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Original investigations/commentaries

Biological Rhythm in Sports Persons

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Abstract

Biological rhythms are of paramount importance in the life of athletes, exerting a significant influence on multiple facets of their performance, recuperation, and general state of health. The importance of biological rhythms in sports and their influence on athletic performance and health have been extensively discussed. A comprehensive understanding of biological rhythms is crucial for athletes, coaches, and researchers in the field of sports science. By strategically coordinating training, competition schedules, and recuperation procedures with these biological cycles, athletes can optimize their performance capabilities and mitigate the likelihood of sustaining injuries and experiencing burnout. Moreover, the use of customized methodologies that take into account the unique variances in biological rhythms across individuals can result in more accurate and efficient sports training and conditioning regimens, thereby enhancing the overall achievements and welfare of athletes.

Keywords: biological rhythm, circadian rhythm, sports persons, blood pressure, heart rate

Introduction

Biological functions are regulated by circadian clock along several periodic time scales. It controls much of the body's normal functions, including performance, behavior, sleep and endocrine rhythms. In mammals, it is located in the SCN of the hypothalamus in the brain (Weaver, 1998). The knowledge of biological rhythms is very important in the field of sports/ games and in treatment of various chronic and acute diseases. Now-a-days greater attention is given to utilize the principles of circadian rhythm for the sports competition and treatment of serious diseases, like childhood acute leukemia, ovarian cancer, breast cancer, diabetes, allergies, asthma, seasonal affective disorders, delayed sleep phase syndrome and advanced sleep phase syndrome, and problems associated with shift work and transmeridian flight.

The circadian rhythm, which is a fundamental biological rhythm, is a 24-hour cycle that governs various physiological and behavioral processes. The circadian rhythm exerts an influence on various aspects within the realm of sports, including but not limited to body temperature, hormone release, and cognitive function. Gaining a comprehensive comprehension of these rhythmic patterns can assist athletes in optimizing their training regimens and scheduling competitions to coincide with their periods of optimal performance. The sleep-wake cycle, a crucial biological rhythm, exerts a direct influence on an athlete's recuperation and performance. Sleep pattern disturbances, which are frequently encountered during travel for competitive events or inconsistent training regimens, have the potential to result in weariness, diminished reaction times, and heightened susceptibility to injuries. It is imperative for athletes to place a high emphasis on maintaining proper sleep hygiene and implementing tactics to mitigate disruptions to their circadian rhythm.

The menstrual cycle holds significant importance for female athletes due to its impact on multiple facets of training and performance. The influence of hormonal variations throughout the menstrual cycle on muscle strength, endurance, and susceptibility to injury has been observed. In order to enhance the performance of female athletes and mitigate the occurrence of overuse injuries, coaches and athletes must take into account the diverse factors that influence training programs and competition planning. In addition, the intricate relationship among biological cycles, nutritional intake, and hydration plays a crucial role in sustaining peak athletic performance. Aligning meal timing and hydration methods with circadian rhythms has the potential to boost the absorption of nutrients and increase energy levels, which may result in higher performance outcomes.

Factor affecting Biological Clock

Many physiological and performances variables display circadian rhythm (Drust *et al.*, 2005; Kline *et al.*, 2007; Reilly *et al.*, 1997; Pati 2001). Indeed, the circadian fluctuations in response to short-term exercise involving anaerobic metabolism have been well described (Guette *et al.*, 2005; Pearson & Onambele, 2005; Racinais *et al.*, 2004, 2005b; Souissi *et al*., 2004). It has been reported that variety of factors, such as the type and intensity of exercise, morningness–eveningness chronotype, age, jet-lag, sleep deprivation, and time of-day of training, can influence the diurnal variation in performance (Montelpare *et al*., 1992; Reilly *et al*., 1997; Souissi *et al*., 2002, 2003). Environmental factors, such as the timing of the rest activity cycle (Apfelbaum *et al*., 1969) and meals (Nelson *et al*., 1975; Zigmond *et al*., 1974) may affect the circadian system. Daytime fasting, modifications in sleep schedule, and psychological and social habits during Ramadan induce changes in the rhythmic pattern of a number of hormonal (Bogdan *et al*., 2001) and nutrition-related biological variables (Iraki *et al*., 1997). Total short-term fasting is detrimental to endurance (Aragon-Vergas, 1993) and anaerobic (McMurray *et al*., 1991) performance. It is also known that a low energy diet reduces the isometric endurance of skeletal muscle, probably because of a decrease in glycogen stores (Bergstrom *et al*., 1967).

