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VARIATION OF EXPLOSIVE FORCE AT DIFFERENT TIMES OF DAY

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ABSTRACT: AIM: The purpose of this study was to compare the explosive force and electromyographic (EMG) activity at three different times of the day. METHODS: Thirty healthy subjects took part in the study, and carried out two maximum isometric voluntary knee extensions to measure explosive force, through contractile impulse (CI) and rate of force development (RFD), and myoelectric signals from quadriceps muscles in the following periods: 07:30-09:30, 13:30-15:30 and 19:30-21:30 (called morning, afternoon and night respectively), on three non-consecutive days. RESULTS: The body temperature was lower in the morning than in the afternoon and night periods. The explosive force, evaluated through contractile impulse (CI) and rate of force development (RFD), was greater at night than in the morning, without differences in the myoelectric signal. CONCLUSION: The ability to produce explosive force varies throughout different times of the day without variation in muscular recruitment, indicating that peripheral and not neural mechanisms could be responsible for this variation.

KEY WORDS: **electromyography, median frequency, body temperature, circadian cycle, quadriceps muscle**

INTRODUCTION

The capacity to generate force in short time intervals represents a physical capacity denominated explosive force, which is an important variable in sports such as martial arts, soccer, volleyball and baseball [28], as well as avoidance of falls in the elderly [34]. Rapid movements that demand the maximum possible force production may involve a duration of 50-200 ms [1]. Diverse methodologies are used to measure the ability to produce force in intervals up to 200 ms. The analysis of contractile impulse (CI) and the rate of force development (RFD), obtained by calculating the area over the force curve and the integration moment/time of the force curve respectively, in the first 200 ms of one isometric contraction, have been used as means to study the capacity to generate explosive force [1,3].

Cyclic changes occur in diverse organic systems during a complete 24-hour period, controlled by encephalic structures, located especially in the diencephalon, constituting the changes called the circadian cycle [21]. There is growing interest to understand how these events occur and are regulated and if these changes may significantly influence physical performance [7,26].

It is known that exercise may influence the biological rhythm and that different physiological responses are observed after performing exercises at different times of the day [14]. It is also postulated that the circadian cycle may influence physical performance, due to cyclic modifications in hormonal secretion and body temperature. However, contradictory results are found in relation to muscular performance throughout different times of the day [13,15,31].

There are in the literature some studies involving analysis of physical performance in aerobic activities and resistance [5,6,33], muscular strength variation and peak torque, and the electromyography relation force activation has also been described [6,13,18,27,31], but there were not found studies related to explosive force and its possible variations at different times of the day.

The influence of different times of the day on muscular performance gains relevance because it was verified that world records in diverse sporting activities are usually broken in the early evening, coinciding with body temperature peaks [2,18]. Therefore, the purpose of this study is to compare the ability to produce explosive force through contractile impulse (CI) and rate of force development (RFD), and determine if there is variation in EMG activity throughout three different times of the day.

MATERIALS AND METHODS

Subjects. Thirty male individuals volunteered to participate in the study (age 22±1 years; height 175±1 cm; weight 76±2 kg [mean±SEM]). All the subjects were right-handed with no known neuromuscular or orthopaedic disorders. The subjects were not engaged in physical training programmes for at least 6 months prior to the study. The study was approved by the local ethics committee (Protocol #: H194/CEP/2007) and all subjects gave informed written consent to participate in the study.

Study design. The data were obtained on three distinct days with an interval of 48 hours, and the subjects were subjected to the experimental procedure at different times of the day (07:30-09:30, 13:30-15:30 and 19:30-21:30) on each day (Fig. 1). The order of time of day was defined in a random manner for each subject.

Instruments and procedures. The individuals were randomly divided into three different time periods and days as cited above. On each day the individuals were subjected to 5 minutes of adaptation in laboratory conditions, with the temperature controlled between 23 and 25°C, having the body temperature measured with an axillary thermometer (BD® - Germany) with sensitivity of 0.1° C. Next, a warm-up on a stationary cycle ergometer was performed for 5 minutes, with the workload set at 50 W and a pedalling cadence of 50–60 rpm. After the warm-up, the individuals were put on an adjustable extensor chair according to the individual's anthropometric characteristics and were fixed with crossed belts to the trunk and a transverse belt at hip level. The foot was fixed with a strap, and arms crossed in front of the chest.

