Time-of-Day Effects on Short-Term Exercise Performances in 10- to 11-Year-Old Boys

Hichem Souissi, Anis Chaouachi, and Karim Chamari
Research Laboratory Sports Performance Optimization National Center of Medicine and Science in Sports (CNMSS)

Mohamed Dogui
Faculty of Medicine Monastir

Mohamed Amri
Faculty of Sciences Tunis

Nizar Souissi
Research Laboratory Sports Performance Optimization National Center of Medicine and Science in Sports (CNMSS)

The purpose of this study was to examine the time-of-day effects on short-term performances in boys. In a balanced and randomized study design, 20 boys performed four anaerobic tests of strength and power (grip strength, Squat-Jump, Five-jump and cycle Wingate tests) at 08:00, 14:00 and 18:00 hr on separate days. The results showed a time-of-day effect on oral temperature. Analysis of variance revealed a significant time-of-day effect for short-term performances for strength, cycle, and jump tests. The post hoc analysis revealed that performances improved significantly from morning to afternoon but no significant differences were noticed between 14:00 and 18:00 hr. The differences between the morning and the afternoon (the highest value measured either at 14:00 or at 18:00 hr) reached 5.9% for grip strength, 3.5% for the squat jump test, 5% for the five jump test, and 5.5% for $P_{peak}$ and 6% for $P_{mean}$ during the Wingate test. A significant positive correlation was found between temperature and short-term performances. In conclusion, a time-of-day effect in the child’s maximal short-term exercise performances exists in relation with core temperature. Such variations would have pronounced effects when expressed in training programs and competitions.

H. Souissi, Chaouachi, Chamari, and N. Souissi are with the Research Laboratory Sports Performance Optimization National Center of Medicine and Science in Sports (CNMSS), Tunis, Tunisia. Dogui is with the Dept. of Physiology, Faculty of Medicine Monastir, Tunisia. Amri is with the Laboratory of Functional Neurophysiology and Pathology, Faculty of Sciences, Tunis, Tunisia.
Many physiological variables exhibit circadian rhythms that reflect the direct influence of an endogenous pacemaker clock located in the suprachiasmatic nuclei (24). Circadian fluctuations have been observed under experimental conditions in many biological variables that induce time-of-day modifications in response to exercise (11,27). The majority of studies reported in the literature have focused on circadian and diurnal rhythms in exercise performance in adult subjects (11). It is generally accepted that maximal force (13,14,19,21,29), anaerobic power and capacity (18,7,22,23,30–33), and aerobic performances (2,3,8) varies within the 24-hr of the solar day with peak values being observed in the late afternoon/early evening concomitantly to the peak of the body temperature curve (13). Some studies have suggested that the simultaneous increases in both body temperature and muscular performance are causally related, and that the circadian rhythm of body temperature could be regarded as a passive warm-up effect (22). In addition, many biological functions that vary with time-of-day are known to affect maximal muscle performance. These functions include central (central nervous command, arousal, motivation) and peripheral (contractility, metabolism, and muscle fibers morphology) factors which can be influenced by hormonal and ionic variations (7,17,19,23).

Circadian, as well as diurnal, changes have been documented in ratings of psychological tests of children (35). To the best of our knowledge, there appears to be one study examining diurnal variation in children’s sport performance (15). The authors observed that for skills in the ball-and-cup game, the best performance occurred at 15:40 hr. However, for sprints with flying and standing starts, the best performances (higher speed) occurred at 08:30 and 10:30 hr, respectively. Thus, in this last mentioned study, differences between children and adults are likely to exist with regard to peak time location for sprint performances. This is unexpected because adults and children show the same temperature circadian pattern (16). Huguet and collaborators (15) didn’t explain clearly why the temporal order of children differed from that of adults. Therefore, the aim of the current study was to analyze the daily variations in maximal anaerobic performance during short-lasting physical tests in boys and to relate any eventual changes in these parameters to the diurnal fluctuation in oral temperature. Anaerobic function has been chosen because, during growth, it has not received the same attention from researchers, as aerobic function. This is a little surprising with respect to the anaerobic energy used daily during infancy, childhood and adolescence. Indeed, during leisure-time activities or sport events, the child is spontaneously more attached to short-burst movements than to long-term activities (1,10).

