The Effect of Training at a Specific Time-of-Day on the Diurnal Variations of Short-Term Exercise Performances in 10- to 11-Year-Old Boys

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The aim of this study was to assess the effect of time-of-day-specific training on the diurnal variations of short-term performances in boys. Twenty-four boys were randomized into a morning-training-group (07:00–08:00h; MTG), an evening-training-group (17:00–18:00h; ETG) and a control-group (CG). They performed four tests of strength and power (unilateral isometric maximal voluntary contraction of the knee extensor muscles, Squat-Jump, Counter-Movement-Jump and Wingate tests) at 07:00 and 17:00h just before (T0) and after 6 weeks of resistance training (T1). In T0, the results revealed that short-term performances improved and oral temperature increased significantly from morning to afternoon (amplitudes between 2.36 and 17.5% for both oral temperature and performances) for all subjects. In T1, the diurnal variations of performances were blunted in the
MTG and persisted in the ETG and CG. Moreover, the training program increased muscle strength and power especially after training in the morning hours and the magnitude of gains was greater at the time-of-day-specific training than at other times. In conclusion, these results suggest that time-of-day-specific training increases the child’s anaerobic performances specifically at this time-of-day. Moreover, the improvement of these performances was greater after morning than evening training.

Regular physical activity as well as a physically active lifestyle during the pediatric years are essential for normal growth and development and may help to reduce the risk of developing some chronic diseases later in life (25).

There is a growing number of school-aged youth participating in resistance training in schools, health clubs, and sport training centers. Indeed, in addition to increasing muscular strength, power and motor skill performance, when appropriately prescribed and supervised, pediatric resistance training program may have a favorable influence on body composition, bone health, and reduction of sports-related injuries of children and adolescents (11,12,14). Over the past decade, evidence-based reports have emerged regarding both the safety and efficacy of youth resistance training (11,12). Nowadays, an expert panel of exercise scientists, physicians, and health/physical education teachers with clinical, practical, and research expertise regarding issues related to pediatric exercise science, sports medicine, and resistance training contributed to this statement (1,2,4,7,11,12,15,23,24).

On the other hand, in adult subjects, adaptation to resistance training has been shown to be time-of-day dependent (26–28,31). In fact, training in the morning hours can improve short-term maximal performance especially at the time of its nadir and, therefore, reduced or blunted the diurnal variations of muscle power and strength (26–28,31). However, these diurnal variations persisted in subjects who trained in the evening hours (26–28,31). To the best of our knowledge, there appear to be two studies examining diurnal variation in children’s sport performance (19,29). Huguet et al. (19) showed that performances for skills in the ball-and-cup game were higher 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. Recently, we found that performances for strength and power (grip strength, Squat-Jump, Five-jump and cycle Wingate tests) improved significantly from morning to afternoon (29).

In view of the above considerations, the question then arises to determine if resistance training at a specific time-of-day can lead to similar or different improvements in child’s short-term maximal performances. It is critical, therefore, for health/physical education teachers, coaches and sports scientists interested in pediatric exercise science to determine the role of a regular participation in resistance training scheduled in the morning or the evening hours to optimize training adaptability (e.g., strength and power gains) and to overcome the morning alteration of short-term maximal performances in boys.

Thus, the aim of the current study was to investigate the effect of 6 weeks of resistance training scheduled in the morning or evening hours on the daily variations of muscle strength and power during short-lasting physical tests in 10–11-years-old boys.
Methods

Participants
Twenty four male untrained healthy youth boys with no significant anthropometrical differences in body mass, body height, body mass index, and Tanner stages volunteered to participate in the current study. Descriptive characteristics of the participants are shown in Table 1. The children were recruited from a public school in the city of Sfax which represents one of the biggest and most extended cities in Tunisia. All participants had exactly the same daily schedules in our school and they participated in their normal physical education class twice per week. However none of the volunteers participated in any after-school activities. A pediatrician determined all boys to be prepubertal (at the first Tanner stage) using the composite score of the widely used method of pubertal stage assessment described by Tanner (33). Before participation in this study, 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. None had any history of musculoskeletal, neurological or orthopedic disorder that might have affected their ability to execute resistance training or to perform strength tests.