Two maximum voluntary isometric contractions (MVIC) of knee extension from the dominant leg at 70° of flexion were performed (0° = total extension). The force signals were recorded using a strain gauge transducer, and the electromyographic activity of the rectus femoris (RF) and vastus lateralis (VL) muscles were simultaneously registered. The interval of 2 minutes was employed between trials of MVIC and the best performance from the two trials was analysed.

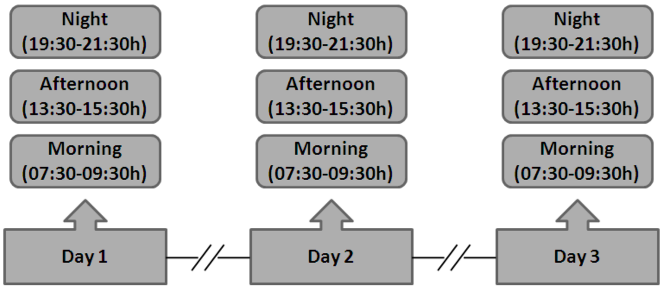

FIG. 1. SCHEDULES FOR DATA ACQUISITION (INTERVAL OF 48 HOURS BETWEEN DAYS)

No form of verbal encouragement was made during the execution of the MVIC.

The surface EMG signals and muscle force were obtained through an eight-channel module (model EMG800C, EMG System, Brazil) and a strain gauge transducer (EMG System, Brazil) with a total amplifier gain of 2000, a common mode rejection ratio of 120 dB and sampled at 2 KHz. A 12-bit converter digitalized the analogue signals with an input range of 5 mV.

Active bipolar superficial electrodes of Ag/AgCl were used with inter-electrode (centre-to-centre) distance of 20 mm. After shaving and cleaning the skin with alcohol, determination of the muscles and anatomical landmarks was done via palpation and the electrodes were placed over the rectus femoris (RF) and vastus lateralis (VL) muscles, according to standard procedures [22] and guided by bone prominences and the direction of the muscle fibres.

Data analysis. The analysis of the force signal was done using the first 200 ms of contraction, taking the point at which a moment/time curve exceeded 7.5 N in relation to the baseline to analyse the contractile impulse (area over moment/time curve), and the rate of force development in intervals of 0-30, 0-50, 0-100 and 0-200 ms and the peak force during the entire interval of 200 ms as used by Aagaard et al. [1]. The measurement of the accumulated area over the force/time curve reflects the history of contraction during the entire period of time analysed, including the influence of other parameters related to the force/time curve with the rate of force development (RFD).

The RFD was determined from the trial with maximal isometric moment of force (maximal voluntary contraction [MVC]). RFD was derived as the average slope of the moment-time curve (Δmoment/Δtime) over time intervals of 0–30, 0–50, 0–100, and 0–200 ms relative to the onset of contraction (Fig. 2), as proposed by Aagaard et al. [1].

To complement the analysis of explosive force, an algorithm able to identify the exact point of deflection in a basic sigmoidal curve (shape characteristic of the curves analysed $r^2=0.98$) was developed in Fortran 90®.