Blood Pressure

In humans, the list of biological functions that exhibit circadian rhythms is endless, for example: Circadian rhythm in blood pressure has been extensively studied in healthy and hypertensive subjects (Chen *et al*., 2001; Gonzalez *et al*., 2002; Halhuber *et al*., 2002; Mitsutake *et al*., 2002; Cornélissen *et al*., 2003; Halberg *et al*., 2004; Sothern *et al*., 2005). Blood pressure varies as function of increasing age (Anjana *et al*., 2005). The forced expiratory volume and peak flow both vary with time of day, falling to minima between 03.00 and 08.00 hour (Gaultier *et al*., 1977).

Jones *et al.* (2008) demonstrated that the reactivity of ambulatory blood pressure to everyday physical activities is higher in the morning. The circadian variation in resting blood pressure dip during the night equal to 10–20% of the daytime mean level and a morning “surge” (Hermida *et al*., 2001; Millar-Craig *et al*., 1978). The blood pressure pattern alters within the 24 h in some cases, such as diabetes and both renal and congestive heart disease (Hermida, 2007; Middeke *et al*., 1991; Portaluppi *et al*., 1991); but, the variation is robust enough for the morning surge in blood pressure have been suggested as a reason for the morning-peak in sudden cardiovascular events (Manfredini *et al*., 2005; Muller *et al*., 1989; Portaluppi *et al*., 1999; Smolensky *et al*., 2007). Many factors influence the morning surge, such as arousal effects of awakening, activation of the sympathetic nervous system, and other haemodynamic adjustments after arising from bed or combinations of all these (Khoury *et al*., 1992; Portaluppi and Smolensky, 2007). Waking from sleep, adoption of an upright posture, intake of the first food of the day, and beginning of physical activity all occur in the morning at the same time as the blood pressure surge. Leary *et al.* (2002) demonstrated that the change in physical activity in the morning is moderately related to the rise in ambulatory blood pressure. A relationship between physical activity and changes in blood pressure was also observed at other times of day (Kario *et al*., 1999). The response of ambulatory blood pressure to everyday physical activities varies with time of day (Jones *et al*., 2006). Blood pressure measured 15 min after calculated “bins” of physical activity assessment was found to show highest reactivity between 08:00 and 10:00 h, with a secondary rise in reactivity between 16:00 and 18:00 h. Jones *et al.* (2006) measured general physical activity using an accelerometer-based device during everyday activities, rather than administering a controlled exercise intervention.

Body Temperature

The circadian rhythm in body temperature has been explored as an excellent marker rhythm for the assessment of circadian system (Harper *et al*., 2005; Waterhouse *et al*., 2005). Circadian time structure of body temperature rhythm can be useful for predictive indicator of illness and can be used for evaluation and management of disease. Temperature rhythm plays a vital role in the regulation of sleep (van Someren, 2000). Numerous studies have demonstrated that the free running body temperature rhythm in humans has a period of 25.0 ± 0.5 h on average (Aschoff, 1965; Wever, 1985).

Large changes in environmental temperature may affect physical performance (Racinais *et al*., 2004; 2005). Roky *et al*., (2001) suggested that all the circadian systems may also be affected by the exclusive evening meals and by repeated partial sleep deprivation. Ramadan fasting reduced anaerobic power compared with the control period, both in the afternoon and evening (souissi *et al*., 2007). Muscle power is mainly determined by its structure, myosin composition, and metabolic factors related to phosphagen stores and velocity of ATP hydrolysis (Bigard *et al*., 1998). It is not clear why Ramadan would affect anaerobic performances only in the afternoon and evening (souissi *et al*., 2007).

Heart Rate

Heart rate rhythm varies as function of age (Mancia *et al*., 1983), and time of day. The trough to peak variation is generally 8-10 beats per minutes. This is relevant to athlete and coaches who use resting heart rate to assess the training (Reilly, 1994). Measurement of heart rate variability has become a widely used tool for assessing the cardiovascular autonomic function in various physiological settings (Lipsitz *et. al.* 1990, Davy *et al.*1996, Tulppo *et.al.* 1996, Pikkiujamsa *et al.* 2001, Tulppo *et al.* 2001). There are few well controlled studies on heart rate variability during and after physical exercise and during physical training interventions influencing cardiovascular autonomic regulation. So far, there has been great deal of research centered on human circadian rhythms but much of it deals with shift workers and airline employees (Pati, 2001; Pati *et al.*, 2001; Pati and Parganiha, 2005). Pickering (1988) reported that circadian rhythms in blood pressure and heart rate are highly influenced by exogenous factors, such as sleep, posture, ingestion of food and activity. Reilly (1990) reported variation of heart rate with amplitude of 5-15% of 24-h mean depending on the extent of the exogenous influence. Its acrophase usually occurs around 15.00. The heart rate varies with amplitude of 5 to 15% of the 24 hour mean and an acrophase of around 15.00. Reilly (1990) and Smolensky et al. (1976) stated that similar rhythm characteristics are found for stroke volume, cardiac output, blood flow and blood pressure.

