

Research article

Time of Day – Effects on Motor Coordination and Reactive Strength in Elite Athletes and Untrained Adolescents

Alessandra di Cagno^{1,2} ✉, Claudia Battaglia¹, Arrigo Giombini², Marina Piazza³, Giovanni Fiorilli², Giuseppe Calcagno², Fabio Pigozzi¹ and Paolo Borrione¹

¹ Department of Health Sciences, Italian University of Sport and Movement of Rome “Foro Italico”, Rome, Italy; ² Department of Health Sciences, University of Molise, Campobasso, Italy; ³ Department of Anatomy, Histology and Forensic Medicine, University of Florence, Florence, Italy

Abstract

Objectives: the issue of time-of-day effects on performance is crucial when considering the goal of reaching peak results in sport disciplines. The present study was designed to examine time-of-day effects in adolescents on motor coordination, assessed with Hirtz's battery and neuromuscular components of strength, evaluated with reactive strength tests. **Methods:** forty-two elite female gymnasts, aged 13.3 ± 0.5 years (Mean \pm SD), were recruited for the study. Fifty healthy female students (aged 12.8 ± 1.7 years) served as the control group. All participants underwent the testing sessions over two days at two different times of day in a randomized order. **Results:** Oral temperature was measured at the two times of the day and a significant diurnal variation ($p < 0.01$) in both groups was found. MANOVA revealed significant group differences in the overall tests ($p < 0.01$). The gymnast group showed no significant differences in the coordination tests with respect to the time of day, but significant differences were observed for reactive strength as assessed with the vertical jump tests ($p < 0.01$). Gymnasts attained better results in the evening in the reactive strength tests [flight time ($F_{1,90} = 17.322$ $p < 0.01$) and ground contact time ($F_{1,90} = 8.372$; $p < 0.01$) of the hopping test]. **Conclusion:** the temperature effect was more evident in the reactive strength tests and orientation test, especially in the gymnast group in which this effect added to their usual training time effect. The time-since-awakening influenced coordination performances in complex tasks more than reaction strength tests in simple tasks. The main outcome of the study was that we did not observe time-of-day effects on coordination skills in elite gymnasts and in untrained adolescents. The time of day in which athletes usually trained these skills could influence these results.

Key words: Circadian rhythm, closed skill sports, gymnasts, motor tasks, temperature.

Introduction

Most human circadian rhythms originate from endogenous pacemakers located in the suprachiasmatic nucleus of the anterior hypothalamus (Moore and Silver, 1998). Circadian fluctuations have been observed under experimental conditions in many biological variables inducing time-of-day modification of different exercise parameters (Drust et al., 2005; Reilly et al., 1997). When considering athletic performances, circadian rhythms may alter, in a time-dependent manner, the level of several physiological processes.

Conceivably, athletic performance occurring before or after the circadian peak value could result in lower performance efficiency. The range of performance due to circadian rhythm variation is estimated to be 10 to 30% of the daily mean (Klein, 1979).

Previous studies investigated several biological functions that influence athletic performances such as pulmonary functions and power (Racinais et al., 2004; 2005), reaction time (Wright et al., 2002), memory and alertness (Jonhson et al., 1992). Generally, peak performance measures, including strength, anaerobic power output and joint-flexibility, have been found in late afternoon, approximately corresponding to the peak of the body temperature. On the contrary, worst performances have been found in the morning (Drust, et al., 2005). However tests of physical fitness, based on heart rate and prolonged submaximal exercise, especially when carried out in hot condition, showed peak time in the morning (Carrier and Monk, 2000). Sprints and rapidity best performances occurred between 8:30 and 10:30 hr (Huguet et al., 1995), and several complex coordinative skills tend to peak earlier in the day than do gross motor skills.

When the diurnal rhythms of performance tasks are considered, those of “simple” tasks, with a small cognitive component, tend to parallel the rhythm of core temperature and peak in the late afternoon and evening. On the other hand, those of more “complex” tasks, with a larger cognitive component, tend to peak earlier in the morning and undergo a more marked fall afterwards (Folkard and Rosen, 1990). Coordination skills are determined by the process of guiding and controlling motor acts (Pehoiu, 2010). This process minimizes the consumption of energy in different situations, achieving the goal required by different tasks, with efficacy.

Coordination represents the qualitative part of psychomotor activity and is a complex and multidimensional phenomenon, in which several systems participate to assure optimal movement control and reaction to environmental variations (Vandorpe et al., 2012). Cognitive performance, on which coordination performances are based, are adversely affected by sleep loss (Akersted et al., 2007; Van Dongen and Dinges, 2005) and the time-since-awakening (Waterhouse, 2010). Thus, several simple coordination skills based on rapidity and reactive strength (Huguet et al., 1995) tend to peak earlier in the day compared to gross motor skills,

