



Review Article

Morning and evening exercise

Dae Yun Seo^a, SungRyul Lee^a, Nari Kim^a, Kyung Soo Ko^a,
Byoung Doo Rhee^a, Byung Joo Park^b, Jin Han^{a,*}^a National Research Laboratory for Mitochondrial Signaling, Department of Physiology, College of Medicine, Cardiovascular and Metabolic Disease Center, Inje University, Busan, Korea^b Division of Leisure and Sports Science, Dong Seo University, Busan, Korea

ARTICLE INFO

Article history:

Received 6 September 2013

Received in revised form

4 October 2013

Accepted 4 October 2013

Available online 14 October 2013

Keywords:

circadian rhythm

evening exercise

hormone

morning exercise

ABSTRACT

A growing body of evidence suggests that exercise may contribute to preventing pathological changes, treating multiple chronic diseases, and reducing mortality and morbidity ratios. Scientific evidence moreover shows that exercise plays a key role in improving health-related physical fitness components and hormone function. Regular exercise training is one of the few strategies that has been strictly adapted in healthy individuals and in athletes. However, time-dependent exercise has different outcomes, based on the exercise type, duration, and hormone adaptation. In the present review, we therefore briefly describe the type, duration, and adaptation of exercise performed in the morning and evening. In addition, we discuss the clinical considerations and indications for exercise training.

© 2013 Korea Institute of Oriental Medicine. Published by Elsevier. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Increased muscle strength and cardiac fitness reflect regular physical activity.¹⁻³ This reflection is strongly associated with time-dependent exercise.^{4,5} Recent studies have attempted to elucidate the manner in which different exercise types and duration are involved in the regulation of several physiological responses through morning and evening exercise because this information is important in improving muscle fitness, aerobic capacity, and well-being.⁵⁻⁸

The beneficial effect obtained from exercise is generally determined by multiple systems such as the motor, physiological, and neurobiological systems.⁹⁻¹¹ In particular, physiological and neurobiological activities are dependent on biological rhythms in the human body; this is also known

as circadian or diurnal rhythms.¹²⁻¹⁵ This phenomenon has been widely described in time-of-day studies. Despite the fact that the data in the literature have shown a significant association between time and aerobic exercise,¹⁶⁻¹⁸ other studies have not indicated any such circadian variations.¹⁹⁻²¹ These results indicate that the time-course effects of aerobic exercise on maximal aerobic velocity and exhaustion time remain unclear.^{11,14} Other reports have described the use of time-of-day for resistance exercise.²²⁻²⁴ The results of time variations during resistance exercise (which involve muscle strength, power, and sprint) range from 3% to 21.2%, depending on the individual being tested, the position of the muscles, and the experimental design.^{25,26}

The warm-up duration, sleep deprivation, and training time prior to exercise training can be affected by diurnal variation.^{27,28} Sedliak et al²⁹ report that exercise performed in

* Corresponding author. National Research Laboratory for Mitochondrial Signaling, Department of Physiology, College of Medicine, Cardiovascular and Metabolic Disease Center, Inje University, 633-165 Gaegeum-Dong, Busanjin-Gu, Busan 614-735, Korea.

E-mail address: phyhanj@inje.ac.kr (J. Han).

<http://dx.doi.org/10.1016/j.imr.2013.10.003>

2213-4220/© 2013 Korea Institute of Oriental Medicine. Published by Elsevier. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

the morning can improve muscle strength. However, another study obtained contradicting results and showed that participants were able to perform more physical activity in the evening, despite the lower physiological variation at this time.³⁰ However, variations in the neuromuscular performance level increased during evening exercise. Thus, further information on the differences in the effects of morning and evening exercises is required. In this review, we discuss the exercise effects on aerobic and anaerobic performance, on short and long duration, and on hormone adaptation through time-of-day exercise studies.