Before testing, subjects were randomly assigned to either a morning training group (MTG, who trained only between 07:00 and 08:00 hr, \( n = 8 \)), evening training group (ETG, who trained only between 17:00 and 18:00 hr, \( n = 8 \)) or a control group (CG, did not train but participated in all tests, \( n = 8 \)). Both the control and training groups were asked to list any activities or sports they performed during the 6-week period of the study, and both groups listed similar activities and sports, such as running, and performing push-ups and sit-ups in physical education class. The primary difference between the control and training groups is that the training group participated in a 6-week resistance training program, whereas the control group did not. All subjects in both control and training groups were untrained individuals and did not have a regular resistance training routine or participated in a formal resistance training program during the 6-week period of the study. No subject withdraws because of injury or other adverse experiences.

Experimental design
Participants attended a total of 6 data collection sessions including a 2-part orientation session. During the orientation phase, each subject was familiarized with the general environment, equipment and the experimental procedures to minimize the learning effect during the course of the study. Subsequently, subjects performed 4 test sessions in the morning (07:00–08:00 hr) and evening (17:00–18:00 hr) before (T0) and after 6 weeks of resistance training (T1). The test sessions were performed on separate days with only one test session a day, allowing a recovery
Table 1  Anthropometric parameters (mean ± SD) of the MTG, ETG and CG recorded in T0 and T1.

<table>
<thead>
<tr>
<th></th>
<th>MTG</th>
<th>ETG</th>
<th>CG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T0</td>
<td>T1</td>
<td>T0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>152.9 ± 6.4</td>
<td>154.1 ± 6.6</td>
<td>151.5 ± 9.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>41.7 ± 8</td>
<td>42.1 ± 7.9+</td>
<td>42.8 ± 7.1</td>
</tr>
<tr>
<td>BMI (Kg · m⁻¹)</td>
<td>17.7 ± 2.2</td>
<td>17.6 ± 2.2</td>
<td>18.6 ± 2.3</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>5.4 ± 2.5</td>
<td>4.9 ± 1.4</td>
<td>5.6 ± 3</td>
</tr>
<tr>
<td>Lean Body mass (kg)</td>
<td>36.3 ± 6.4</td>
<td>37.2 ± 6.6</td>
<td>37.2 ± 5.2</td>
</tr>
</tbody>
</table>

+: significant difference between T0 and T1 at the level of p < 0.05.
period ³36 hr. Two sessions were conducted in the morning (07:00 hr) and two in the afternoon (17:00 hr). During each test session, subjects completed in the same order the Squat-Jump (SJ), Counter-Movement-Jump (CMJ), maximal voluntary contraction (MVC), and cycle Wingate tests. The interval between two tests was 15 min. Before all testing sessions, participants completed a standardized warm-up procedure consisting of 5-min cycling at 60 W (i.e., 60 rpm) on a stationary cycle ergometer and a set of two to three brief (3–5s) and maximal sprint cycling. After warm-up, the participants rested on the cycle ergometer for 2 min.

The test sessions were performed in a random order commencing with oral temperature and body composition (height, body mass, body fat percent, lean 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. Height and weight measurements were taken with children wearing very light clothing and without shoes. Height was recorded to the nearest 0.1 cm using a fixed stadiometer. Body mass was measured on a digital scales (Tanita, Tokyo, Japan; precision) to the nearest 0.1 kg. Body mass index (BMI) was calculated by dividing the participants’ body mass (kg) by the square of their height (m²). Percentage body fat was estimated with an impedance metric balance scale (type Tanita, Tokyo, Japan). The lean body mass was calculated as BM—(BM × percentage of body fat/100).

The MTG trained only in the morning and performed tests in both morning and evening. The ETG trained only in the evening and were also tested in both morning and evening. The morning and evening tests were scheduled at the same time-of-day of training sessions.

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 07:00 hr were requested to come to the laboratory at 06:30 hr, in a fasted state. Only one glass of water was authorized, to avoid the effects of postprandial thermogenesis. When they were tested at 17:00 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.