which are strongly influenced by the core temperature (Racinais et al., 2004; 2005) (Waterhouse 2010). The motor coordination could be associated more with the morning catecholamine peak than with body temperature variation (Reilly et al., 1997) and the amount of hours since awakening (Johnson et al. 1992; Monk et al. 1989). Coordination skills play an essential role in achieving good results in several sports, especially in closed skill disciplines (Miletic et al., 2004). A review of the literature showed that there is still a lack of knowledge when considering the association of circadian rhythms and coordination skills (Forsman et al. 2007). Moreover, the diurnal variation in children and adolescent performance is still poorly investigated (Huguet et al. 1995; Johnson et al. 1992; Soussi et al. 2010 b; Wright et al. 2002). Coordination, flexibility and reactive strength are important determinants of successful performance in rhythmic gymnastics and may have practical implication in talent identification (Douda et al. 2008). Reactive strength is the speed at which the eccentric contraction switches to concentric contraction (Guy and Micheli 2001). Stiffness and reactive strength are used as good indicators in talent selection processes for young athletes (di Cagno et al. 2008). It is well known that adolescents prefer later timing of activities than younger individuals (Giannotti et al. 2002), and that the pubertal stage is positively associated with a developmental circadian phase delay (Carskadon et al. 2004; Crowley et al. 2007). Moreover, a slower accumulation of homeostatic sleep pressure during puberty also allows adolescents to stay awake longer and delay the sleep/wake cycle. Thus, it could be crucial to identify the best time of day to test athletes.

Therefore, the aim of the present study was to analyse the daily variation of motor coordination and neuromuscular components of strength, as reactive strength, in two groups of adolescents: elite athletes and matched untrained adolescents. We hypothesised that motor coordination and reactive strength tests would show better results in the early morning, in which the time-since-awakening should guarantee better cognitive performance, mood states and concentration.

Methods

Participants

Ninety-two female participants were enrolled into the study. Forty-two elite female gymnasts, aged 13.3 ± 0.5 years, height 1.55 ± 0.05 m and body mass 43.1 ± 0.3 kg, composed the study group. Inclusion criteria included competing in the premier league of the Italian Gymnastics Federation (FGI). The following exclusion criteria were applied: health problems or injuries, gymnastics training for less than five years, and not a member of the FGI. Fifty, not specially trained, healthy female students of middle school, aged 12.8 ± 1.7 years, height 1.54 ± 0.02 m and body mass 46.8 ± 0.9 kg, were voluntarily enrolled as the control group. Participants had regular sleeping schedules, and woke up at around 7.00 am. They were requested to maintain their habitual physical activity, to avoid strenuous activity during the

24h before each test session and to keep their usual sleeping habits, with at least 8 hours of sleep before the morning session. Parents gave their written consent for the study, as all the participants were underage athletes. This study, designed according to the Declaration of Helsinki, was approved by the local Ethics Committee.

Experimental design

This study had a repeated measures design intended to evaluate four coordination skills: upper and lower limb kinesthetic discrimination ability, and upper and lower limb response orientation ability. Two jumping tests were also performed to assess ground reaction time and stiffness of the participants, which are indicators of the level of the neuromuscular components of strength, used in the talent selection process of sports like gymnastics (di Cagno et al., 2008) and of the ability to combine simple consecutive movements (Chamari et al., 2008). These tests were performed by elite gymnasts and untrained adolescents over two days, in two different weeks, and at two different times of the day, in a randomized order: the first half of the participants in the early morning (8.30-9.30 a.m.) and then in the evening (7.00-8.00 p.m), and the other half in the evening and then in the early morning (Blonc et al. 2010; Racinais et al. 2004; Souisse et al. 2010a; 2010b). The order of the morning and evening test sessions, for all participants, was assigned using a randomization list, generated by a random number generator. Order assignments were placed in sealed, opaque consecutively numbered envelopes, and were concealed by one of the study investigators involved in the randomization process. All tests were performed in July. Room temperature (21.5 ± 1.2 °C) and relative humidity (50.5 ± 5.2 %) were maintained constant during the morning and evening testing sessions to minimise potential effects of environmental variables on performances.

Procedures

Temperature

Oral temperature was measured at 08:00 h and 18:30 h, with a calibrated digital clinical thermometer (accuracy: 0.05°C), inserted sublingually for at least three minutes with the participants in a seated resting position. Only fruit juice was allowed as breakfast, one hour and half before the testing session beginning, and only one glass of water (20 cL) was allowed, as well as a fasting state at least 15 minutes before taking the measurement, to avoid postprandial effects on thermogenesis.

Chronotype

The Horne and Osberg (1976) self-assessment questionnaire was administered by the researchers the day before the first testing session, to assess the morningness-eveningness chronotype of the participants. The chronotype reflects the time of the day in which physical functions (hormone level, body temperature, cognitive faculties, eating and sleeping) are active. Morning and evening type individuals differ in endogenous circadian phase of their biological clock (Waterhouse, 2010): morning type individuals are active

and alert during the morning, as well as the evening types reflect the characteristic of being most active and alert during the evening. Verbal instructions on how to complete the questionnaire were given.

Coordination tests

After a 30 minute moderate-intensity warm-up, all participants underwent a pre-test based on four motor coordination tests that were performed over two days, at two different times of day, in a randomized order: first half of the participants in the early morning (8.30-9.30 a.m.) and then in the evening (7.00-8.00 p.m), and the other half in the evening and then in the early morning. The same order was maintained for all the tests. The motor coordination tests included four tests that were selected from a test battery for field evaluation. No familiarization practice had been organized before the test in order to minimize the learning effect during the course of the study. The test battery was validated by Hirtz et al. (1985) through administration to a large and representative sample of school-aged children. This battery has high test-retest reliability (Intraclass correlation coefficient (ICC) range 0.80–0.85, authors' unpublished data).