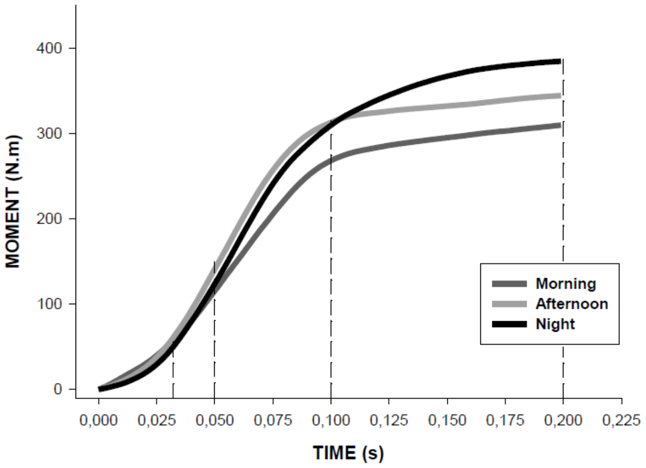

FIG. 2. AVERAGE MOMENT-TIME CURVES (N=30) OBTAINED IN MORNING, AFTERNOON AND NIGHT PERIODS

The EMG data were analysed in Matlab 7.0 (MathWorks, Natick, MA) adopting the first 200 ms of muscular contraction, considering the 70 ms that preceded the initial contraction on the moment/time curve, due to electromechanical retardation. The EMG signals were filtered (Butterworth order 4, band pass 20–500 Hz) to eliminate noise from the movement of artefacts and to consider the band of the power spectrum of higher energy. Fast Fourier transform (FFT) of 512 points (Hamming window processing) was applied to identify the median frequency of the power spectrum periodogram.

Statistical analysis. Standard statistical methods were used to calculate means and standard error (SE). ANOVA with repeated measures was applied to compare the variables temperature, contractile impulse (CI) and rate of force development (RFD) at different times of day. When a significant F ratio was obtained, one-way analysis of variance with a Bonferroni post hoc test was applied, and significance was accepted at $p < 0.05$. Pearson product-moment correlation coefficients were calculated to identify significant correlations between body temperature and explosive force parameters (RFD and CI), and significance was accepted at $p < 0.05$. All statistical analyses were done with SPSS 13.0 for Windows (SPSS Inc, Chicago, Illinois).

RESULTS

Body temperature, commonly used as a physiological periodic change marker influenced by the circadian cycle, showed significant variation in the intervals of time analysed. The lowest body temperatures were observed in the morning period compared to the afternoon and night ($p<0.05$) (Fig. 3).

The contractile impulse was different when the morning and night periods were compared but only when the CI was calculated for the entire period of 200 ms (morning: 37.6±3.3; afternoon: 43.7±3.9; night: 49.5±3.5 N.m.s) ($p<0.05$). No difference was observed at the initial instances of contraction, 0-30 (0.6±0.1; 0.5±0.1; 0.5±0.1 N.m.s), 0-50 (2.3±0.5; 2.0±0.4; 2.1±0.3 N.m.s) and 0-100 ms (10.6±1.3; 12.6±1.6; 13.8±1.4 N.m.s) in the morning periods, afternoon and night respectively ($p<0.05$) (Fig. 4).

The RFD contributes to the analysis of capacity to increase force in a determined period of time. The analysis of this variable did not demonstrate differences in the three times of the day in the intervals of 0-30 (1499±278; 1573±288; 1462±219 N.m.s), 0-50 (2015±318; 2448±367; 2527±347 N.m.s) and 0-100 ms (2378±238; 2749±267; 3030±269 N.m.s) ($p>0.05$). A difference was observed only at the final analyzed time (i.e. 0-200 ms), a difference being observed between morning and night periods. The values of RFD at 0-200 ms were: 1465±95; 1592±120; 1885±109 N.m.s ($p<0.05$) in the morning, afternoon and night respectively (Fig. 5).

Table 1 shows the peak force attained during the contraction period analysed (200 ms) and the time and force when greater deflection of the sigmoidal moment/time curve occurred. Figure 6 shows the inclination of the moment/time curve, obtained by reason of moment/time at the moment of greatest deflection of the moment/time curve; no significant difference was observed between different times of the day (morning: 2875±316 N.m.s; afternoon: 3332±332 N.m.s; night: 3394±333 N.m.s) ($p>0.05$).