Training Programs

The participants assigned to the MTG and the ETG trained on 2 sessions per week for 6 weeks. They had at least 48 hr rest between two successive sessions. The training program variables were designed according to the basic principles described by Kraemer and Fleck (20), Faigenbaum et al. (14), and Faigenbaum and Myer (11,12). Every training session included 2 sets of 10 repetitions at 50% of the one repetition maximum (1-RM) during the first 2 weeks of training and 60% of the 1-RM during the last 4 weeks of 5 different exercises in a variable
resistance machine (bench press, Hack squat, leg extension, leg curl, pullover machine). One repetition maximum (1-RM) values for all exercises were obtained during the first session at training week and adjusted after 2 weeks of training. The subjects were allowed a 2 min rest between each set and a 3 min rest between each of the 5 different exercises. The duration of the training sessions was about 60 min. Each session was supervised by trained research assistants and included a warm-up of about 10 min with jogging, static stretching, and light exercises of the involved muscle groups and approximately 5–8 min of stretching to cool down. Trained research assistants were responsible for monitoring exercise techniques, monitoring subjects for safety, and provided motivation.

**Exercise Protocol**

**Squat Jump (SJ) and Counter Movement Jump (CMJ) Tests.** The SJ and CMJ were 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 SJ and CMJ. In the starting position, the participants flexed their knees to approximately 90°, and then they performed a vertical jump with maximum effort during SJ. In contrast, during CMJ subjects initiated the jump from an extended leg position, descended to 90° knee flexion, and immediately performed an explosive concentric action for maximal height. In these jumping conditions, the subjects were instructed to keep their hands on the hips. Subjects performed 3 maximal vertical jumps of each jump tests separated by 2 min of rest. The best of the 3 was retained for the determination of maximal jump height during SJ and CMJ.

**Maximal Voluntary Contraction (MVC).** Subjects performed three 5 s MVC of the knee extensors (120° knee flexion) of the dominant leg. They were strongly encouraged while visual feedback was provided to reach maximal level. The subjects were secured to a sitting position in a knee extension device (Leg extension machine, PANATTA SPORT, Italia). The torso was fixed with two horizontal safety belts in the chest and waist area, and the upper extremities were placed next to the body holding handgrips. Moreover, both thighs were strapped. The force generated during muscle contraction was measured by a strain gauge (Globus Italia, Codogno, Italy) properly mounted on the leg extension machine with chains attached to the sliding axis of the seat. The strain gauge was positioned at the distal end of the tibia, proximal to the medial malleoli. The signal from the strain gauge was sampled at 100 Hz and stored on a computer for later analysis with commercially available software (TCS-SUITE 400, Globus Italia).

The MVC was determined as the highest force value reached over the 5 s duration from three trials separated by 2-min rest.

**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 (3; 0.070 kg · kg⁻¹ body mass). The Wingate test
Souissi et al. 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 or fatigue index (FI), 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 three-way analysis of variance (ANOVA) [3 (groups) × 2 (pre/posttraining) × 2 (time-of-day)] with repeated measures on the last two factors. When appropriate, significant differences among means were tested using the LSD post hoc test. Anthropometrical data were analyzed using a two-way ANOVA [3 (groups) × 2 (pre/posttraining)] with repeated measures. Unpaired t tests were used to compare relative changes (delta change values) from before to after training between the MTG and ETG. The data are expressed in mean ± SD (standard deviation), and the significance level was set at \( p < .05 \). All analysis were performed using STATISTICA Software (StatSoft, France).

**Results**

**Anthropometrical Parameters**

There was a significant main effects for pre/posttraining \( (F_{(1,7)} = 20.68, p < .01) \) only for body weight. The post hoc analysis showed that body weight was significantly higher at T1 in comparison with T0 for both training groups \( (p < .05) \). However, no main effect for pre/posttraining for body height, lean body mass, BMI and body fat. Likewise, the groups effect and the groups × pre/posttraining × time-of-day interaction were not significant for all the anthropometrical parameters.

**Temperature**

A significant diurnal variation was found for the at-rest oral temperature \( (F_{(1,7)} = 171.22, p < .001) \). The mean value of oral temperature measured at 17:00 hr was higher than the one measured at 07:00 hr \( (p < .001, \text{see Figure 1}) \) with an amplitude of 2.5 ± 1.09%. There were no significant main effects for groups \( (F_{(2,14)} = 0.10, p > .05) \), or pre/posttraining \( (F_{(1,7)} = 0.06, p > .05) \). Neither was there a significant groups × pre/posttraining × time-of-day interaction \( (F_{(2,14)} = 0.86, p > .05) \) indicating that time-of-day effects did not change with training at the same time-of-day.