According to the focus of the present study, the tests assessed kinesthetic discrimination and response orientation abilities. Kinesthetic ability is a capacity of

kinesthetic differentiation that allows a fine differentiated control of the dynamic spatio-temporal parameters of movement. The response orientation ability is a substructure of coordination that allows modification of the position of the movement of the body in space and time, in relation to a certain field of action, choosing rapidly between alternative movement patterns (Pehoiu, 2010). Each test primarily involved either upper limb or lower limb effectors, in order to avoid possible confounding between the measured coordination ability and the "backwards ball throw", assessed the upper limb kinesthetic discrimination ability. The second test consisted of a "low jump test" to assess lower limb kinesthetic discrimination abilities in which participants were instructed to land with their heels on a marking point. The third test involved a "hanging target throw test" to assess upper limb response orientation ability. The fourth test consisted of "orientation shuttle run test" to assess lower limb reactivity and orientation ability (Table 1).

Reactive strength tests

Successively, participants performed two variations of a vertical jump, to assess reaction strength in the following order: hopping test (HT) and drop jump test (DJ). The HT is a series of seven successive jumps with free arms, using small amplitude counter movements and a short

Table 1. Hirtz's battery test description (Hirtz et al., 1985).

Test	Description	
Backwards ball throw test	Participants performed a one-hand overhead throw backwards with a tennis ball. They were instructed to center a ground target located 250 cm behind the performer. The target had a 20 cm diameter. After a training throw, participants performed five consecutive trials. Five points were assigned for each centered target. Scores of 4, 3, 2, 1 and 0 were assigned with increasing distance of the contact point of the ball from the target and the sum of score was computed.	To assess upper limb kinesthetic discrimination ability which allows a fine differentiated control of the dynamic spatio-temporal parameters of movement.
Low jump test	Participants jumped with the legs together from a plinth to a ground marking at a set distance (1 m). They were instructed to land with their heels on the marking. The test was performed twice and the distance of each heel from the marking was measured in centimeters for each trial. Distance values were collapsed across heels and trials to obtain one mean value.	To assess lower limb kinesthetic discrimination ability.
Hanging target throw test	One of the investigators of the study was in front of the participant, 3 m apart, swinging a hoop of 80 cm diameter. Participant tried to throw a tennis ball through the swinging hoop during its backswing. After one training throw, participants performed five consecutive trials. The points assigned were 2, 1 or 0 points, respectively, if the ball passed through, touched or passed outside the hoop. The sum of score was computed.	To assess upper limb response orientation ability that allows modification of the position of the body in space and time in relation to a certain field of action.
Orientation shuttle run test	The participant was instructed to run three times, as quickly as possible, from a start marker toward one of five numbered goal markers located behind him/her. The goal markers were 3m apart from her and 1.5m apart from another on a hypothetical circumference arc. The sequence of goal markings to be reached was not known previously. The next marking number was announced when the participant returned to the start ball and touched it for the next run to begin without pausing. After demonstration by an experimenter, participants performed the test that was scored in seconds. The best score was computed.	To assess lower limb response orientation ability

ground contact time. The HT was also used to assess leg stiffness, which highly correlated to the short ground contact time (GCT) during the test (Arampatzis et al., 2001), and the ability to combine consecutive movements (Chamari et al., 2008). This last ability allows the development of connections between automated motor skills (such as running and jumping) (Pehoiu, 2010). In the DJ, the gymnasts stepped down from a measured drop height (0.3 m), landing on the ground and subsequently performing a maximal effort vertical jump (flight time (FT), measured in sec). DJ is the most common reactive strength test that gives a measure of storage and utilisation of elastic energy, which is defined as jump reactivity (Cronin and Hansen, 2005) and rapidity (Lehmann et al., 1991). A thirty-second rest was given between the three trials of each jump and the maximum value was taken. Participants were accustomed to the set-up and the testing procedures by performing several practice jumps, the day before the test. The jumping tests were assessed with the Next Optojump System (Microgate, Bolzano, Italy), which is an optical acquisition system that measures, within a precision of 1/1000th s, flight and ground-contact times during a sequence of jumps. It has high reliability: an ICC range of 0.88 to 0.98 (di Cagno et al., 2009). Another advantage of this system is that the measurement surface is the same on which the athletes train daily. All pre-training and post-training measures were determined by the same researchers, who were unaware of the purpose of the study. The instructions given to the participants for practical execution were "jump as high as you can" and "jump higher and a little faster than your previous jump".

Statistical analysis

All data were presented as mean and standard deviation in the morning and evening tests, for the gymnasts and control group. First, a MANOVA test was conducted on the full two set of tests: coordination and reactive strength tests. Subsequently, a repeated measures 2X2 ANOVA was used to determine the variation between groups (gymnasts vs. controls), within group (morning vs. evening), and their interaction within each subtest of the coordination and reactive strength tests, as well as oral temperature. If significant main effects were found, Bonferroni post hoc test was used to identify the differences. Correlation analysis (Pearson product moment), between the temperature and the tested parameters, and between chronotypes and motor coordination and reactive strength tests respectively, were performed. Statistical power was determined to be 0.80 for the sample size used at the 0.05 Alpha level. All statistics were performed using SPSS for Windows (version 16.0).