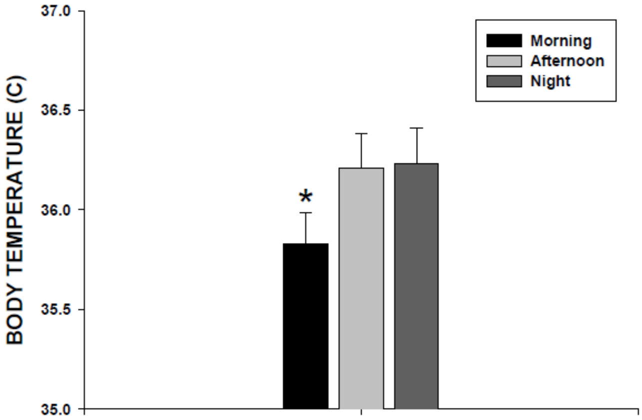

FIG. 3. VARIATION OF BODY TEMPERATURE (MEAN ± SE).
Note: *Significant difference in the morning when compared with afternoon and night ($p<0.05$).

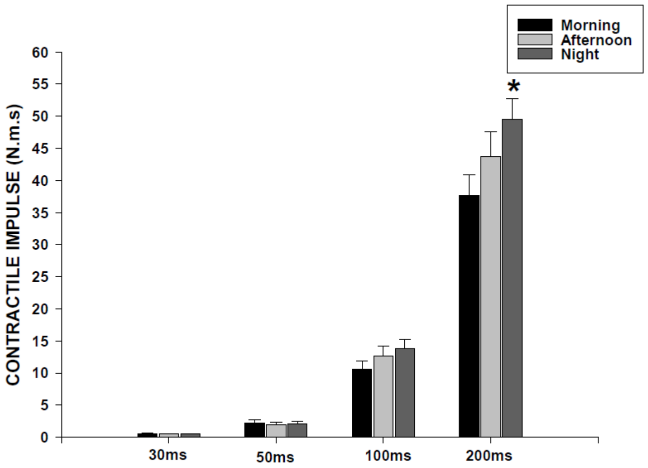

FIG. 4. CONTRACTILE IMPULSE (MEAN ± SE) IN MORNING, AFTERNOON AND NIGHT PERIODS
Note: Contractile impulse, defined as the area covered by the moment-time curve, was calculated in the time intervals of 0–30, 50, 100, and 200 ms from the onset of contraction. (*) Significant difference between morning and night ($p<0.05$).

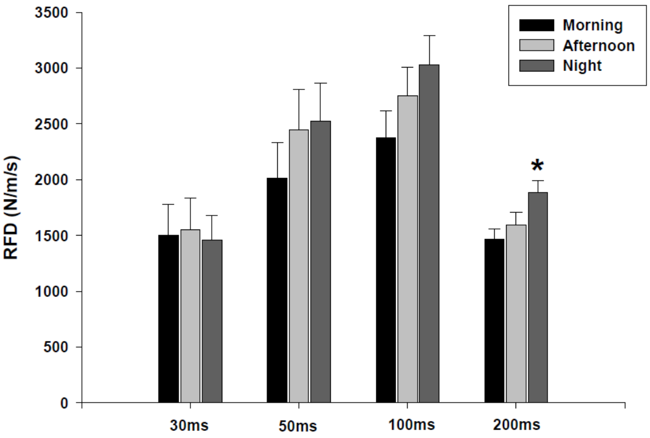

FIG. 5. RATE OF FORCE DEVELOPMENT (RFD) (MEAN ± SE) IN MORNING, AFTERNOON AND NIGHT PERIODS
Note: RFD was calculated in the time intervals of 0–30, 50, 100, and 200 ms from the onset of contraction. (*) Significant difference between morning and night ($p<0.05$).

TABLE 1. PEAK FORCE ATTAINED DURING THE CONTRACTION PERIOD ANALYSED (200 MS) AND THE TIME AND FORCE WHEN THE GREATEST DEFLECTION OF THE SIGMOIDAL MOMENT/TIME CURVE OCCURRED (MEAN ± SE).

	Morning	Afternoon	Night
Peak of Force (N)	313±20	345±22	388±18*
Force (N)	248±25	289±23	299±24
Time (ms)	92±10	89±3	92±4

Note: * - Significant difference between morning and night ($p<0.05$).