**Wingate Test**

Table 2 present the results of the Wingate test variables calculated in the morning and in the evening, in T0 and T1, on all groups.
Figure 1 — Mean and SD of oral temperature ($n = 24$) in the morning and the evening tests at T0 and T1 for all groups. *** Significant differences between the time points at the level $p < .001$.

Table 2 Performances (Mean ± SD) on the Wingate Test ($P_{\text{peak}}$ (W•Kg$^{-1}$), $P_{\text{mean}}$ (W•Kg$^{-1}$) and FI (%)) Recorded at the Two Times of Day in T0 and T1.

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th></th>
<th>T1</th>
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<tbody>
<tr>
<td></td>
<td>07:00 h</td>
<td>17:00 h</td>
<td>07:00 h</td>
<td>17:00 h</td>
</tr>
<tr>
<td>MTG</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$P_{\text{peak}}$ (w/kg)</td>
<td>8.57 ± 0.97</td>
<td>9.11 ± 1.01***</td>
<td>9.23 ± 0.97+++</td>
<td>9.39 ± 1.14+</td>
</tr>
<tr>
<td>$P_{\text{mean}}$ (w/kg)</td>
<td>7.12 ± 0.64</td>
<td>7.48 ± 0.59**</td>
<td>7.63 ± 0.68++</td>
<td>7.61 ± 0.51</td>
</tr>
<tr>
<td>FI (%)</td>
<td>0.34 ± 0.1</td>
<td>0.35 ± 0.11</td>
<td>0.33 ± 0.07</td>
<td>0.36 ± 0.11</td>
</tr>
<tr>
<td>ETG</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$P_{\text{peak}}$ (w/kg)</td>
<td>7.99 ± 1.3</td>
<td>8.66 ± 1.19***</td>
<td>8.26 ± 1.25+</td>
<td>9.28 ± 1.43**, +++</td>
</tr>
<tr>
<td>$P_{\text{mean}}$ (w/kg)</td>
<td>7.01 ± 0.85</td>
<td>7.48 ± 0.97**</td>
<td>7.22 ± 1.00</td>
<td>7.98 ± 1.06***, +++</td>
</tr>
<tr>
<td>FI (%)</td>
<td>0.32 ± 0.07</td>
<td>0.33 ± 0.04</td>
<td>0.34 ± 0.08</td>
<td>0.35 ± 0.06</td>
</tr>
<tr>
<td>CG</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$P_{\text{peak}}$ (w/kg)</td>
<td>8.15 ± 1.2</td>
<td>8.67 ± 1.15***</td>
<td>8.22 ± 1.01</td>
<td>8.74 ± 1.05***</td>
</tr>
<tr>
<td>$P_{\text{mean}}$ (w/kg)</td>
<td>6.89 ± 0.81</td>
<td>7.24 ± 0.54*</td>
<td>6.9 ± 0.75</td>
<td>7.23 ± 0.35*</td>
</tr>
<tr>
<td>FI (%)</td>
<td>0.39 ± 0.09</td>
<td>0.43 ± 0.12</td>
<td>0.36 ± 0.09</td>
<td>0.4 ± 0.11</td>
</tr>
</tbody>
</table>

*: **: ***: significant difference between 07:00 and 17:00 h at the level of $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively.

+: ++: +++: significant difference from T0 at the level of $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively.
Peak Power

There was no main effect for groups (\(F_{(2.14)} = 0.68, p > .05\)). In contrast, there was a significant main effects for the time-of-day (\(F_{(1.7)} = 73.7, p < .001\)) and pre/posttraining (\(F_{(1.7)} = 38.67, p < .001\)). Moreover, there was a significant groups × pre/posttraining × time-of-day interaction (\(F_{(2.14)} = 3.92, p < .05\)).