Variability in heart rate has been extensively studied during the past decade for its value as a predictor of cardiac death (Kleiger *et al.*, 1987, Bigger *et al.* 1992, Tsuji *et al.*, 1996a, Huikuri *et al.*, 2000, Makikallio *et al.*, 2001, Tapanainen *et al.*, 2002 and Jokinen *et al.*, 2003). Heart rate exhibits circadian (24-h) rhythm. It is important to point out that normal cardiovascular regulation is essential to maintain the 24-h periodicity. Extreme variability in heart rate is associated with disease status. The level of heart rate remains high during activity period and it attains its nadir during the period of rest, usually night hours.

Circadian Rhythm in Physical Performances

Physical activity or rest activity rhythm is an important output of circadian clock. Activity is normally restricted to the natural day. There is considerable inter-individual variation in the preferred timing of the rest-activity rhythm, with extreme morning and evening types (Roenneberg *et al.,* 2003). All most all cognitive and physical performance exhibit circadian rhythm (Carrier and Monk, 2000; Colquhoun, 1971; Dagan and Doljansky, 2006; Johnson *et al*., 1992; Monk, 1992; Monk *et al*., 1983; Reilly and Waterhouse, 2004; Reilly *et al*., 1997; Waterhouse *et al*., 2001, Dagan and Doljansky, 2006; Reilly and Waterhouse, 2004). Chevalier *et al.* (2003) suggested that a marked 24-h activity rhythm was associated with better prognosis and prolonged existence. Barger *et al* (2004) have examined that the physical exercise of moderate intensity (65-75% heart rate maximum) facilitated resynchronization to a new sleep/wake cycle (9-h delay of the subject habitual sleep period). Although physical activity is associated with the increase in core body temperature, the level of which is circadian phase dependent, and the increment is larger in the rest phase than in active phase among mammals including humans (Waterhouse *et al*., 2004).

The performance as well as the effect of physical exercise is known to depend on the time of day when the exercise is performed (Waterhouse *et al*., 2005). It has been well established that the sports performance is the best at the time of daily temperature peak. The time of interventions demanded by experimental designs are often not feasible in sports competitions. Consequently, research worker have tended to consider the effect of time of the day on performance in time trials or simulated contest.

Reilly and Walsh (1981) in their study of male soccer players during indoor five-a-side games that sustained for four days reported the fastest pace of play at about 18.00 h and a nadir at 05.00 h to 06.00 h each day. Feelings of fatigue were negatively correlated with the level of activity. The self-paced level of activity conformed closely to the curves in body temperature and in heart rate; this relation persisted throughout successive days. The fact that the freely chosen intensity of exercise is the highest at about the time the body temperature rhythm reaches the top of its diurnal curve has important implications for training as well as for certain competitive sports. Conroy and O'Brrien (1974) found that six runners, three weight throwers and three rowers performed better in the evening than in the morning. Rodahl *et al* (1976) demonstrated that swimmers produced faster times over hundred meters at 17.00 h compared with that at 07.00 h in three of the four strokes studied. Reilly (1987) studied the speed of running in a five-minute test and found that the speed varied in close correspondence to the circadian curve in body temperature. Minors and Waterhouse (1981) studied that body temperature falls to minimum during sleep at around 04.00 hours and begins to rise until the acrophase of the rhythm is reached at around 18.00 hours. Gifford (1987) reported marked rhythms in joint flexibility across a wide range of human movement. Hill *et al* (1992) reported that total working high intensity exercise on a cycle ergometer at constant work rate was higher in the afternoon compared with the morning. Cable *et al* (1995) concentrated on the cost of exercise hypotension and reported that the fall in blood pressure during recovery from exercise was more pronounced in the morning. The amplitude of rhythm in minute ventilation is increased during light or moderate exercise. Aldemir (1999) described the time-course of the changes in core temperature and forearm skin blood flow during 30-min bouts of exercise of equal intensity at 08:00 and 18:00.