TABLE 2. PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS (R) BETWEEN BODY TEMPERATURE AND EXPLOSIVE FORCE PARAMETERS (RFD AND CI) AND THE RESPECTIVE SIGNIFICANCE (P).

	r	*P*
Temperature vs RFD 30ms	0.75	0.01
Temperature vs RFD 50ms	0.73	0.01
Temperature vs RFD 100ms	0.81	0.01
Temperature vs RFD 200ms	0.84	0.01
Temperature vs CI 30ms	0.78	0.01
Temperature vs CI 50ms	0.74	0.01
Temperature vs CI 100ms	0.85	0.01
Temperature vs CI 200ms	0.89	0.01

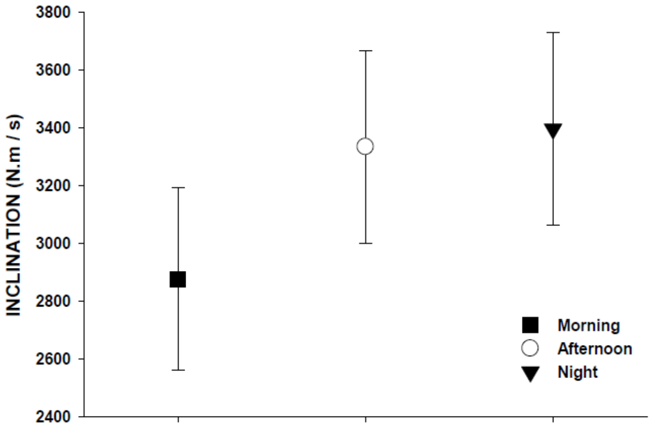

FIG. 6. INCLINATION OF THE MOMENT-TIME CURVE, OBTAINED THROUGH THE REASON MOMENT-TIME AT THE MOMENT OF GREATEST DEFLECTION OF THIS CURVE.

Pearson product-moment correlation coefficients demonstrated significant correlations between body temperature and explosive force parameters (RFD and CI), as presented in Table 2.

Figure 7 demonstrates the mean of the median frequency referring to the first 200 ms of muscle contraction. No difference was observed in this variable in the studied periods of the day for the rectus femoris (morning: 104±3; afternoon: 109±3; night: 110±3 Hz) and vastus lateralis muscle (morning: 91±3; afternoon: 96±4; night: 95±2 Hz) ($p>0.05$).

DISCUSSION

Our results showed differences in the ability to increase the force in short time intervals, which seems to be related to body temperature variations, without a relationship with neuromuscular variations. The findings are discussed separately below.

Body temperature variations. The results obtained in this study demonstrate variation in body temperature during the day. The difference in body temperature observed here corroborates other studies [11,13,18,31] where the temperature in the morning was lower than the afternoon and night periods. The body temperature variation is shown to be an adequate physiological change marker mediated by the circadian cycle [21].

The axillary temperature was used for temperature measurement in this study. However, the result obtained by this method was lower than the results from studies where the core temperature, measured as rectal temperature, was used [31], especially in the morning (35.8±0.5ºC). Racinais et al. [31] used rectal and skin temperatures and observed variations in both, but the lowest temperatures were from skin measurements. Thus, we may verify that the temperature measurement by different means of evaluation for circadian variation of this variable indicates that there are variations through the day, independently of measurement means, but there are differences in the values according to the body region evaluated.

Variations in explosive force. Contradictory results have been obtained regarding the physical performance at different times of the day. In a recent study, Kline et al. [23] observed circadian cycle influence