In T0, the post hoc revealed that, for all groups, \(P_{\text{peak}}\) improved between the morning and the evening (\(p < .001\)) [Amplitude: 5.89 ± 5.04, 7.98 ± 4.66 and 6 ± 6.26%, for MTG, ETG and CG, respectively].

In T1, these diurnal variations persisted in the ETG and the CG (\(p < .001\)) with amplitudes of 10.97 ± 4.1 and 5.81 ± 5.6%, respectively. However, these daily fluctuations are blunted in the MTG (\(p > .05\)).

When we consider the effect of training, the MTG and ETG improved their \(P_{\text{peak}}\) in the morning (\(p < .001\) and \(p < .05\) respectively) and in the evening (\(p < .05\) and \(p < .001\) respectively). However, the relative increase was larger in the morning than in the evening (7.18 ± 3.2 vs 2.78 ± 4.73% respectively) in the MTG but gains were lower in the morning than in the evening (3.33 ± 2.23 vs 6.46 ± 2.19% respectively) for the ETG.

The improvement of \(P_{\text{peak}}\) was greater after training in the morning than in the evening hours (\(p < .05\); 7.18 ± 3.2 vs 6.46 ± 2.19% respectively).

Mean Power

For \(P_{\text{mean}}\), the main effect for groups (\(F_{(2.14)} = 0.81, p > .05\)) was not significant. However, the main effects for time-of-day (\(F_{(1.7)} = 27.5, p < .01\)), pre/posttraining (\(F_{(1.7)} = 39.71, p < .001\)) and groups × pre/posttraining × time-of-day interaction (\(F_{(2.14)} = 3.88, p < .05\)) were significant.

In T0, a diurnal variation (evening > morning) was found in all groups (\(p < .01\)). The amplitude of the rhythm was 4.94 ± 3.24, 6.16 ± 4.07 and 5.07 ± 4.54% for MTG, ETG and CG, respectively.

This daily variation disappeared in the MTG and persisted in the ETG and the CG (\(p < .01\)) in T1. Moreover, the amplitudes of the diurnal rhythm increased in the ETG between T0 and T1 (6.16 ± 4.07 vs 9.36 ± 6.56%).

When we consider the effect of training, the MTG improved their \(P_{\text{mean}}\) significantly only in the morning (\(p < .01\)). However, the ETG improved their \(P_{\text{mean}}\) significantly only in the evening (\(p < .001\)).

The improvement of \(P_{\text{mean}}\) was greater after training in the morning than in the evening hours (\(p < .05\); 6.67 ± 5.18 vs 6.18 ± 2.64% respectively).

Fatigue Index (FI)

For the FI, the main effects for groups (\(F_{(2.14)} = 1.51, p > .05\)), time-of-day (\(F_{(1.7)} = 2.88, p > .05\)) and pre/posttraining (\(F_{(1.7)} = 0.1, p > .05\)) were not significant. Moreover, the groups × pre/posttraining × time-of-day interaction (\(F_{(2.14)} = 0.06, p > .05\)) was not significant.

Maximal Voluntary Contraction (MVC)

There were significant main effects for time-of-day (\(F_{(1.7)} = 22.84, p < .01\)) and pre/posttraining (\(F_{(1.7)} = 30.31, p < .001\)), whereas, there was no main effect for groups
(F(2.14) = 1.68, p > .05). The groups × pre/posttraining × time-of-day interaction (F(2.14) = 3.87, p < .05) was significant (Table 3).

In T0, the MVC values for all groups were significantly higher at 17:00 hr than at 07:00h (p < .05). The amplitude of the rhythm was 10.96 ± 21.48, 11.54 ± 12.41 and 8.37 ± 17.37%, for MTG, ETG and CG, respectively.

In T1, these diurnal fluctuations persisted in the ETG and the CG (p < .001 and p < .05, respectively). The amplitude of the rhythm was 21.63 ± 13.13 and 7.5 ± 21.7 respectively. However, the daily variations on MVC disappeared with training in the morning hours.

Concerning the effect of training, the MTG and ETG improved their MVC in the morning (p < .001 and p < .01 respectively) and in the evening (p < .05 and p < .001 respectively). However, the percentage differences were greater in the morning than in the evening (31.1 ± 19.98 vs 20.49 ± 11.89% respectively) in the MTG and in the evening than in the morning (22.31 ± 8.89 vs 11.49 ± 13.89% respectively) in the ETG.