2. Differential effect of exercise type

2.1. Aerobic training

In general, aerobic exercise plays a role in weight loss management,³¹ and improves peak maximal oxygen consumption (VO_2max)³² and workload.³³ Several studies have recently confirmed the presence of time-of-day effects of exercise on these variables.^{34,35} Therefore, health and disease outcomes in response to exercise may depend on the time of day the exercise is performed.^{36,37} Hobson et al³⁸ suggest the existence of a time-of-day effect on aerobic exercise for improving aerobic exercise capacity. The authors observed that the endurance exercise capacity of men during exhaustive cycling exercise at 65% peak VO_2 was significantly greater in the morning than in the evening. In addition, Shiotani et al³⁰ found that a two-month aerobic exercise program, which consisted of ergometer cycling, increased the heart rate in the morning. However, another study found that an evening exercise training group had a greater work capacity after 5 weeks of high-intensity training, compared to the morning exercise training group.³⁹ Faisal et al⁴⁰ similarly indicated the presence of a time-of-day specificity on the effects of aerobic exercise training. Therefore, the studies in the literature indicate that different effects may be elicited, depending on the exercise duration, time, and the individual.

2.2. Resistance training

Resistance exercise elicits improved muscle strength and power, and elicits changes in anabolism/catabolism, depending on the time of the day.^{41,42} Souissi et al⁴³ found that, compared to evening exercise, morning exercise yielded more beneficial effects on anaerobic performance after 6 weeks of resistance training. After examining study participants who underwent resistance training for 6 weeks in the morning, Chtourou et al²⁷ similarly noted that muscle performance—determined by the one-repetition, squat jump, and Wingate tests—was significantly higher among this group than among individuals who performed resistance training in the evening. By contrast, certain researchers have reported that evening exercise is more effective than morning exercise, and one study showed a significant improvement in peak muscle power in well-trained cyclists in the evening than in the morning.⁴⁴ Furthermore, Edwards et al⁴⁵ showed that grip strength, isokinetic knee flexion, peak power, and peak torque were higher in the evening than in the morning.

However, Sedliak et al^{46,47} observed that after 10 weeks of exercise in a diurnal pattern the maximum isometric strength was not altered in the morning and evening. In a similar study, some researchers indicated that no time-of-day changes were observed in muscular anaerobic performance. Chtourou et al⁴⁸ measured electromyography (EMG) activity in study participants performing the 30-second Wingate test in the morning and evening; however, the authors did not note any significant differences in EMG activity during the entire 30 seconds between the morning and evening exercise. In another study, Chtourou et al²⁷ similarly indicated that, after 8 weeks of lower extremity progressive resistance training, the muscle strength was similar between the participants who performed the exercise in the morning and participants who performed the exercise in the evening. Sedliak et al⁴⁷ did not show any time-of-day-specific adaptations during unilateral isometric knee extension peak torque training. Zarrouk et al⁴⁹ investigated the time-of-day effects on repeated sprint ability, but did not observe any significant time-of-day effects on the EMG activity levels of four thigh muscles during a repeated pedaling sprint exercise. Chtourou et al⁵⁰ moreover showed no significant difference in muscular power or strength between the morning and evening tests. To understand better the time-of-day effects on muscle strength responses, future studies should assess the main physiological variations following resistance exercise adaptations.

2.3. Differential effect of exercise duration

Many scientists have investigated different exercise types, times, durations, and intensities of exercise training. Exercise duration is particularly important. Many studies have shown that short-term performance changes with different exercise times. In addition, short-term exercise training, which enhances anabolic metabolism, can be influenced by several factors such as time-of-day training.^{47,51} In previous studies, exercise training improved anaerobic performance in the morning and/or evening^{29,46} (Table 1). Most investigations have shown that evening exercise is better than morning exercise.^{27,47,50,52} Souissi et al⁴³ indicated that 6 weeks of resistance training in 10-year-old and 11-year-old boys improved muscle strength and power to a significantly greater extent in the evening than in the morning. Brisswalter et al⁵³ investigated the effects of moderate exercise and determined that VO_2 kinetics were significantly higher in the morning than in the evening. Souissi et al²⁸ observed the effect of different exercise training times on anaerobic performance, including peak anaerobic power, jump performance, and peak knee extension torque. Their study found that the group that was trained in the evening had greater improvements in anaerobic performance. Lricollais et al⁵⁴ moreover showed that, during the 60 second Wingate test, muscle fatigue was lower in the evening than in the morning.