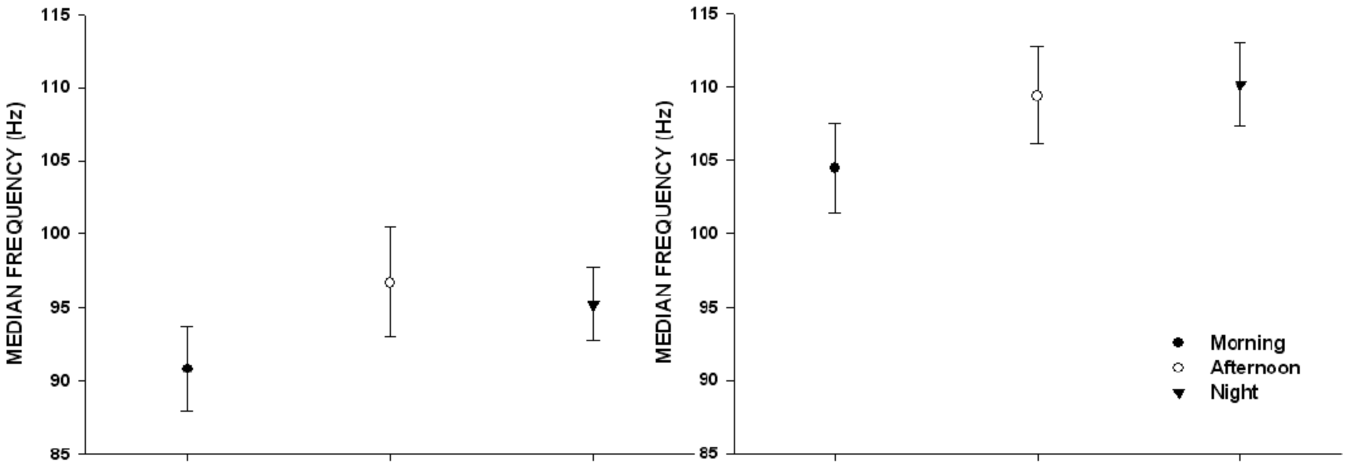

FIG. 7. MEDIAN FREQUENCY (MEAN ±SE) OF THE VASTUS LATERALIS (LEFT) AND RECTUS FEMORIS (RIGHT) MUSCLES.

in the swimming performance in individuals subjected to environmental stress. Differences in aerobic work performance have also been studied. Bernard et al. [5] identified better pedalling performance in the afternoon period and early evening, 14:00 and 18:00 respectively, when compared to the morning period (09:00). Dalton, McNaughton and Davoren [11] did not observe a difference in 15-minute pedalling performances in similar periods of the day to the previously cited study. However, the methodical differences may have been important for the discrepancy in these findings.

It is postulated that the capacity to generate muscular force may also be influenced by the circadian cycle. Racinais et al. [31] verified differences in the measurements of isometric force and electromyographic activation of healthy individuals at different times of the day and in different humidity and temperature circumstances. Deschenes et al. [13] only observed variation in the muscular force performances at high angular velocities through isokinetic dynamometry. It can thus be seen that there is divergence in the studies related to muscular performance at different times of the day, while there have not been found studies analysing the explosive force production manifested in the first 200 ms of maximum voluntary isometric contraction at different times of the day.

The analysis of the area over the force curve in the first 200 ms provides a parameter for explosive force analysis, since it provides a measurement of area accumulated over the moment/time curve [1,3], which represents an analysis of force behaviour throughout previously stipulated time periods. In the present study the force performance is 24% higher at night than in the morning, but only when the total 200 ms interval is analysed, indicating that the force accumulation during the period of time studied is greater at night than in the morning, and this fact may be related to neural and/or metabolic factors.

The moment/time curve analysis informs about the capacity to generate explosive force, in other words, the ability to generate a rapid increment of force in a short space of time. This methodology was applied by Aagaard et al. [1], with the goal of evaluating the influence of force training in muscular performance. The application of this methodology in our study allowed us to identify a greater increase in the rate of force in the night period compared to the morning in the first 200 ms of muscular contraction, and that the most marked difference was after 100 ms.

The analysis of the RFD in time intervals up to 100 ms did not reveal differences among the three periods of the day, which explains the difference found in the analysis of CI only when including time periods above 100 ms. In the night period, the capacity to increase force in short time intervals (i.e. after the first 100 ms of muscular contractions up to 200 ms) was 22% higher at night compared to the morning.

The capacity to produce maximum force in short time intervals seems to be modified by diverse factors, suggesting that the capacity to synchronize motor units, capacity to modify the activation frequencies of the motor units, variation in velocity of nervous and muscular conduction, predominance of MHC isoforms, performance velocity in the formation cycle of cross-bridges and calcium ion kinetics may exercise influence over this result [1,8,17,19,20].