The improvement of MVC was greater after training in the morning than in the evening hours (p < .001; 31.1 ± 19.98 vs 22.31 ± 8.89% respectively).

Jump Performances
Table 3 present the SJ and CMJ results calculated in the morning and in the evening, in T0 and T1, on all groups.

Table 3  Performances (mean ± SD) on Vertical Jump Tests (SJ (cm) and CMJ (cm)) and MVC (N) Recorded at the Two Times of Day in T0 and T1.

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>T1</th>
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<tbody>
<tr>
<td></td>
<td>07:00 h</td>
<td>17:00 h</td>
</tr>
<tr>
<td>MTG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC (N)</td>
<td>325.22 ± 128.24</td>
<td>395.2 ± 131.61***</td>
</tr>
<tr>
<td>MVC (N/kg)</td>
<td>7.59 ± 1.59</td>
<td>9.3 ± 1.87*</td>
</tr>
<tr>
<td>SJ (cm)</td>
<td>21.48 ± 3.44</td>
<td>24.91 ± 4.33***</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>22.39 ± 4.14</td>
<td>26.48 ± 6.12***</td>
</tr>
<tr>
<td>ETG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC (N)</td>
<td>352.07 ± 51.17</td>
<td>405.29 ± 81.8*</td>
</tr>
<tr>
<td>MVC (N/kg)</td>
<td>8.36 ± 1.46</td>
<td>9.68 ± 2.31*</td>
</tr>
<tr>
<td>SJ (cm)</td>
<td>18.95 ± 4.16</td>
<td>21.79 ± 4.05**</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>19.56 ± 4.3</td>
<td>23.63 ± 4.41***</td>
</tr>
<tr>
<td>CG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC (N)</td>
<td>331.03 ± 73.6</td>
<td>385.87 ± 75.11*</td>
</tr>
<tr>
<td>MVC (N/kg)</td>
<td>7.92 ± 1.7</td>
<td>9.25 ± 1.93*</td>
</tr>
<tr>
<td>SJ (cm)</td>
<td>21.34 ± 4.22</td>
<td>23.8 ± 4.51**</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>22.85 ± 4.04</td>
<td>25.29 ± 5.41*</td>
</tr>
</tbody>
</table>

*, **, ***: significant difference between 07:00 and 17:00 h at the level of p < 0.05, p < 0.01 and p < 0.001 respectively.

+, ++, +++: significant difference from T0 at the level of p < 0.05, p < 0.01 and p < 0.001 respectively.
**Squat Jump (SJ)**

There was no main effect for groups \((F_{(2,14)} = 2.56, p > .05)\). In contrast, there was a significant main effects for the time-of-day \((F_{(1,7)} = 44.01, p < .001)\) and pre/posttraining \((F_{(1,7)} = 13.52, p < .01)\). Moreover, there was a significant groups × pre/posttraining × time-of-day interaction \((F_{(2,14)} = 5.49, p < .05)\).

In T0, the post hoc analysis showed that SJ values recorded at 17:00 hr were higher than those recorded at 07:00 hr, with amplitudes of \(12.82 \pm 12.36, 12.86 \pm 11.2\) and \(9.99 \pm 8.98\%\) for MTG, ETG and CG respectively.

In T1, these diurnal fluctuations persisted in the ETG \((p < .001)\) and the CG \((p < .01)\) with amplitudes of \(18.23 \pm 11.97\) and \(12.83 \pm 6.52\%\), respectively. However, these daily fluctuations disappeared in the MTG \((p > .05)\).

Regarding the effect of training, the MTG improved their SJ in the morning \((p < .001)\). However, the ETG improved their SJ in the evening \((p < .01)\).

The relative increase of SJ was greater after training in the morning than in the evening hours \((p < .01; 13.84 \pm 8.77 vs 9.36 \pm 6.9\%\) respectively).

**Counter Movement Jump (CMJ)**

For CMJ, the main effect for groups \((F_{(2,14)} = 1.78, p > .05)\) was not significant. However, the main effects for time-of-day \((F_{(1,7)} = 76.11, p < .001\) pre/posttraining \((F_{(1,7)} = 13.78, p < .01)\) and groups × pre/posttraining × time-of-day interaction \((F_{(2,14)} = 3.84, p < .05)\) were significant.