There was a more rapid rise of core temperature coupled with slow rise of cutaneous blood flow in the morning compared with the evening exercise. Fluctuation in body temperature mediates many circadian rhythms in performance.

Joint flexibility (range of movement) shows marked rhythmicity across the wide range of human movements. Gifford (1987) noted that circadian variation in lumber flexion and extension, glenohumeral lateral rotation and whole body forward flexion. Amplitudes of these rhythms can be as high as 20% of the 24-hour mean value. There can be large inter-individual differences in the peak times for flexibility Reilly *et al* (2000) have reported that although in many human subjects the performance measures tend to follow closely the circadian rhythm in body temperature; these are also affected by the sleep-wake cycle and local physiological conditions. There is an additional impact of biological rhythm on athletic performance and on the inclination or ability to train hard.

Hill and co-worker (1992) demonstrated that the total work performed at high intensity, constant-work-rate exercise on cycle ergometer was significantly higher in the afternoon as compared to that of morning. Similar result was witnessed in another study (Reilly and Baxter, 1983) in longer work times and higher blood lactate level when a set higher intensity exercise was performed at 22:00 h compared with 6:30 hours.

All most all events of physical performance exhibit circadian rhythms closely to variation in body temperature (Drust *et al*., 2005). In contrast, rhythms of complex mental tasks and mood states do not agree with the variation in core temperature. The peak in physical performance may occur later in the day than that of mental performance. Reilly *et al*. (2007) found that alertness level showed marked time–of–day effect and peaked at 20.00 h at evening which is opposite trend to fatigue and the reaction time peaked slightly earlier than the time of peak alertness level.

Aldemir *et al*. (2000) illustrated that during sustained sub-maximal exercise, core temperature rises more quickly early in the morning compared to that of late in the evening. Guette *et al*. (2006) showed time of training can influence the peak isokinetic movements. Similarly, Atkinson *et al*. (2005) showed in cyclists that the reduced power output in the morning, compared to the evening, can be partially ameliorated by training at that particular time of day.

The weight bearing associated with activity during the day does have consequences as the day progresses. One is the shrinkage in spinal length which from morning to night–time can approach 19 mm in males and 15 mm in females (Reilly *et al*. 1984; Wilby *et al*. 1987). The intervertebral discs stiffen as they lose height rendering them more vulnerable to injury.

Chronotype and Sports Performances

There are individual differences in performance rhythm of athletes. On the basis of sleep and waking time individuals have been classified into morning type, evening type and intermediate type. Hill *et al*. (1988) compared the response to exercise (at 100 W and also at a work rate corresponding to VO_2 max) on a cycle ergometer between morning and evening type. Diurnal variations in sub maximal heart rate and rating of perceived exertion (RPE) were not affected by individual chronotype. However, in the group of evening type, VO_2 max was best in the evening.

The peak in energetic arousal occurs earlier in morning-types than in evening-types subjects (Adan and Guardia, 1993). Moreover, while the energetic arousal level in morning-types was found to be higher than that in evening-types in the morning, the chronotypes did not differ in the evening at 19:30 h (Matthews, 1988). Tense arousal levels have been accounted higher either in the morning (Matthews, 1988) or in the evening hours (Adan and Guardia, 1993). Hedonic tone was found higher in morning-types than in evening-types (Matthews, 1988). Moreover, in the former study (Adan and Guardia, 1993), the peak of hedonic tone occurred earlier in the day in morning - types than in evening - types.

Metabolism

Circadian rhythm affects sub-maximal and maximal exercise performances. During exercise the metabolism is elevated many times over the resting level and the amplitude of the circadian rhythm existing at rest is consequently reduced when calculated as a percent of the maximal exercise value. Performance is dependent on energy release from both anaerobic and aerobic processes (Granier *et al*., 1995; Kavanagh and Jacobs, 1988; Smith and Hill, 1991). According to Granier *et al*. (1995), the duration of this maximal and submaximal exercise is both too short to exhaust the anaerobic energy system and not long enough for the contribution of aerobic metabolism.