Long-term exercise has beneficial effects on aerobic capacity, cardiac function, and rehabilitation. In particular, this type of exercise is important in exercises involving time trials such as cycling, rowing, swimming, running, football, and table tennis. In a previous study, Deschenes et al²¹ observed that during aerobic exercise, the mean arterial blood pressure was higher

Table 1 – The effect of time of day on short-term exercises.

Refs	Participants	Age (y)	Measurement parameters	Acrophase	Amplitude
Atkinson et al ⁶⁹	Trained (n = 7) Untrained (n = 7)	19–29 Trained, 23.9 ± 3.3 Untrained, 24.3 ± 2.4	Whole-body flexibility Back and leg strength Grip strength Flight time in a vertical jump Self-chosen work rate	17:00–19:00 h	Trained > untrained (~ 2–10% vs. ~ 1–7%)
Wyse et al ⁷⁰	9 Collegiate sportsmen	19.6 ± 9.6	Extension peak torque Flexion peak torque	18.00–19.30 h	~ 5–12%
Gauthier et al ⁵²	13 Physical education participants	M: 22.0 ± 2.0 physical education	Elbow flexor torque	18:00 h	~ 4%
Martin et al ⁷¹	13 Healthy participants (12 M and 1 F)	22–40	MVC	18:00 h	8.9%
Callared et al ⁷²	6 M ultradistance cyclists	33.4 ± 3.4	MVC	19:30 h	6%
Souissi et al ⁷³	13 M physical education students	22.4 ± 2.4	Maximal power during the force velocity test	18:00 h	8.3%
Castaingts et al ⁷⁴	11 M	18–30	MVC	18:00 h	8.6%

F, female; M, male; MVC, maximal voluntary contraction; NS, not significant.
 Note. From “The effect of training at a specific time of day: a review”, by H. Chtourou and N. Souissi, 2012, *J Strength Cond Res*, 26, p.1984–2005. Copyright 2013, Wolters Kluwer Health. Reprinted with permission.

in the morning than in the evening (Table 2). In agreement with these studies, Edwards et al⁵⁵ investigated the effect of submaximal cycling at 60% of VO₂max, and found that the morning exercise group exhibited greater improvements in lactate levels, compared to the evening exercise group.⁴³ By contrast, Reilly and Garrett¹⁹ indicated a higher power output during a 60-minute cycle ergometer test in the evening than in the morning. Atkinson and Reilly¹³ also indicated that, after a 1.6-km time trail exercise, the heart rate and blood lactate levels exhibited greater improvements in the evening exercise group than in the morning exercise group. However, previous studies did not indicate any difference in the time-of-day effect on exhaustion during maximal^{19,21} and submaximal cycling.⁵⁵

2.4. Hormone adaptation

The role of adrenal steroids in response to exercise training is very important for improving muscle cell and protein

synthesis.^{56–58} Many researchers have revealed different time-of-day effects of anabolic hormones (such as testosterone and cortisol) on muscle strength and protein synthesis within skeletal muscle.^{6,59,60} Testosterone is a male sex hormone and its anabolic effects are observed during male adolescence and adulthood.⁶¹ During exercise training and physical activity, the main effect of testosterone is on insulin sensitivity and on the maintenance of muscle protein synthesis within the muscular system.^{62,63}

Cortisol is catabolic in nature, and is a stress hormone.⁶⁴ Florini⁶⁵ found that cortisol exerts catabolic effects on muscle tissue. Increased cortisol levels may also inhibit protein synthesis.⁶⁶ Testosterone and cortisol both exhibit diurnal variations in peak concentrations in the morning and/or evening.⁶⁷ Florini⁶⁵ observed increased cortisol levels in the morning, which may stimulate an increase in gluconeogenesis, proteolytic activity, and skeletal protein turnover.⁵⁹ This effect may generate the catabolic status of muscle tissue. Increased testosterone levels may

Table 2 – The effect of time of day on longterm exercises.