Results

Temperature

A significant diurnal variation was observed in the oral temperature ($F_{1,90} = 161.729$; $p < 0.01$). The mean value and SD of morning temperature for gymnasts and control

group (36.2 ± 0.3 °C and 36.5 ± 0.3 °C, respectively) was lower than the one measured in the late afternoon (36.8 ± 0.3 °C and 37.0 ± 0.2 °C, respectively). Also, a significant difference between the groups was found for oral temperature, gymnasts having a lower temperature than the control group ($F_{1,90} = 22.847$; $p < 0.01$) at both times of the day. The significant time-group interaction ($F_{1,90} = 5.743$; $p < 0.05$) suggests that the morning-evening temperature increase in gymnasts was significantly higher than the one observed in the control group (Figure 1).

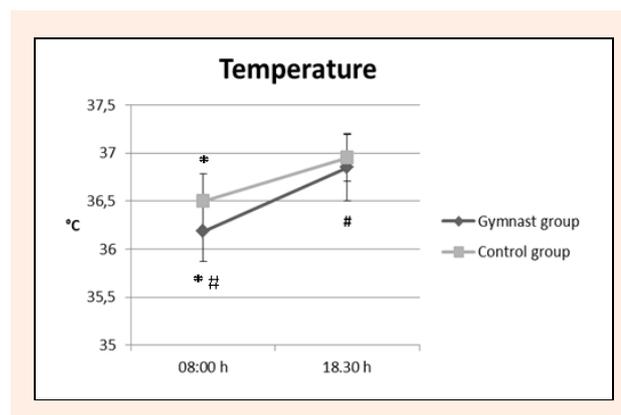


Figure 1. Mean and SD values for temperature. * $p < 0.01$, significant differences in comparison with late afternoon testing session. # $p < 0.01$ significant differences in comparison with control group.

Chronotype

The gymnasts were grouped as "moderately morning type" ($n = 6$), "neither type" ($n = 28$) and "moderately evening type" ($n = 8$), on the basis of their answers to the Horne and Osberg (1976) self-assessment questionnaire, which assesses morningness-eveningness. The controls were "moderately morning time" ($n = 11$), "neither type" ($n = 30$) and "moderately evening type" ($n = 9$). No extreme chronotypes were found in the sample of this study.

Coordination tests

All participants completed the experimental testing session. First, a MANOVA test was run on the full set of coordination tests, which showed significant differences between the two groups ($F_{1,90} = 10.36$; $p < 0.01$). No significant differences between the two different time of day and interaction group*time were found, except in the orientation shuttle run test in which overall participants showed significant differences when morning and afternoon results are concerned ($F_{1,90} = 8.868$; $p < 0.01$), along with a significant group-training interaction ($F_{1,90} = 5.563$; $p < 0.05$). Results for the two-way repeated measures ANOVA are shown in Table 2 (Panel A).

Reactive strength tests

As far as the reactive strength tests are concerned, preliminary MANOVA suggested significant group ($F_{1,90} = 24.50$; $p < 0.01$), time ($F_{1,90} = 4.82$; $p < 0.01$) and group-time interaction differences ($F_{1,90} = 5.50$; $p < 0.01$). Significant differences of the single component of

Table 2. Mean (SD) and ANOVA results.

	Morning		Late afternoon		F, p-value		
	Gymnast	Control	Gymnast	Control	Group	Time	Group-Time
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)			
Panel A – Coordination tests							
Backwards ball throw	7.9 (4.2)##	5.4 (3.2)	7.5 (4.2)##	4.4 (2.4)	20.63 ††	2.38	.48
Low jump	2.3 (1.8)	3.2 (3.1)	1.7 (2.1)	2.4 (2.9)	4.62 †	2.67	.08
Hanging target throw	5.3 (2.1)	5.6 (2.7)	6.1 (2.3)##	4.8 (2.6)	1.56	.004	5.39 †
Orientation Shuttle Run	15.1 (1.0)##	16.0 (1.8)**	15.0 (1.2)	15.1 (2.0)	2.79	10.28 ††	5.63 †
Panel B – Reactive strength tests							
Hopping test FT	.497 (.038)**#	.474 (.049)*	.538 (.030)#	.464 (.046)	34.17 ††	12.68 ††	50.09 ††
Hopping test GCT	.246 (.050)	.256 (.074)*	.212 (.034)#	.254 (.074)	8.37 ††	3.29	2.96
Drop jump test FT	.564 (.051)##	.527 (.043)**	.573 (.047)##	.508 (.034)	38.50 ††	1.23	7.05 ††

* and ** denote $p < 0.05$ and 0.01 respectively compared with late afternoon training session. # and ## denote $p < 0.05$ and 0.01 respectively compared with control group. † and †† denote $p < 0.05$ and 0.01 respectively by ANOVA. FT = Flight time; GCT = Ground contact time.

the HT and the flight time of DJ are shown in Table 2 (Panel B).

Temperature, chronotype and reactive strength correlations

A significant positive correlation was found between oral temperature and flight time of HT ($p < 0.01$; $r = 0.404$) and a significant negative correlation was found between oral temperature and HT ground contact time ($p < 0.05$; $r = -0.254$). No correlations were found between chronotypes (neither type, moderately morning/moderately evening types) and motor coordination tests, and reactive strength tests respectively.