Hormones associated with arousal (e.g., adrenalin and noradrenalin) are elevated during the day compared with night-time values (Minors and Waterhouse, 1981). The greater blood volume reported during the night compared to daytime and glucose tolerance is impaired in the afternoon, although blood glucose levels tend to be higher at that time than in the morning (Zimmet *et al*., 1974). Muscle glycogen also shows diurnal variation which cannot be explained by hormonal or metabolic rhythms

(Conlee *et al*., 1976), suggesting the existence of a local timekeeper within skeletal muscle.

Muscle Strength

Isometric muscle strength is known to vary with time of day in close accordance with the curve in deep body temperature. This applies to grip strength and to back strength. Carbri *et al.* (1988) did not find significant circadian rhythm in peak torque for slow and fast isokinetic movement under concentric and eccentric conditions.

Faria and Drummond (1982) obtained ratings of exertion at treadmill running speeds eliciting heart rates of 130, 150 and 170 beats min-1 as the heart rate response to a fixed sub-maximal exercise intensity is lowest at night, it follows that more exercise can be performed at a given heart rate at that time.

Souissi *et al.* (2002) suggested that several weeks of repeated strength training performed in the morning hours may reduce the typical diurnal pattern by increasing maximum strength more in the morning than at other times of day. Serum testosterone and cortisol both exhibit a circadian pattern, with early morning peaks and evening nadirs (Van Cauter *et al*., 1996; Veldhuis *et al*., 1987). A number of factors can temporarily alter the circadian (diurnal) rhythm parameters of testosterone and cortisol, particularly if assessed under normal, everyday conditions. Viru and Viru (2001) listed seasonal variation, sleep deprivation, nutritional status, and emotional strain among the confounding factors. Moreover, cortisol levels are especially sensitive to exposure to various acute or chronic stressors. For instance, anticipation of the actual exercise test has been shown to acutely increase cortisol concentration prior to testing (Mason *et al*., 1973). A single bout of strength exercise of adequate volume, intensity, and duration is another potent stressor eliciting acute elevations in blood testosterone and cortisol concentrations (Ahtiainen *et al*., 2003; Guezennec *et al*., 1986; Hickson *et al*., 1994; Kraemer *et al*., 1998; 1999).

Short-term exercise and anaerobic metabolism show diurnal fluctuations (Gauthier *et al*., 1996; Guette *et al*., 2005; Hill and Smith, 1991; Melhim, 1993; Pearson and Onambele, 2005; Racinais *et al*., 2005; Souissi *et al*., 2007; 2004). Peak power (Ppeak) and mean power (Pmean) fluctuate with time of day with an acrophase at 17:24h and 18:00 h, respectively, in diurnally active persons (Souissi *et al*., 2007; 2004). Souissi *et al*., (2007) demonstrated that the VO_2 and aerobic contribution were higher in the afternoon than in the morning in the diurnally active subjects. Bernard *et al.* (1998) and Melhim (1993) suggested that daily variations in anaerobic power may depend on changes in body temperature. Souissi *et al.* (2007) found statistically significant circadian rhythm in body temperature with a circadian acrophase at 18:16 ± 00:25. Higher body temperature may enhance metabolic reactions, increase the extensibility of connective tissue, reduce muscle viscosity, and increase the conduction velocity of action potentials (Shephard, 1984). Bergh and Ekblom (1979) have demonstrated in warming and cooling experiments that maximal anaerobic power drops by 5% for every 1^0C drop in muscle temperature.

Bigard *et al*. (1998) demonstrated a rapid decrease in maximum isometric strength (MVC) of elbow flexor muscles and in muscular endurance at both 35% and 70% MVC during Ramadan. Additionally, Sweileh *et al*. (1992) showed a decrease in maximal oxygen uptake ($VO_{2\ max}$) during the first week of Ramadan with a return to the pre-Ramadan levels in the last week. Wilby *et al.* (1987) demonstrated that the standard circuit or weight training was harder when conducted at 07:30 h compared to 22:00 h. Back strength was higher in the evening as compared to those of morning. Greater training loads would be tolerated in the evening compared to earlier in the day. Further, Reilly and Young *et al.* (1982) revealed that performing exercise was harder in the night time and perceived exertion was marginally elevated in the afternoon time. Circadian variation in pain perception might be relevant in the context of sport injury. Minimum levels of pain are noted in the morning. Subjects becoming more sensitive and the pain perception threshold falls as the day proceeds. The highest epicritic pain was at about 03:00-06:00 h, whereas more diffuse pain was at 11:00 h (Baxter, 1987)

Wilby et *al*. (1987) compared the losses of height as a result of a 20-min circuit weight – training regimen at 07:30 and 23:00 h. The disc was a more effective shock absorber in the morning compared to the evening. Further he concluded that the greater the muscle strength the less height that was lost. The daily activity level and postures can influence the amount of contraction during the day. Intervention procedures for unloading the spine prior to heavy physical training in the evening have been advocated.