Refs	Participants	Age (y)	Measurement parameters	Acrophase
Dalton et al ²⁰	7 M competitive cyclists or triathletes	22.3 ± 2.3	Total work during a timed trial cycling performance of 15-min duration Average power output during a time trial cycling performance of 15 min duration	NS
Bessot et al ^{72,75}	10 M competitive endurance cyclists	21.5 ± 1.5	Free pedal rate during 4 × 5 min cycling exercise	NS
Edwards et al ⁵⁵	8 M recreational cyclists	24.3 ± 4	Work rate during 30-min submaximal cycling at 60% of VO ₂ max	NS

M, male; NS, not significant; VO₂max, maximal oxygen consumption.
 Note. From “The effect of training at a specific time of day: a review”, by H. Chtourou and N. Souissi, 2012, *J Strength Cond Res*, 26, p. 1984–2005. Copyright 2013, Wolters Kluwer Health. Reprinted with permission.

furthermore offset the effects of cortisol on skeletal protein degradation.⁶⁸

Several investigators have indicated that hormonal responses can be influenced by the time of exercise training and the intensity, and duration of exercise. Sedliak et al²⁹ indicated that testosterone levels did not change in response to resistance training in the morning. Another study showed that 10 weeks of training did not induce any significant differences in testosterone and cortisol levels.²⁴ Deschenes et al²¹ also report that resistance exercise has no effect on the diurnal variations in cortisol and testosterone levels. However, Bird and Tarpenning²³ showed that cortisol levels were lower in the evening than in the morning. These results suggest that the skeletal muscle metabolism may be improved at that time of the day. However, further research is required to support the use of different exercise timings, based on hormonal responses.

3. Limitations

The present study indicates the defenses in the time-of-day effects of exercise, exercise type, exercise duration, and hormone adaptation among healthy individuals. However, we did not assess the beneficial time-of-day effect in patients with a chronic disease. Therefore, if further studies assess the beneficial time-of-day effect in patients with chronic disease, such studies should carefully consider only the results of physiological variation.

4. Conclusions

The literature contains more than 70 different exercise types, times, and hormonal adaptations. In the present review, we confirm that the diurnal or hormone variations lead to differences in physical performance, depending on the time of the day. In addition, the results indicate differences in physical performance for exercise performed in the morning and evening, thus suggesting that these factors should be considered by scientists, coaches, and athletes.

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgment

This work was supported by the 2005 Inje University research grant.