Discussion

The main outcome of the study was that we did not observe time-of-day effects on coordination skills in elite gymnasts and untrained adolescents, in contrast to the initial hypothesis based on previous literature findings (Folkard and Rosen, 1990; Monk et al., 1992). In the reactive strength tests, the elite gymnasts achieved the best results in the evening, even though the untrained adolescents reached the best performance in the morning. The differences between the two kinds of skills are well known. Especially for untrained participants, when considering coordination skills as complex tasks, with a high level of cognitive component, better results would be expected in the morning because they are highly correlated with psychomotor vigilance and arousal (Neri, 2004; Reilly and Ekblom, 2005; Van Dongen, 2004). When considering reactive strength tests, better results could also occur in the evening because, as simple tasks, they are less influenced by the decrement due to the time since awakening than the complex tasks (Waterhouse 2010).

The control subjects had poorer motor performances than gymnasts overall and showed different trends in the time-of-day effect, as demonstrated by the significant interactions in our results. The untrained adolescents were more affected by the markers of CNS output, both in simple and complex tasks, than the gymnast group, which was more influenced by training temporal effects. In fact, the lack of time effects on the coordination tests in the gymnasts

could be explained by the findings of previous studies demonstrating the temporal specificity of training effects, in which greater improvements were obtained at the time of the athlete's training (Blonc et al., 2010). All the gymnasts participating this study usually trained in the evening and it is possible that the training temporal effect could have counterbalanced the circadian fluctuation of coordinative skills. There are also considerable individual differences in the degree of vulnerability to performance impairment as a result of circadian rhythms (Van Dongen, 2004). It has been important to assess the subject's morningness-eveningness because it is well known that cognitive tasks are strongly affected by this different time-of-day typologies (Monk et al., 1986). Nevertheless, no extreme morningness-eveningness types were found in the two groups of the present sample. Thus no correlations were found between the chronotypes of this sample and motor coordination tests and between chronotypes and reactive strength tests.

Temperature

The relationships between the diurnal fluctuations in psychomotor performance and the rhythm of the core body temperature were considered in the present study. According to the literature (Waterhouse, 2010), the sample temperature is 1 to 2°C higher during the day than night. The gymnasts' temperature increased significantly more than that of the controls. This might have occurred because gymnasts performed their usual training in the evening, and this habit may have influenced their temperature diurnal variation. Nevertheless in the day of the evening testing session the gymnasts did not practice any kind of physical activity (Cajochen et al., 1999). A correlation between motor performance and temperature was found only in the reactive strength test, which involved more muscular activity than the coordination tests. The coordination tests peaked earlier in the day than the body temperature.

Influence of time-since-awakening and sleeploss on coordination and reactive strength

Sleep pressure can exert a strong influence on cognitive performance and consequently on senso-motor coordination and reaction times of motor performance, even if the influence of circadian modulation of alertness

may have counterbalanced the sleep pressure (Lack and Wright, 2007). Several authors have affirmed that the circadian alerting signal peaks in the early evening to maintain wakefulness until bedtime. After reaching its high point in the early evening, circadian alertness decreases, corresponding to the nocturnal secretion of pineal melatonin and the decline of body temperature (Cajochen et al., 1999; Dijk et al., 1992). This could be an explanation for the best results achieved in the evening in several coordination tests, as “orientation shuttle run test”, and reactive strength tests. Therefore, increasing the hours of being awake could be a factor influencing the circadian fluctuation of coordination skills (Dijk et al., 1992; Folkard and Rosen, 1990). It is well known that the speed and accuracy of responses deteriorate between 0.00 and 6.00 hours, but recovers afterwards during the next rest period of 20.00 to 1.00 (Steinborn et al., 2010). This period may contrast sleep inertia and impairments produced by short episodes of sleep (Matchock, 2010). Elite gymnasts observed regular rhythms of awake-time and sleep-time (9 h at night and a post-prandial nap of 1 h). Moreover gymnasts were less affected by the time since awakening and fatigue due to their habits of compensating for sleep loss with a post-prandial nap, which counteracts the deterioration in cognitive performance and fatigue effects (Van Dongen, 2004).

Coordination tests

Hangar target throw test and backwards ball throw test

Since shot ball tests are skill-based, a significant influence of circadian rhythm was expected, being most prevalent in the early hours of the morning (Hobbs et al. 2010). The “hangar target throw test”, executed standing in front of the target, showed better results in the morning; conversely, the “backwards ball throw test” revealed no significant differences in either group. The main difference between the two tests relied on eye-sight control. It should be noted that vision in humans is the predominant sense and is conditioned by day light (Roberts 2001). The visual information pathway is linked to the hypothalamus and the retinohypothalamic tract (RHT) mediates light entrainment of circadian rhythms (Lubkin et al. 2002). We could suppose that in the upper limb response orientation ability, eyesight has a strong influence on performance, while perceptual motor organization, prevalent in the control of the backwards throw, is less influenced by time-of-day effects in untrained adolescents.

Orientation shuttle run test and low jump test

Significant differences between morning and evening performances were also found in the “orientation shuttle run test” only in untrained adolescents. It is possible that the orientation ability was influenced by the time-of-day effect on the body temperature more than the other tests. The “low jump test” displayed no significant differences between morning and evening in both groups, probably because it is less influenced by gross motor capacities.