Body temperature is considered an influential factor for the capacity to produce force, which is confirmed by the findings of significant correlations between body temperature and explosive force. Farina et al. [16] reported a relationship between skin temperature and conduction velocity of motor units, and Petrofsky and Laymon [29] found an inverse relationship between velocity of conduction of motor units and the temperature after cooling. Thus, the temperature seems to be negatively correlated with the duration of muscular action potential and positively correlated with the conduction velocity of the sarcolemma [10], affecting the conduction velocity of the muscular action potential with a consequent influence on the capacity of the muscular cell to initiate new contraction cycles, contributing to the force production in short time intervals.

The highest temperature attained in the afternoon and night periods may contribute to the higher explosive force production in the night period compared to the morning. Previous studies have already reported the influence of body temperature and muscular temperature in the production capacity of muscular force [4,9,31] and in neurobehavioral activities [35]. The increment in conduction velocity may be related to the highest explosive force capacity.

Electromyography. Electromyography represents a useful tool to study the neuromuscular behaviour during maximum isometric contractions, being the analysis of the EMG signal in the frequency domain, through the median frequency of power spectra, an information source about the muscular fibre conduction velocity [24,30].

In spite of the differences in body temperature and explosive force at different times of the day, variation was not observed in median frequency. The small variation in body temperature, around 0.5^{o}C, may not have been sufficient to modify the permeability of the sarcolemma to sodium ions, without influencing the conduction velocity and muscle recruitment level. In addition, studies investigating the hypothesis of temperature influence on membrane properties were done with temperature modifications up to 24 and 25^{o}C [16,29]. The measurement of body temperature may limit the conclusions about the influence of temperature in the median frequency, since this may not reflect the temperature of the different muscles, constituting a limitation of this study.

The analysis of addition of muscle fibres of greater diameter during maximum isometric contractions demonstrated a change in median frequency [30]. Hence, the hypothesis of variation in fibre recruitment of greater diameter during different times of the day is rejected.

Guette et al. [18] observed variation in peak torque of knee extension, being highest at 18:00. In the previously mentioned study the electromyographic data were collected simultaneously with torque data, and variations in EMG data analysed in the time domain were not demonstrated. Thus, the authors concluded that the variation of force at different times of the day is due to peripheral factors (i.e. intramuscular mechanisms).

The absence of variation in the muscle recruitment levels, represented by the median frequency, at different times of the day may indicate that intramuscular mechanisms may be responsible for the force variation, since a difference in muscle recruitment capacity mediated by the nervous system has not been observed.

Other hypotheses are suggested to explain the force variation during the day, including the possibility of hormonal influence and other local factors, such as the muscle homeostasis of calcium and phosphate ion [25,31,32], and the velocity of the cross-bridge transition cycle [8], which were previously reported as factors influenced by temperature and the circadian cycle [25]. All previously cited factors may influence force production in short time intervals and may explain the greater force increment of 19% in the night period compared to the morning, without modifications in muscular recruitment, observed through median frequency analysis.

Methods. Only individuals who were not practising regular physical activities were included in this sample, since previous studies demonstrated that the training schedule may influence physical performance in a specific time period [11].

To measure the physical force and electromyographic activity, maximum voluntary isometric force contractions were used, since this type of contraction is the most informative for analysis of relations between force and EMG [12].

The time periods chosen to record data were not used previously. Most of the studies used other fixed times and identified 18:00 as the best moment of the day for muscular performance, which declines after this time. However, our results indicate that the decline in muscular performance previously identified between 18:00 and 22:00 [18] is not sufficient to reduce explosive force to the values of the morning and afternoon periods.

More studies are recommended to repeat the methodologies already applied and controlling variables that were not analysed, such as the daily routine of the participants, aiming to increase the scientific knowledge about the influence of biological rhythms in muscular performance.

CONCLUSIONS

Our results demonstrated that the capacity to produce explosive force is greatest in the later period of the day, which coincides with the highest body temperature, and this may be responsible for the variation in explosive force, since an influence of neural mechanisms was not identified. This information may contribute to improving our understanding of the differences in sports results at different times of the day and orient athletic training of modalities where the development of explosive force is essential.

Acknowledgements

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