In T0, the post hoc revealed that all groups behaved similarly; CMJ augmented between the morning and evening \((p < .001\) for MTG and ETG and \(p < .05\) for CG) test sessions [Amplitude: \(13.15 \pm 15.86, 17.5 \pm 7.35\) and \(8.15 \pm 12.12\%\) respectively].

In T1, these diurnal variations persisted in the ETG and the CG \((p < .001\) and \(p < .05\) respectively) [Amplitude: \(21.87 \pm 8.69\) and \(9.14 \pm 6.6\%\) respectively] and disappeared in the MTG.

After training, the MTG showed an improvement on CMJ only in the morning \((p < .001)\). However, the ETG improved the CMJ values only in the evening \((p < .01)\).

The relative increase of CMJ was greater after training in the morning than in the evening hours \((p < .01; 16.2 \pm 14.14 vs 11.2 \pm 12.4\%\) respectively).

**Discussion**

The purpose of this study was to examine the effect of 6 weeks of resistance training on diurnal patterns of short-term performances in boys. The major result of our study was that resistance training displayed a temporal specificity. In fact, our results showed that 6 weeks of resistance training performed either in the morning or in the evening hours resulted in significant increases in anaerobic performances. However, the magnitude of gains was greater at the time-of-day at which training was conducted than at other times. Moreover, training in the morning hours blunted the diurnal fluctuations of child’s maximal voluntary contraction and short-term anaerobic powers during cycling and jumping.

**Diurnal Fluctuation Before Training**

Before training, 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 5 to 17%. Our results are at odds with those of Huguet et al. (19), 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. The discrepancies between our findings and those of Huguet et al. might be due to the sex of the subjects (boys and girls in the Huguet et al. (19) 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). Indeed, gender, the length of the solar days and the school schedule are factors which may modify the children’s curves of circadian changes (34). However, ours results are in agreement with previous research on adults (26,30,32) and on boys (29) who reported a diurnal variation during short-term maximal performances. In fact, we showed that 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 (29).

**Training Effect**

In this study, the two training groups showed improved performances after 6 weeks of resistance training performed 2 times per week. These findings are supported by others who found that regular participation in a youth strength-training program may increases muscle strength and power, beyond that which occur during normal healthy growth and development (8–10,13,15–17). These reported strength and power increase improvements in youth is large. In fact, strength and power gains of approximately 30% are typically reported following short-term resistance training programs (8,9,15,16). Moreover, Faigenbaum et al. (9), reported strength gains of up to 74% after only 8 weeks of progressive resistance training using weight machines.

Moreover, our results showed a greater improvement of short-term performances for strength, cycle, and jump tests in the morning than in the evening. However, to the best of our knowledge, there is no data with regard to the temporal specificity of resistance training in boys. It is difficult to explain why greater increases seem to occur in the morning, because the resistance training effect represented by the increase in short-term maximal performances in boys is the sum of several physiological processes. Therefore, further research are required to identify the mechanisms by which resistance training may improve anaerobic performances in boys especially after morning training sessions.

Although our program was effective at increasing strength and power in children, it was unable to affect lean body mass. No significant Group × Test interaction was found which suggests that strength gains were independent of changes in muscle size. This indicated that neural factors rather than muscle factors account for the observed strength gain in the current study. Our results are in agreement with what has been recently reported by Granacher et al. (18), who reported strength gain in children following 10 weeks of strength training without affecting soft lean mass and cross-sectional area.