**Methods**

**Participants**
Twenty male untrained healthy youth boys (age = 10.7 ± 0.4 years [mean ± SD], body height = 143.7 ± 6.1 cm, body mass = 74.3 ± 4.734.8 ± 3.1 kg), recruited from a public Sfax city school in Tunisia, volunteered to participate in the current study. A pediatrician determined all boys to be prepubertal (at the first Tanner stage; 39). All subjects participated in their physical activity classes one to two times per week and could be considered physically active. For all boys, the morning session
of each school day commenced at 08:00 hr. Before testing, the subjects were given a letter that included written information about the study and a request for consent from the parents to allow their children to participate in the study. Parental and subject informed consent was obtained after the participants and their parents were informed of the experimental procedure. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Clinical Research Ethics Committee and the Ethic Committee of the National Centre of Medicine and Science of Sports of Tunis (CNMSS) before the commencement of the assessments. Subjects and their parent/guardian were also informed that participation was voluntary and that they could withdraw from the study at any time.

Subjects had regular sleeping schedules based on the actigraphic assessment of sleep/wake patterns. Spontaneous body movement was assessed continuously by wrist actigraphy (Actiwatch; Cambridge Neurotechnology Ltd, Cambridge, UK; Mini Mitter, Respironics Inc., Bend, Oregon, USA). The hardware of the actigraphs consists of a piezoelectric accelerometer with a sensitivity of 0.05 g. Boys were instructed to wear the Actigraph at all times, except when bathing and swimming, for 7 consecutive days. The actigraphs were returned to the laboratory and the data downloaded from the memory into a PC via an Actigraph Interface Unit. Actiwatch data were analyzed by Actiwatch Activity & Sleep Analysis 5 version 5.32 software (Cambridge Neurotechnology Ltd). The variables obtained were total sleep time, sleep start-time, sleep end-time and sleep latency. Sleeping data are given in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean (± SD) Values of Sleep Measures During Week and Weekend Days (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week days</td>
</tr>
<tr>
<td>Total sleep time</td>
<td>08:00 ± 00:32*</td>
</tr>
<tr>
<td>Sleep start time</td>
<td>23:12 ± 00:31*</td>
</tr>
<tr>
<td>Sleep end time</td>
<td>07:13 ± 00:34*</td>
</tr>
<tr>
<td>Sleep latency</td>
<td>00:46 ± 00:22*</td>
</tr>
</tbody>
</table>

* Significantly different from week-end.

**Experimental design**

Participants attended a total of 8 data collection sessions including a 2-part orientation session. During the orientation phase, each subject was familiarized with the general environment and the testing procedures. The remaining 6 sessions were completed during the course of the subsequent week. Each subject performed over two days a selected tests of strength and power (functional performance measures) at three different times of day: 08:00, 14:00 and 18:00 hr, so that approximately 24 hr separated each test day. This procedure was chosen to minimize any performance changes that could occur over a longer time period. On the first test session, each subject completed in the same order the grip strength, the Squat-Jump, and
the Five-jump tests. The interval between two tests was 15 min. On the second session, subjects completed a Wingate test. The test sessions were performed in a random order commencing with oral temperature and body mass measurements. Oral temperatures were taken with a calibrated digital clinical thermometer (Omron, Paris, France; accuracy: 0.05 °C) inserted sublingually for at least 3 min with the subjects in a seated resting position for at least 15-min. Digital scales were used to determine body mass (Tanita, Tokyo, Japan; precision: 100 g).

Instructions about sleep and diet were given to the subjects before the experimentation. They were directed to get a good night’s sleep before each test and to avoid strenuous activity during the 24-hr preceding each test session. Compliance with the directions relating to pretest sleep and activity was checked by actimetry (Actiwatch; Cambridge Neurotechnology Ltd, Cambridge, UK; Mini Mitter, Respironics Inc., Bend, Oregon, USA) and daily activity diaries. During the period of investigation, subjects were prohibited from consuming food, beverages, or any known stimuli (e.g., caffeine) that would possibly enhance or compromise alertness. Subjects to be tested at 08:00 hr were requested to come to the laboratory at 07:30 hr, in a fasted state. Only one glass of water was authorized, to avoid the effects of postprandial thermogenesis. When they were tested at 14:00 hr and 18:00 hr, the subjects had not to have performed intense physical activities during the day and had to have eaten their last meal at least three hours before the beginning of the test session. All subjects had the same standard isocaloric meal before testing. Only water was allowed ad libitum.

