJ and VJ at 19:00h. The effect of motivation on performance was highlighted previously by Reilly and Down (24), who suggested that the motivation required for maximum efforts in these tests can interfere with results and minimise any existing time of day effects. It seems reasonable to assume that in this study motivation did affect the results, as subject's were most 'positively engaged' with the task which resulted in them producing their peak performance during the last trial. It could also be argued that subjects were holding back during the early trials to ensure they were able to complete the tests without negative consequences.

There is no consensus in the current literature regarding the time-of-day effect on high intensity exercise performance, however similar to the results of the present study, Reilly and Down (1992) (24) found no significant circadian rhythms for PPO or mean power output (MPO) during a 30s Wingate test. Likewise no circadian rhythmicity was found in maximal anaerobic power during an arm isokinetic test on a swim bench (23). In addition Burgoon et al. (8) compared two maximal treadmill tests, one in the morning and one in the evening, and did not find any significant differences in exercise performance.

In contrast to the results of the present investigation, a number of studies have found evidence of a time-of-day effect on high-intensity performance, and although results are not directly comparable due to protocol differences their results still merit discussion. Hill and Smith (17) found PPO to differ across testing times with the mean at 21:00h about 8% higher ($P < 0.05$) than at 03:00h during 30s Wingate tests. The time at which these differences occurred was not reproducible in the present study, as our rationale focused on 'normal working hours'. Lericollais et al. (19) found MPO to be significantly higher at 18:00 h than 06:00 h during a 60s Wingate in highly trained cyclists. However the authors did speculate that the diurnal variations in power output could be partly attributed to the daily variation in motivation level (27). It has also been suggested that circadian rhythms are more pronounced in physically active than inactive individuals (2, 14, 15). Although our subjects were physically active they were not highly trained like the cyclists used by Lericollais et al. (19). Other researchers who have found significant time of day effects during high intensity exercise performance include Souissi et al. (27) who found a significant time of day effect on the 30s Wingate test, with PPO found to be significantly higher at 18:00 h than 06:00 h. Similarly, the same group found that PPO, MPO and total work done increased significantly from morning to afternoon (28). Bernard et al. (6) found maximal anaerobic power to be significantly higher at 14:00 h and 18:00 h than 09:00 h during repetitive maximal sprints of 6-8 seconds.

Limited studies have investigated the time of day effect on the remaining performance variables included here. To our knowledge only two studies have investigated the time of day effect on a SBJ. Reilly and Down (24) found a significant rhythm in the SBJ test with the acrophase occurring 17:45 h. It may be important to note that this was not a measured time point, it was calculated after the data had been subjected to cosinor analysis. In a later study by the same author, no time of day effect was found in SBJ (25). Handgrip strength in footballers was investigated in two separate studies and was found to be significantly affected by the time of day, with a peak occurring at 20:00 h ($P < 0.05$) (25). Bernard et al. (6) found significant circadian rhythmicity in vertical jump performance, where jumping height was significantly greater at 18:00 h and 14:00 h than at 09:00 h. However it may be important to note that subjects were not tested at equal time increments. Similar to the results in the present study Reilly et al. (25), found no differences in VJ across a 12h period when subjects were tested at 4h intervals.

As mentioned previously the methodology used in this study prevents direct comparisons with most other studies in this area. A large number of studies which have investigated the time of day effect on performance have tested subjects at time points throughout an entire solar day in order to achieve a complete description of circadian rhythms, this classical 24h rhythm can be represented by a cosine function (26) Although unable to describe an entire circadian rhythm, a testing period of 12 hours was chosen for this study for a number of reasons. The primary reason was to create a "real world" occupational and sporting condition within which muscular performance would normally occur. Testing during 'normal working hours' eliminates disrupting normal sleeping patterns and therefore avoids the problem of sleep inertia (26). It was decided to test subjects every hour to allow for a better description and more precise characterization of diurnal variation (26, 27) and to attempt to reveal the true extent of diurnal variation (30). The importance of this is highlighted by Reilly et al. (25) who found the peak for intra-aural temperature to occur at 20:00h but, in their discussion the authors state that the peak actually occurs at 18:00 h when measured at more frequent intervals which emphasises the importance of testing at frequent time points.

As subjects were asked to perform maximal exercise at regular intervals, fatigue is a potential problem which cannot be overlooked. However it was deemed suitable to test subjects at such regular intervals due to the short duration of the high intensity exercise. With regards to phosphocreatine (PCr), previous research has shown that after exhaustive exercise, near complete replenishment of PCr may take from < 5minutes to in excess of 15minutes, depending on the extent of PCr depletion, severity of acidosis, muscle motor unit and fibre type characteristics (4). Bogdanis et al. (7)

found that immediately following a 30s sprint on a cycle ergometer PCr was depleted to 19.5 ± 1.2% of resting levels. After 1.5m of recovery PCr was restored to 65.0 ± 2.8% and after another 4.5 minutes of recovery it slightly increased to 85.5 ± 3.5%. The authors used mathematical predictions to infer that it would take 13.6 minutes for PCr to reach 95% of resting values following the cessation of exercise. In the present study, subjects were given adequate recovery time to ensure almost complete PCr recovery. Although subjects were asked to perform maximally each hour on the hour and on the half hour maximal exercise periods were very brief, therefore glycogen depletion was negligible and they were given a sufficient recovery period of 23 minutes. In addition all subjects were well-accustomed to regular high intensity exercise. However it is possible that both central and peripheral fatigue could have a masking effect on any improvements throughout the day. EFI scores revealed mean values for physical exhaustion to be significantly higher at 16:00h and 17:00h than at 14:00h and significantly higher at 17:00h than 10.00h. Although an indication of fatigue, this does not produce clear picture of fatigue levels in participants. However as performance generally peaked in the last trial it seems unlikely fatigue had a significant influence on performance. It is also important to remember that there are large intraindividual differences in perceptual feeling and how it relates to subsequent performance (7).

CONCLUSION

As no significant differences were found in any of the performance variables over the course of the 12h it can be concluded that for short-duration high-intensity exercise is not affected by circadian rhythms during normal working hours (08:00h – 20.00h). However it would still be recommended that time of testing should be consistent within a study or a series of studies to eliminate any possibility of a confounding variables and allow a valid comparison to be made. This is particularly important if using highly trained athletes as their circadian rhythms are more pronounced than in less well-trained individuals. It is a plausible assumption, based on this limited data set, that athletic power performance is unaffected by time of day and as such there should be little variation in performance between morning, afternoon, or early evening competitive sessions.

While the physical aspect of performance seems to be unaffected, the EFI results suggest the behavioural components of performance may indeed be influenced by time of day and circadian rhythms. In practical application, these findings imply thatwhen engaged in high intensity exercise consideration of motivational strategy and state is necessary to ensure true peak performance.

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