Reactive strength tests

No significant differences between morning and evening were found in the DJ in both groups. This performance is under the control of the CNS, like alertness and cognitive performance, and usually shows a significant decline over the course of a waking day (18.7 hours) (Johnson et al., 1992). This characteristic could counterbalance the time-of-day effect of temperature, which increases the conduction velocity of action potentials (Shephard, 1984). Owens et al. (1998) suggested that alertness could be used to predict time-of-day effect on performance, even when considering the variations of the other performance measures. Significantly better results in the flight and ground contact times of the HT, which assesses stiffness (Arampatzis et al., 2001) and the ability to combine consecutive movements (Chamari et al., 2008), were found in the evening, only in elite gymnasts. Simple repetitive tasks involving motor activity that have a small cognitive load, like the HT, have a time-of-day effect similar to the circadian rhythm in body temperature (Kleitman, 1963). Moreover, as we indicated before, the sample of this study showed a significant diurnal increase in oral temperature (Waterhouse et al., 2005). It has been demonstrated that jumping performances decrease by 5% for every 1°C decline in muscle temperature (Bergh and Ekblom, 1979). In this case the body temperature increase may exert a beneficial passive warm-up effect (Racinais et al., 2005). Whereas the untrained adolescents reached HT better results in the morning, because they are more influenced by the time since awakening and alertness than athletes.

Conclusion

Motor performance, requiring coordination and reactive strength, may have different diurnal variation due to a hierarchy of biological clocks, which are commanded by the “master” clock in the CNS, acting in synchrony with the environment and activity (Waterhouse, 2010; Richter et al., 2004).

References

- Akerstedt, T., Kecklund, G., Alfredsson, L. and Selen, J. (2007) Predicting long-term sickness absence from sleep and fatigue. *Journal of Sleep Research* **16**, 341-345.
- Arampatzis, A., Schade, F., Walsh, M. and Bruggemann, G.P. (2001) Influence of leg stiffness and its effect on myodynamic jumping performance. *Journal of Electromyography and Kinesiology* **11**, 355-364.
- Bergh, U. and Ekblom, B. (1979) Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiologica Scandinavica* **107**, 33-37.
- Blonc, S., Perrot, S., Racinais, S., Aussepe, S. and Hue, O. (2010) Effects of 5 weeks of training at the same time of day on the diurnal variations of maximal muscle power performance. *Journal of Strength and Conditioning Research* **24**, 23-29.
- Cajochen, C., Khalsa, S.B., Wyatt, J.K., Czeisler, C.A. and Dijk, D.J. (1999) EEG and ocular correlates of circadian melatonin phase and human performance decrements during sleep loss. *American Journal of Physiology* **277**, R640-649.
- Carskadon, M.A., Acebo, C. and Jenni, O.G. (2004) Regulation of adolescent sleep: implications for behavior. *Annals of the New York Academy of Sciences* **1021**, 276-291.