REFERENCES

- Sumide T, Shimada K, Ohmura H, Onishi T, Kawakami K, Masaki Y, et al. Relationship between exercise tolerance and muscle strength following cardiac rehabilitation: comparison of patients after cardiac surgery and patients with myocardial infarction. *J Cardiol* 2009;54:273–81.
- Nishitani M, Shimada K, Masaki M, Sunayama S, Kume A, Fukao K, et al. Effect of cardiac rehabilitation on muscle mass, muscle strength, and exercise tolerance in diabetic patients after coronary artery bypass grafting. *J Cardiol* 2013;61:216–21.
- Dolinsky VW, Jones KE, Sidhu RS, Haykowsky M, Czubyrt MP, Gordon T, et al. Improvements in skeletal muscle strength and cardiac function induced by resveratrol during exercise training contribute to enhanced exercise performance in rats. *J Physiol* 2012;590:2783–99.
- Zambon AC, McDearmon EL, Salomonis N, Vranizan KM, Johansen KL, Adey D, et al. Time- and exercise-dependent gene regulation in human skeletal muscle. *Genome Biol* 2003;4:R61.
- Rowland T, Unnithan V, Barker P, Lindley M, Roche D, Garrard M. Time-of-day effect on cardiac responses to progressive exercise. *Chronobiol Int* 2011;28:611–6.
- Labsy Z, Prieur F, Le Panse B, Do MC, Gagey O, Lasne F, et al. The diurnal patterns of cortisol and dehydroepiandrosterone in relation to intense aerobic exercise in recreationally trained soccer players. *Stress* 2013;16:261–5.
- Dufour Doiron M, Prud'homme D, Boulay P. Time-of-day variation in cardiovascular response to maximal exercise testing in coronary heart disease patients taking a beta-blocker. *Appl Physiol Nutr Metab* 2007;32:664–9.
- Hill DW, Borden DO, Darnaby KM, Hendricks DN, Hill CM. Effect of time of day on aerobic and anaerobic responses to high-intensity exercise. *Can J Sport Sci* 1992;17:316–9.
- Dishman RK, Berthoud HR, Booth FW, Cotman CW, Edgerton VR, Fleshner MR, et al. Neurobiology of exercise. *Obesity (Silver Spring)* 2006;14:345–56.
- Rupp T, Jubeau M, Millet GY, Wuyam B, Levy P, Verges S, et al. Muscle, prefrontal, and motor cortex oxygenation profiles during prolonged fatiguing exercise. *Adv Exp Med Biol* 2013;789:149–55.
- Edwards AM. Respiratory muscle training extends exercise tolerance without concomitant change to peak oxygen uptake: Physiological, performance and perceptual responses derived from the same incremental exercise test. *Respirology* 2013;18:1022–7.
- Meijer JH, Watanabe K, Detari L, Schaap J. Circadian rhythm in light response in suprachiasmatic nucleus neurons of freely moving rats. *Brain Res* 1996;741:352–5.
- Atkinson G, Reilly T. Circadian variation in sports performance. *Sports Med* 1996;21:292–312.
- Giovanna C, Andi W, Sigurd B, Angela M. Morning or evening exercise: effects on the heart rate circadian rhythm above the Arctic Circle. *Sport Sci Health* 2010;1:9–16.
- Park S, Jastremski CA, Wallace JP. Time of day for exercise on blood pressure reduction in dipping and nondipping hypertension. *J Hum Hypertens* 2005;19:597–605.
- Torii J, Shinkai S, Hino S, Kurokawa Y, Tomita N, Hirose M, et al. Effect of time of day on adaptive response to a 4-week aerobic exercise program. *J Sports Med Phys Fitness* 1992;32:348–52.
- Hill DW, Cureton KJ, Collins MA. Circadian specificity in exercise training. *Ergonomics* 1989;32:79–92.
- Williams H, Langlois PF, Kelly JL. The effect of simultaneous intravenous administration of nitroglycerin and heparin on partial thromboplastin time. *Mil Med* 1995;160:449–52.
- Reilly T, Garrett R. Effects of time of day on self-paced performances of prolonged exercise. *J Sports Med Phys Fitness* 1995;35:99–102.
- Dalton B, McNaughton L, Davoren B. Circadian rhythms have no effect on cycling performance. *Int J Sports Med* 1997;18:538–42.
- Deschenes MR, Sharma JV, Brittingham KT, Casa DJ, Armstrong LE, Maresh CM. Chronobiological effects on