Three nights of sleep restriction of at least 2 h does not seem to affect gross motor functions, including muscle strength and lung power or endurance running performance in both men (Reilly and Deykin, 1983) and women (Bambaeichi *et al*., 2005; Reilly and Hales, 1988). One night of total sleep deprivation did not have any negative effects on muscular strength and power (Meney *et al*., 1998). It has been demonstrated that the effects of sleep loss on muscular performances are dependent on the time-of-day of the recordings (Souissi *et al*., 2003). Further, it was demonstrated that one night of sleep deprivation impaired anaerobic performance of men in the evening at 18:00 h but not in the morning at 06:00 h. long term dietary restriction and repeated partial sleep loss results the physiological changes (Reilly and Waterhouse, 2007).

Sleep deprivation primarily affects the higher cognitive centers of the central nervous system (Bonnet, 1980), and motivation is a key factor in the validity of tests of anaerobic power and capacity. The classic observation of Ikai and Steinhaus (1961) showed how maximum voluntary muscular contraction is closely dependent on the level of arousal in the individual. Sleep deprivation both dampens and distorts the normal circadian cycle of arousal, with a decrease of alpha wave activity on the electroencephalogram (Kollar *et al*., 1966; Shephard, 1984).

Marathon

Suitable time for marathon races is in the morning rather than in the afternoon in hot climates, which is based on the lower environmental heat stress in the morning. The ideal ambient temperature for marathon running is about 13°c (Maughan, 1990). Physical factors known to vary with time of day affect muscular function are joint stiffness and flexibility. The format refers to the internal resistance to movement while the latter indicates range of movement about a joint. Stiffness is greatest late in the evening than early in the morning (Wright *et al*., 1969).

Gifford (1987) documented that the Peak values in flexibility was higher at around early afternoon (13:30 h) and trough values first thing in the morning. Further he stated that the specific flexibility also varies with it peaks; it peaked at 18:10 h in the evening. He suggested that the exercise should be preceded by warm–up particularly in the morning.

Edwards *et al*. (2007) found that the accuracy of performance of the short- and long distance short motor task was circadian rhythmic phased similarly to those of the rhythms of alertness or fatigue and as with alertness and fatigue, accuracy was associated positively with core temperature and negatively with time-awake. Complex physical tasks and movements that require large amounts of neurally-mediated control, the peak time of the circadian rhythm in performance tends to be slightly earlier than that of core temperature (Reilly *et al*., 2006; 2007).

Milan *et al*. (2007) demonstrated that 10 weeks of time-of-day specific strength training performed in the morning hours resulted in a reduced morning resting cortisol concentration. In addition, the diurnal pattern of maximum isometric strength was dulled after the time of day specific training period in the morning group but not in the afternoon group. The time of day specific training period had no significant effect on resting total testosterone concentration and its diurnal pattern.

Maximum Oxygen Consumption

Brisswalter *et al*. (2007) demonstrated that VO_2 responces are affected by the time of the day and could be related to variability in muscle activity pattern. In this study the researcher demonstrated that during moderate exercise, the time constant and amplitude of VO_2 kinetics were statistically significantly higher in the morning compared to those of the evening. The net efficiency increased from the morning to evening (17.3 vs. 20.5%; $p < 0.05$), and the variability of cycling cadence was greater during the morning than evening. It has been found that the oxygen uptake (VO_2) and body temperature mostly reported to peak in the late afternoon (Reilly, 1990; Reilly and Brooks, 1982). In some other studies during light intensity exercise VO_2 is greater in the evening (Cable and Reilly, 1987; Hill *et al*., 1989). Reilly and Brooks (1990) suggested that resting minute ventilation and oxygen uptake are higher in the afternoon, when core body temperature is at its peak. The oxygen uptake kinetics was slower and oxygen uptake amplitude values of the mono-exponential function significantly higher in the morning compared to evening.