- Carrier, J. and Monk, T.H. (2000). Circadian rhythms of performance: new trend. *Chronobiology international*. **17**, 719-732.
- Chamari, K., Chaouachi, A., Hambli, M., Kaouech, F., Wisloff, U. and Castagna, C. (2008) The five-jump test for distance as a field test to assess lower limb explosive power in soccer players. *Journal of Strength and Conditioning Research* **22**, 944-950.
- Cronin, J.B. and Hansen, K.T. (2005) Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research* **19**, 349-357.
- Crowley, S.J., Acebo, C. and Carskadon, M.A. (2007) Sleep, circadian rhythms, and delayed phase in adolescence. *Sleep Medicine* **8**, 602-612.
- Di Cagno, A., Baldari, C., Battaglia, C., Brasili, P., Merni, F., Piazza, M., Toselli, S., Ventrella, A.R. and Guidetti, L. (2008) Factors influencing performance of competitive and amateur rhythmic gymnastics-gender differences. *Journal of Science and Medicine in Sport* **12**, 411-416.
- Di Cagno, A., Baldari, C., Battaglia, C., Monteiro, M.D., Pappalardo, A., Piazza, M. and Guidetti, L. (2009) Factors influencing performance of competitive and amateur rhythmic gymnastics--gender differences. *Journal of Science Medicine in Sport*. **12**, 411-416.
- Dijk, D.J., Duffy, J.F. and Czeisler, C.A. (1992) Circadian and sleep/wake dependent aspects of subjective alertness and cognitive performance. *Journal of Sleep Research* **1**, 112-117.
- Donati, A., Lai, G., Marcello, F. and Masia, P. (1994) La valutazione nell'avviamento allo sport [Evaluation in youth sport]. Roma: Societa' Stampa Sportiva. (In Italian).
- Douda, H.T., Toubekis, A.G, Avloniti, A.A. and Tokmakidis, S.P. (2008) Physiological and anthropometric determinants of rhythmic gymnastics performance. *International Journal of Sports Physiology and Performance* **3**, 41-54.
- Drust, B., Waterhouse, J., Atkinson, G., Edwards, B. and Reilly, T. (2005) Circadian rhythms in sports performance - an Update. *Chronobiology International* **22**, 21-44.
- Folkard, S., Wever, R.A. and Wildgruber, C.M. (1983) Multi-oscillatory control of circadian rhythms in human performance. *Nature* **15**, 223-226.
- Folkard, S. and Rosen, S.D. (1990) Circadian performance rhythms: some practical and theoretical implications [and discussion]. *Philosophical Transaction of the Royal Society B* **327**, 543-553.
- Forsman, P., Haeggström, E., Wallin, A., Toppila, E. and Pykkö, I. (2007) Daytime changes in postural stability and repeatability of posturographic measurements. *Journal of Occupational and Environmental Medicine* **49**, 591-596.
- Giannotti, F., Cortesi, F., Sebastiani, T. and Ottaviano, S. (2002) Circadian preference, sleep and daytime behaviour in adolescence. *Journal of Sleep Research* **11**, 191-199.
- Guy, J.A. and Micheli L.J. (2001) Strength training for children and adolescents. *Journal of the American Academy of Orthopaedic Surgeons* **9**, 29-36.
- Hirtz, P. and Starosta, W. (2002) Sensitive and critical periods of motor coordination development and its relation to motor learning. Available: *Journal of Human Kinetics* **7**, 19-28.
- Hirtz, P., Arndt, H.J., Holtz, D., Jung, R., Ludwig, G., Schielke, E., Wellnitz, I., Willert, H.J. and Vilknor, H.J. (1985) *Koordinative Fähigkeiten im Schulsport [Coordinative abilities in physical education]*. Berlin: Volk und Wissen Verlag. (In German).
- Hobbs, A., Williamson, A. and Van Dongen, H.P. (2010) A circadian rhythm in skill-based errors in aviation maintenance. *Chronobiology International* **27**, 1304-1316.
- Horne, J.A. and Ostberg O. (1976) A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology* **4**, 97-110.
- Huguet, G., Toutou, Y. and Reinberg, A. (1995) Diurnal changes in sport performance of 9- to 11-year-old school children. *Chronobiology International* **12**, 351-362.
- Johnson, M.P., Duffy, J.F., Dijk, D.J., Ronda, J.M., Dyal, C.M. and Czeisler, C.A. (1992) Short-term memory, alertness and performance: a reappraisal of their relationship to body temperature. *Journal of Sleep Research* **1**, 24-29.
- Klein, D.C. (1979) Circadian rhythms in the pineal gland. In: *Endocrine Rhythms*. Ed: Krieger, D.T. New York: Raven Press. 203-223.
- Kleitman, N. (1963) *Sleep and Wakefulness*, Chicago: University of Chicago Press.
- Lack, L.C. and Wright, H.R. (2007) Clinical management of delayed sleep phase disorder. *Behavioral Sleep Medicine* **5**, 57-76.
- Lehmann, M., Dickhuth, H.H., Gendrich, G., Lazar, W., Thum, M., Kaminski, R., Aramendi, J.F., Peterke, E., Wieland, W. and Keul, J. (1991) Overtraining: a prospective, experimental study with experienced middle- and long-distance runners. *International Journal of Sports Medicine*. **12**, 444-452.
- Lubkin, V., Beizai, P. and Sadun, A.A. (2002) The eye as metronome of the body. *Survey of Ophthalmology* **47**, 17-26.
- Matchock, R.L. (2010) Circadian and sleep episode duration influences on cognitive performance following the process of awakening. *International Review of Neurobiology* **93**, 129-151.
- Miletić, Đ., Katić, R. and Maleš, B. (2004) Some anthropologic factors of performance in rhythmic gymnastics novices. *Colegium Antropologicum*. **28**, 727-737.
- Monk, T.H. and Leng, V.C. (1986) Interactions between inter-individual and inter risk differences in the diurnal variation of human performance. *Chronobiology International* **3**, 171-177.
- Monk, T.H., Moline, M.L., Fookson, J.E. and Peetz, S.M. (1989) Circadian determinants of subjective alertness. *Journal of Biological Rhythms* **4**, 393-404.
- Monk, T.H., Reynolds, C.F., Machen, M.A. and Kupfer, D.J. (1992) Daily social rhythms in the elderly and their relation to objectively recorded sleep. *Sleep* **15**, 322-329.
- Moore, R.Y. and Silver, R. (1998) Suprachiasmatic nucleus organization. *Chronobiology International* **15**, 475-487.
- Neri, D.F. (2004) Preface: Fatigue and Performance Modeling Workshop, June 13-14, 2002. *Aviation, Space, and Environmental Medicine* **75**, A1-A3.
- Owens, D.S., Macdonald, I., Tucker, P., Sytnik, N., Minors, D., Waterhouse, J., Totterdell, P. and Folkard, S. (1998) Diurnal trends in mood and performance do not all parallel alertness. *Scandinavian Journal of Work Environment & Health* **24** (Suppl. 3), 109-114.
- Pehoiu, C. (2010) Spatio-temporal orientation development during the physical education class, with 5th and 6th form pupils. *World Academy of Science Engineering and Technology* **72**, 76-85.
- Racinais, S., Hue, O., Blonc, S. and Le Gallais, D. (2004) Effect of sleep deprivation on shuttle run score in middle-aged amateur athletes. Influence of initial score. *The Journal of Sports Medicine and Physical Fitness* **44**, 246-248.
- Racinais, S., Blonc, S., Jonville, S. and Hue, O. (2005) Time-of-day influences the environmental effects on muscle force and contractility. *Medicine & Sci in Sports & Exercise* **37**, 256-261.
- Reilly, T., Waterhouse, J. and Atkinson, G. (1997) Aging, rhythms of physical performance, and adjustment to changes in the sleep-activity cycle. *Occupational and Environmental Medicine* **54**, 812-816.
- Reilly, T. and Ekblom, B. (2005) The use of recovery methods post-exercise. *Journal of Sports Science* **23**, 619-627.
- Richter, H.G., Torres-Farfán, C., Rojas-García, P.P., Campino, C., Torrealba, F. and Serón-Ferré, M. (2004) The circadian timing system: making sense of day/night gene expression. *Biological Research* **37**, 11-28.
- Roberts, J.E. (2001) Ocular phototoxicity. *Journal of Photochemistry and Photobiology B*. **64**, 136-143.
- Shepard, R.J. (1984) Sleep, biorhythms and human performance. *Sports Medicine* **1**, 11-37
- Souisse, N., Driss, T., Chamari, K., Vandewalle, H., Davenne, D., Gam, A., Fillard, J.R. and Jouselin, E. (2010a) Diurnal variation in Wingate test performances: influence of active warm up. *Chronobiology International* **27**, 640-652.
- Souissi, H., Chaouachi, A., Chamari, K., Dogui, M., Amri, M. and Souissi, N. (2010b) Time-of-day effects on short-term exercise performances in 10- to 11-year-old boys. *Pediatric Exercise Science* **4**, 613-623.
- Steinborn, M.B., Bratzke, D., Rolke, B., Gordijn, M.C., Beersma, D.G. and Ulrich, R. (2010) The effect of 40 hours of constant wakefulness on number comparison performance. *Chronobiology International* **27**, 807-825.
- Van Dongen, H.P. (2004) Comparison of mathematical model predictions to experimental data of fatigue and performance. *Aviation Space of Environmental Medicine* **75**, A15-36.
- Van Dongen, H.P. and Dinges, D.F. (2005) Sleep, circadian rhythms, and psychomotor vigilance. *Clinical Journal of Sports Medicine* **24**, 237-249.