**Exercise Protocol**

**Handgrip Strength.** The maximal handgrip strength of the dominant hand was measured with a calibrated hand dynamometer (T.K.K. 5401; Takei, Tokyo, Japan). Hand dominance was determined by asking the subject which hand was used to hold a pencil and to throw a ball. The subjects were standing comfortably with the shoulder adducted. The dynamometer was held freely without support; it was not touching the subject’s trunk. The position of the hand remained constant, with a downward direction. The palm did not flex on the wrist joint. The subjects were required to exert maximal strength on the dynamometer (maximum voluntary contraction). All subjects performed 3 trials with the dominant hand, and the best performance was used. The scale of the dynamometer indicated handgrip strength in kilograms. Maximal grip strength was calculated in Newtons by multiplying the dynamometer index by 9.81.

**Squat Vertical Jump.** The squat vertical jump was performed with both feet on an infrared jump system (Optojump, Microgate, Bolzano, Italy) interfaced with a microcomputer. The Optojump photocells placed 6 mm from the ground, were triggered by the feet of the participant at the instant of take-off and were stopped at the instant of contact upon landing. Participants stood between two 1-m infrared sensor bars to perform the squat jump. In the starting position, the participants flexed their knees to approximately 90°. Their hands were crossed in front of their chest. Then, without any other movement (arm or leg countermovement) they performed a vertical jump with maximum effort. Subjects performed 3 maximal vertical jumps separated by 2 min of rest. The best of the 3 was retained for the determination of maximal jump height.
**Five-Jump Test.** This test measures muscle explosive power; elastic properties, and ability to combine consecutive movements (9). The test was started from a standing position, with feet next to each other. Subjects tried to cover the longest distance they could by performing a series of five forward jumps with alternate left- and right-leg contacts. The fifth leap was finished again with joined feet. The total distance of the five jumps divided by five was used as the outcome. Subjects performed 3 Five-jump tests separated by 2 min of rest. The best of the 3 was used for analysis.

**Wingate Test.** The Wingate test was conducted on a friction-loaded cycle ergometer (Monark 894E Monark-Crescent AB, Varberg, Sweden) interfaced with a microcomputer. The seat height and handlebars were adjusted appropriately for each subject. The Wingate test consisted of a 30-s maximal sprint against constant resistance. For each subject the load was determined according to body mass using the optimization tables of Bar-Or (5; 0.070 kg · kg⁻¹ body mass). All subjects completed a standardized 3-min warm-up involving pedalling at 60 rpm interspersed with three 2- to 3-s all-out sprints. A recovery period of 5 min was allowed between the warm-up and the test. The Wingate test commenced from a rolling start, at 60 rpm against minimal resistance (weight basket supported). When a constant pedal rate of 60 rpm was achieved, a countdown of “3–2–1 go” was given, and the test resistance was applied and the computer activated. Subjects were verbally encouraged throughout the test to avoid pacing and to sustain their supramaximal effort throughout the test. The power output was calculated each second for the duration of the test. The Peak power (P_peak) over 1-s and the Mean power (P_mean) over the 30-s period were recorded. The percentage of decrease in power (W_d) or fatigue index, is the difference between the instantaneously-1sec highest and lowest powers divided by the highest power.

**Statistical Analysis**

The calculated and measured variables were analyzed using one-way analysis of variance (ANOVA) with repeated measurements using the factor time. When appropriate, significant differences among means were tested using Least Significant Different (LSD) Fisher post hoc test. A correlation analysis (Pearson product moment) between the temperature and anaerobic performance parameters was also performed. A probability level of 0.05 was selected as the criterion for statistical significance. All statistical tests were performed using STATISTICA Software (StatSoft, France). Data are reported as the mean ± SD (standard deviation) in the text, and is displayed as the mean ± SE (standard error) in the figures.

The level of significance was set at \( p < .05 \).