It has been demonstrated that the overall adaptation of oxygen uptake is faster after heavy exercise, whereas light or moderate exercise does not affect oxygen kinetics (Bohnert *et al*., 1998; Burnley *et al*., 2001; Gerbino *et al*., 1996). In day-active persons, the afternoon is associated with an increase in rectal temperature and a peak of some hormonal secretions like adrenalin (Atkinson and Reilly, 1996). Xu and Rhodes (1999) demonstrated that faster gas kinetics at evening is the result of an enhancement in muscle perfusion and oxygen delivery before exercise. Many study observed that the circadian rhythms in maximal isometric and isokinetic contractions and muscle strength peaks in the early evening (Gauthier *et al*., 2001; Guette *et al*., 2005; Nicolas *et al*., 2005). Neuromuscular efficiency, corresponding to the root mean square/torque ratio, has also been reported to be improved in the late afternoon (Callard *et al*., 2000; Martin *et al*., 2001). Neuromuscular function may benefit from higher core body temperature in the late afternoon (Racinais *et al*., 2005). An increase in core or muscle temperature is linked to an improvement in nerve conduction velocity (Rutkove *et al*., 1997), range of movement (Adams *et al*., 1987; Baxter and Reilly, 1983), and muscular coordination. The rise in muscle temperature is also related to decrease in muscle viscosity.

The amplitude of the rhythm in heart rate is 4 beats min-1 (Reilly et al., 1984). The rhythm in heart rate leads the rhythm in oxygen uptake (VO_2) and ventilation which in turn show a phase lead over core temperature (Reilly and Brooks, 1982; 1990). The consistency of phase and amplitude of heart rate rhythm has been shown for both arm (Cable and Reilly, 1987) and leg (Reilly *et al.*, 1984) exercise. It is not known if the lower heart rate at night-time compromises blood flow to active muscles. During performance of armergometry the VO_2 peak V_E peak and highest heart rate have been found to demonstrate a circadian rhythm, the highest values being observed close to the crest time of rectal temperature (Cable and Reilly, 1987). The result reflected a rhythm in the total work performed in the incremental arm exercise test to tiredness (Cable and Reilly, 1987)

Reilly and Baxter (1983) investigated whether exercise to voluntary exhaustion at exercise intensity close to VO_2 max exhibited circadian variation. Subjects performed the task on a cycle ergometer at 06:30 h and at 22:00 h. They were capable of exercising for longer in the evening than in the morning, mean values being 436 and 260 s, respectively. Besides, they tolerated higher blood lactate levels in the evening, the greater levels being a result of the increase in total work performed at that time.

Human Stature

Reilly and colleagues (1984) provided a comprehensive characterization of the circadian rhythm in human stature. Wilby *et al.* (1987), by using a stadiometer accurate to 0.01 mm, reported that the diurnal variation was 1.1% of our stature. Peak stature was measured at 07.30 hours, with the greatest rate of shrinkage occurring in the hours immediately after getting up from the bed. A period of rest before training or competing in the evening helps to unload the spine and restore its normal response to compressive loads.

Psychological aspects of the sports performance have been studied extensively. Mood and subjective alertness are important for human performance because such states can alter an individual's motivation for strenuous physical exercise. Circadian variation in mood states may affect the "team cohesion" of sports squad. Folkard (1990) has shown that factors, such as subjective and mental states are directly associated with the sports performance. Alertness and positive mood show peak in the waking hours. However, mood disturbance has been reported to be prominent in the afternoon or in the early evening. Other studies by McNair *et al.* (1971) has indicated that alertness and positive mood states peak in the waking hours.

Mood

Konard *et al.* (2008) demonstrated that the three dimensions of the mood are circadian rhythmic. Higher level of tense arousal and lower level of hedonic tone (pleasant - unpleasant) are found in evening type as compared to those of morning type individuals. Energetic arousal in morning - types increased in the morning and decreased to the lowest in the evening. Unipolar affective disorder are marked by depressed mood during the day, with particularly low mood levels in the morning hours (Morris *et al.*, 2007; Murray, 2007) and atypically increased activity of physiological processes in the evening (Young *et al.*, 1994). The study of chronotype and mood disorders is interesting. The relationship between eveningness and depressiveness (Chelminski et al., 1999), depression (Drennan et al., 1991), and SAD (Murray et al., 2003) has been reported.

Mood is a crucial psychological function and it determines life satisfaction and ability to meet environmental requirements (Larsen, 2000). The positive component of mood was found to exhibit diurnal variation. Exactly, positive affect is initially low in the morning, increases during the day, attaining its peak around midday, and decreases in the evening (Clark *et al.*, 1989; Thayer *et al.*, 1988; Watson, 2000). Negative affect is stable over the day (Clark *et al.*, 1989) or achieves its peak in the morning (Boivin *et al.*, 1997; Ciarkowska, 2001).