**Effect of Time-of-Day of Training**

Concerning the effect of time-of-day of training, our results mainly show that, after 6 weeks of regular resistance training, MVC and maximal anaerobic powers during cycling and jumping were significantly lower in the morning than in the evening for the ETG and the CG. However, those of the MTG measured at 07:00 hr and 17:00 hr did not differ. Thus, resistance training scheduled at a particular hour increases
child’s performances specifically at this time-of-day and modified the diurnal variations of short-term maximal performances in subjects who training in the morning. These findings are consistent with previous studies who reported significant temporal specificity after resistance training in adults (26–28,31). These authors suggested that a significant diurnal variations in power (Wingate test and loaded squat jumps) and strength (peak torque, MVC and half-squat 1-RM) decreased after 6 (31) and 10 (26–28) weeks of regular resistance training in the MTG but not in the ETG or the CG. In contrast with these data, Blonc et al. (6) reported no significant training at a specific hour effect on SJ and CMJ performances after 5 weeks of training (sprints, jumps and others exercises). However, the authors suggested that the passive warm-up effect of the environment may contribute to the apparent no effect of time-of-day on either performance or training benefit.

The results of the current study suggested that adaptations to resistance training are greater at the time-of-day at which training was performed than at other times. Moreover, 6 weeks of pediatric resistance training increases the child’s anaerobic performances to a greater degree specifically after morning than evening training. However, it is difficult to explain why greater increases seem to occur (i) at the hour at which resistance training is regularly performed or (ii) after morning training, because the training effect represented by the increase in power and strength is the sum of many different physiological processes. We could speculate that hormonal and neuromuscular adaptations to resistance training are factors which may explain this time-of-day-specific effect even if to the best of our knowledge no investigation showed any of these tendencies. Sedliak et al. (26) observed a significant decrease in the serum cortisol concentration after training in the morning hours. However, they suggested that this morning pretraining increase in serum cortisol concentration is due to a higher anticipatory stress compared with the morning posttraining test session. The electromyographic amplitude could be used as an index to quantify the neural drive and thus to identify the putative role of the central mechanism in the adaptation to resistance training (27). Sedliak et al. (27) failed to show any adaptation to resistance training at a specific time-of-day, in electromyography of the knee extensors during unilateral isometric knee extension peak torque. They concluded that peripheral rather than neural adaptations are the main source of temporal specificity in resistance training. More recently, Sedliak et al. (28) observed that the magnitude of muscular hypertrophy (quadriceps femoris cross-sectional areas (CSA) and volume) did not differ between morning and evening training. As this is the first study examining the effect of training at different time-of-day on short-term maximal performance in boys, it is difficult to compare our results to the literature. However, the authors believe that there should not be different neural or mechanical mechanisms during the day but there are diurnal variations in endocrine secretions. Perhaps there is greater anabolic versus catabolic hormone release allowing greater results during a particular time-of-day (morning versus evening). To date, there are no studies with children supporting this statement. There are a number of possible mechanisms that could be involved as well but an extended discussion would be based on speculation as the mechanisms were beyond the scope of this experiment. Thus, further research, which may include hormonal measurements, is required to identify the mechanisms by which resistance training may improve anaerobic performances after evening or morning training sessions with children.
Among the factors frequently presented in the literature to explain the diurnal variation in muscular strength and power, some authors have hypothesized that the higher value of short-term muscular performances in the afternoon may be linked to the diurnal changes in body temperature (5,22). In agreement, our results showed a significant diurnal variation in oral temperature with higher values recorded at 17:00 hr than at 07:00 hr before and after training in the MTG and ETG. However, the results of the current study showed that, in the MTG, diurnal fluctuations in muscular strength and power disappeared after the training program. These results suggested that the diurnal fluctuation in oral temperature is not the only explanation of the time-of-day effects on anaerobic performances. This finding was in accordance with data of Martin et al. (21), who showed that the diurnal variations in muscle strength persisted despite an artificial heating of the adductor pollicis muscle by 5 °C in the morning.

In conclusion, our results indicated that youth resistance training has the potential to offer observable strength and power benefits. However, these benefits are greater (i) at the time-of-day at which training was performed and (ii) after morning training. Moreover, training in the morning hours may improve typically poor morning performances to the same or even higher level as their normal daily peaks typically observed in the evening. Thus, school-aged youth may be advised to participate in resistance training programs during morning hours in schools, health clubs, and sport training centers. Moreover, boys required to compete at a certain time-of-day (e.g., morning qualifications) may be advised to coincide physical preparation with the time-of-day at which one’s critical performance is programmed. Further research is needed to confirm the present results and to examine the mechanisms underlying the effect of time-of-day-specific resistance training on the diurnal variations of short-term maximal performances in boys.

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References