**Results**

**Temperature**

A significant diurnal variation was found for the at-rest oral temperature \( (F_{(2, 38)} = 60.2; p < .001) \). The mean value of oral temperature measured at 18:00 hr was higher than the one measured at 08:00 hr \( (p < .001) \) and 14:00 hr \( (p < .05) \; (Figure 1) \), and the amplitude of the rhythm was \( 0.63 ± 0.1 \; ^{\circ}C (~1\%) \).
Handgrip Strength

There was evidence of diurnal fluctuation in grip strength ($F_{(2, 38)} = 4.3; p < .05$). The mean value of grip strength measured at 08:00 hr was significantly lower than that measured at 14:00 hr ($p < .05$) and 18:00 hr ($p < .001$; Figure 2). However, no significant differences were noticed between 14:00 and 18:00 hr values. The amplitude of the rhythm was $1.1 \pm 0.7$ kg (5.9%). A significant positive correlation was found between oral temperature and grip strength ($r = .39; p < .01$).

Squat Jump Test

The maximal jump height (HJ) data showed a significant diurnal increase ($F_{(2, 38)} = 9.1; p < .001$). HJ was found to be lower at 08:00 hr than at all other time points measured ($p < .001$; Figure 2). However, no significant differences were noticed between 14:00 and 18:00 hr values. The amplitude of the rhythm was $1.1 \pm 0.6$ cm (3.5%). A significant positive correlation was found between oral temperature and HJ ($r = .3; p < .01$).

Five-Jump test

ANOVA revealed a significant ($F_{(2, 38)} = 15.8; p < .001$) time-of-day effect for performance during the five-jump test (5JT). The post hoc analysis revealed significant differences ($p < .001$) between the morning and the afternoon but no significant differences between 14:00 and 18:00 hr (Figure 2). The amplitude of the rhythm was $7.5 \pm 4.0$ cm (5%). A significant positive correlation was found between oral temperature and 5JT ($r = .22; p < .05$).

Wingate Test

For $P_{peak}$, there was a significant effect of time-of-day ($F_{(2, 58)} = 4.4; p < .01$). $P_{peak}$ improved significantly from morning to afternoon ($p < .01$; Figure 2). However,
no significant differences were noticed between 14:00 and 18:00 hr. The amplitude of the rhythm was $0.4 \pm 0.2$ (W · kg$^{-1}$; 5.5%). A significant positive correlation was found between oral temperature and $P_{\text{peak}}$ ($r = .24; p < .05$). There was also a significant effect for time-of-day ($F(2, 38) = 36.5; p < .001$) on $P_{\text{mean}}$. The post hoc analysis revealed significant differences ($p < .001$) between the morning and the afternoon but no significant differences were noticed between 14:00 and 18:00 hr (Figure 2). The amplitude of the rhythm was $0.43 \pm 0.3$ (W · kg$^{-1}$; 6.3%). A significant positive correlation was found between temperature and $W_d$ ($r = .26; p < .05$).

There was a significant ($F(2, 38) = 2.4; p < .05$) time-of-day effect for Power decrease. The post hoc test showed that power decline was greater in the afternoon than in the morning ($p < .05$; Figure 2). However, no significant difference was observed between 14:00 and 18:00 hr values. The amplitude of the rhythm was $4.6 \pm 3.9$ (%) (10.2%). A significant positive correlation was found between temperature and $W_d$ ($r = .26; p < .05$).
Discussion

The purpose of this study was to provide the first experimental assessment of the time-of-day effect on short-term performances in boys. Our results mainly show that (i) child’s grip strength and maximal anaerobic powers during cycling and jumping are significantly higher at 14:00 hr and 18:00 hr than at 08:00 hr and (ii) short-term performances and oral temperature fluctuate concomitantly.