Adan and Guardia (1993) demonstrated that both energetic arousal and hedonic tone decrease over the day between 09:00 and 21:00 h, while tense arousal displays an opposite trend. A number of regularities and differences have been found in the diurnal variation of mood in persons with different chronotypes. Daytime levels of negative affect do not differentiate between morning - types and evening - types (Clark *et al.*, 1989). The level of positive affect is generally low in the morning, irrespective of the individual chronotype. However, while in morning - types the level of positive affect rapidly raises to a peak before noon or early afternoon, in evening - types the peak is delayed to the late afternoon or evening. Moreover, the level of positive affect is higher over the day in morning - types than evening - types, and it is only in the evening or at night that the difference evaporates (Ciarkowska, 2001; Clark *et al.*, 1989).

There is an interaction between sleep loss and circadian rhythms in that impairments in human performance during sleep deprivation are most pronounced at nighttime. In self - paced activity comprised of 4-a- side indoor soccer sustained for 3-4 days, the activity level was found to peak at about 18:00 h, coinciding with the daily high point of body temperature (Reilly and Walsh, 1982).

Sleep is needed more for 'brain restitution' rather than for tissue restitution was further supported in study of effects of partial sleep deprivation on swimmers (Sinnerton and Reilly, 1990). Swimming times were faster in the evening (17:30 h) compared to morning (06:30 h), replicating the findings of Reilly and Hales (1988) that the time of day effect on gross motor functions exceeds that of sleep loss. The most pronounced effect of the sleep loss is deterioration in mood.

The motor performances rhythms are close in phase to the curve in body temperature. Arousal is also an important determinant of performance as it affects motivations towards strenuous exercise and the subjective reactions to it. Blomquist and Holt (1994) found statistically significant diurnal variation in testosterone concentration. Strength exercise performed in the afternoon (McMurray *et al*., 1995; Nindl *et al*., 2001), but not in the morning (Kraemer *et al*., 2001), has been reported to temporarily alter overnight testosterone release. The total cortisol serum concentrations also demonstrated a typical diurnal decrease (Deschenes *et al*., 1998; Van Cauter *et al*., 1996; Veldhuis *et al*., 1987) at both Pre and Post. Mason *et al*. (1973) demonstrated increased cortisol level an hour before the physical exercise.

Circadian Rhythm and Ramadan

Partial sleep deprivation can be expected to occur in Ramadan and supramaximal exercise performance can be maintained under sleep deprivation (Mougin *et al*., 1996; Symons *et al*., 1988, Takeuchi *et al*., 1985). One night's sleep deprivation impaired anaerobic performance during both Wingate and force-velocity tests at 18:00 h, but not in at 06:00 h (Souissi *et al*., 2003). Waterhouse *et al*. (2008) observed that during Ramadan, the daytime hours were associated with more fatigue and less physical and mental activity than the normal days. During the Ramadan individual prepare for daytime fasting by rising earlier and eating breakfast before sunrise; after sunset, they take food and fluids to refill energy and fluid level before retiring later than normal. Such alterations in the sleep-wake cycle are responsible for many changes in the circadian rhythms of core temperature (Roky *et al*., 2000) and several hormones (Bogdan *et al*., 2001). Food and fluid intake between and sunrise and sunset (Ramadan) results in many changes to individuals physiological and biochemical status (Benaji *et al*. 2006, Leiper *et al*. 2003, Reilly and Waterhouse, 2007; Roky *et al*. 2004). This restriction affects the nocturnal sleep, shorten the nocturnal sleep and its architecture changed (Roky *et al*., 2003), more naps are taken during the daytime (Waterhouse, 2008; Margolis and Reed, 2004). Such changes in sleep deprivation report the negative effects upon mood and the willingness to work (Karaagaoglu and Yucecan, 2000), as well as for decreases in the ability to perform physical and mental activities (Waterhouse, 2008; Kadri *et al*., 2000; Roky *et al*., 2000) and increase the fatigue (Waterhouse, 2008). During this time road traffic accidents was reported higher in some (Roky *et al*., 2004), but not all (Kammash and Al-Shouha, 2006) studies. While body mass is not always reduced, the ratio [high-density lipoprotein cholesterol]/ [low-density lipoprotein cholesterol] is increased (Qujeq *et al*., 2002; Roky *et al*., 2004), suggesting a beneficial effect, as the ratio is a predictor of cardiovascular risk.

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