- Vandorpe, B., Vandendriessche, J., Vaeyens, R., Pion, J., Matthys, S., Lefevre, J., Philippaerts, R. and Lenoir, M. (2012) Relationship between sports participation and the level of motor coordination in childhood: A longitudinal approach. *Journal of Science and Medicine in Sport* **15**, 220-225.
- Waterhouse, J., Drust, B., Weinert, D., Edwards, B., Gregson, W., Atkinson, G., Kao, S., Aizawa, S. and Reilly, T. (2005) The circadian rhythm of core temperature: origin and some implications for exercise performance. *Chronobiology International* **22**, 207-225.
- Waterhouse, J. (2010) Circadian rhythms and cognition. *Progress in Brain Research* **185**, 131-153.
- Wright, K.P., Hull, J.T. and Czeisler, C.A. (2002) Relationship between alertness, performance, and body temperature in humans. *American Journal of Physiology Regulatory, Integrative and Comparative Physiology* **283**, 1370-1377.

Key points

- The results obtained in this study suggested that the best time to perform a particular task depends specifically on the nature of the task, the precise size of the cognitive load and the level of practice of the participants.
- In the field of practice, it is incumbent for coaches to organise sports selection based on reactive strength, using the morning hours for untrained adolescents, when alertness and the benefits of sleeping could improve performance. Evening hours, conversely, should be used for elite gymnasts who specifically train at that time (specific “temporal training effect”).
- These study results cannot give indications about the best time of the day to organize selection tests based on coordination skills.

AUTHORS BIOGRAPHY



Alessandra di CAGNO
Employment
 University Professor
Degree
 Assistant Professor
Research interests
 Sport Sciences and Coaching
E-mail: alessandra.dicagno@unimol.it



Claudia BATTAGLIA
Employment
 University tutor with part-time contract
Degree
 PhD
Research interests
 Sport Sciences and Coaching
E-mail: claudia.battaglia@uniroma4.it



Arrigo GIOMBINI
Employment
 University Professor
Degree
 Assistant Professor MD
Research interests
 Sport Medicine
E-mail: arrigo.giombini@unimol.it



Marina PIAZZA
Employment
 Italian Gymnastics Federation Director
Degree
 Associated Professor
Research interests
 Sport Sciences and Coaching
E-mail: marina.piazza@unifi.it



Giovanni FIORILLI
Employment
 Manager
Degree
 PhD
Research interests
 Sport Sciences and Coaching
E-mail: fiorilli@unimol.it



Giuseppe CALCAGNO
Employment
 University Professor
Degree
 Associated Professor MD
Research interests
 Biochemistry and Genetic Testing
E-mail: giuseppe.calcagno@unimol.it



Fabio PIGOZZI
Degree
 Full Associated Professor MD
Research interests
 Sport Medicine
E-mail: fabio.pigozzi@uniroma4.it



Paolo BORRIONE
Employment
 University Professor
Degree
 Assistant professor MD
Research interests
 Sport Medicine
E-mail: paolo.borrione@uniroma4.it

✉ Alessandra di Cagno

Department of Health Sciences, Italian University of Sport and Movement of Rome “Foro Italico”, P.zza. Lauro de Bosis 15, 00198, Rome, Italy