The data presented in this experiment, indicate that the child’s short-term performances were better in the afternoon than in the morning with an amplitude ranging from 3.5 to 6%. This amplitude might underestimate the absolute performance amplitudes for the assessed physical capacities. Indeed, in the current study, the earliest session was assessed at 08:00 hr, whereas, in the literature, the times of the minimal values in the circadian rhythm were generally observed between 05:00–06:00 hr in adults. Our results are at odds with those of Huguet et al. (15), who observed time-of-day effect in sprint performances (a 20-m run) with the highest performance in the morning in French children 9–11 years of age. We could speculate that the sex of the subjects (boys and girls in the Huguet et al. (15) study and only boys in the current study), the environment synchronizer (Tunisia vs France) and the school schedule (4 school days per week in French and six days per week in Tunisians) are factors which may explain the differences among the studies even if to the best of our knowledge no investigation showed any of these tendencies. Indeed, gender, the length of the solar days and the school schedule are factors which may modify the children’s curves of circadian changes (35).

The results of the present investigation, concerning the diurnal fluctuations of child’s muscular power are consistent with previous studies on adults (7,11,14,18,19,21–23,30–33). The fact that child’s short-term performances were lower in the morning than in the afternoon raises the question of what limits these performances in the morning.

It has been suggested that the higher value of muscular power and strength in the afternoon may be linked to changes in body temperature (7,18). In support, oral temperature, recorded as a biological marker of the experimental population, shows a diurnal variation with higher values recorded at 14:00 hr and 18:00 hr than at 08:00 hr, and the morning/afternoon gain of 0.63 °C is in the range of the previous studies on adults, which showed an amplitude ranging from 0.5 to 1 °C (18,28). It would seem, therefore, that measures of child’s short-term performances closely reflect the changes in body temperature during the course of the daytime. This association between the diurnal temperature variation and many aspects of physical performance has been found on many previous occasions in adults (11). Some authors have postulated the hypothesis of a causal link between core temperature and muscular power fluctuation (2,7). Although the exact mechanisms explaining this relationship are not known yet, it has been suggested that higher body temperature may enhance metabolic reactions, increase the extensibility of connective tissue, reduce muscle viscosity and increase conduction velocity of action potentials (28). Thus, in the current study, the lower muscular power and strength observed in the early morning could be partly explained by the lower core temperature at this time. Nonetheless, the mean range of variation in oral temperature observed in our study was low (0.63 °C) and seems insufficient to account for the totality of the changes observed in the property of muscle contraction. In addition, the correlation between
temperature and muscle performances was relatively low even if significant ($0.22 < r < .39$). In that regard, despite the fact that oral temperature increased from 14:00 hr to 18:00 hr, there was no change in short-term performances between these two times of day. Furthermore, Martin and coworkers (17) have shown that, despite an artificial heating of the adductor pollicis muscle by $5 \, ^\circ C$ at 07:00 hr, the diurnal fluctuation in muscle strength persisted. It thus seems unlikely in the present experiment that child’s muscular power was totally led by the changes in body temperature. While temperature and short-term performances do covary, causality cannot be concluded. The parallel variations in these parameters may stem from the drive of a common oscillator, the suprachiasmatic nuclei in the hypothalamus and the pineal gland which interact to form the body clock (13).

The grip strength and the jump tests performances are referred to as a maximal voluntary contraction. This is dependent on central and peripheral factors. Circadian fluctuation of muscle strength is mainly linked to modifications prevailing at the muscular, rather than the neural level (14). Previous experiment in adults, showed that muscle strength developed by adductor pollicis (17) or knee extensor muscles (14) fluctuates throughout the day without any significant variation of the electromyographic signals (14, 17).

The present results show that decline in the Wingate test’ power ($W_d$: fatigue index) is greater in the afternoon than in the morning in prepubertal boys. These results seem to disagree with our previous study in adults (31) in which we have shown a greater decrease in power in the morning with respect to the evening despite a higher peak power in the afternoon which predisposes the subject for a subsequent greater decrease in power. Better use of aerobic energy in the afternoon could have helped the adult subjects to minimize the fatigue index observed at this time of day (31). In the current study the $W_d$ was correlated with $P_{peak}$ ($r = .71$). This finding suggests that the higher $P_{peak}$ observed in the afternoon may have contributed to the greater $W_d$ observed at that moment.

In conclusion, the present experiment has shown the existence of a diurnal fluctuation in short-term exercise performances during strength, power, cycle, and jump tests in boys. It may therefore be of benefit to scientists, clinicians, and coaches to consider the effect of time of day in studies, training programs, and competitive events involving boy’s short-term performances.

References