- exercise performance and selected physiological responses. *Eur J Appl Physiol Occup Physiol* 1998;77:249–56.
22. Bernard T, Giacomoni M, Gavarry O, Seymat M, Falgairette G. Time-of-day effects in maximal anaerobic leg exercise. *Eur J Appl Physiol Occup Physiol* 1998;77:133–8.
 23. Bird SP, Tarpenning KM. Influence of circadian time structure on acute hormonal responses to a single bout of heavy-resistance exercise in weight-trained men. *Chronobiol Int* 2004;21:131–46.
 24. Kraemer WJ, Loebel CC, Volek JS, Ratamess NA, Newton RU, Wickham RB, et al. The effect of heavy resistance exercise on the circadian rhythm of salivary testosterone in men. *Eur J Appl Physiol* 2001;84:13–8.
 25. Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T. Circadian rhythms in sports performance—an update. *Chronobiol Int* 2005;22:21–44.
 26. Someren EJ, Hagebeuk EE, Lijzenga C, Scheltens P, de Rooij SE, Jonker C, et al. Circadian rest-activity rhythm disturbances in Alzheimer's disease. *Biol Psychiatry* 1996;40:259–70.
 27. Chtourou H, Chaouachi A, Driss T, Dogui M, Behm DG, Chamari K, et al. The effect of training at the same time of day and tapering period on the diurnal variation of short exercise performances. *J Strength Cond Res* 2012;26:697–708.
 28. Souissi N, Gauthier A, Sesboue B, Larue J, Davenne D. Effects of regular training at the same time of day on diurnal fluctuations in muscular performance. *J Sports Sci* 2002;20:929–37.
 29. Sedliak M, Finni T, Cheng S, Kraemer WJ, Hakkinen K. Effect of time-of-day-specific strength training on serum hormone concentrations and isometric strength in men. *Chronobiol Int* 2007;24:1159–77.
 30. Shiotani H, Umegaki Y, Tanaka M, Kimura M, Ando H. Effects of aerobic exercise on the circadian rhythm of heart rate and blood pressure. *Chronobiol Int* 2009;26:1636–46.
 31. Fisher G, Hunter GR, Gower BA. Aerobic exercise training conserves insulin sensitivity for 1 yr following weight loss in overweight women. *J Appl Physiol* 2012;112:688–93.
 32. Wezenberg D, de Haan A, van der Woude LH, Houdijk H. Feasibility and validity of a graded one-legged cycle exercise test to determine peak aerobic capacity in older people with a lower-limb amputation. *Phys Ther* 2012;92:329–38.
 33. Jendzjowsky NG, Tomczak CR, Lawrance R, Taylor DA, Tymchak WJ, Riess KJ, et al. Impaired pulmonary oxygen uptake kinetics and reduced peak aerobic power during small muscle mass exercise in heart transplant recipients. *J Appl Physiol* 2007;103:1722–7.
 34. Scheer FA, Hu K, Evoniuk H, Kelly EE, Malhotra A, Hilton MF, et al. Impact of the human circadian system, exercise, and their interaction on cardiovascular function. *Proc Natl Acad Sci USA* 2010;107:20541–6.
 35. Leise TL, Harrington ME, Molyneux PC, Song I, Queenan H, Zimmerman E, et al. Voluntary exercise can strengthen the circadian system in aged mice. *Age (Dordr)* 2013 Jan;23 [Epub ahead of print].
 36. Havelkova A, Siegelova J, Fiser B, Mifkova L, Chludilova V, Pochmonova J, et al. Circadian blood pressure variability and exercise therapy. *Scr Med (Brno)* 2007;80:191–6.
 37. Moriguchi T, Shimomitsu T, Odagiri Y, Ichimura S, Fukuda J, Tomoda A. Circadian changes in urinary bicarbonate, nitric oxide metabolites and pH in female player during handball camp involved in an exercise, rest and sleep cycle. *Tohoku J Exp Med* 2002;196:281–91.
 38. Hobson RM, Clapp EL, Watson P, Maughan RJ. Exercise capacity in the heat is greater in the morning than in the evening in man. *Med Sci Sports Exerc* 2009;41:174–80.
 39. Hill DW, Leiferman JA, Lynch NA, Dangelmaier BS, Burt SE. Temporal specificity in adaptations to high-intensity exercise training. *Med Sci Sports Exerc* 1998;30:450–5.
 40. Faisal A, Beavers KR, Hughson RL. O₂ uptake and blood pressure regulation at the onset of exercise: interaction of circadian rhythm and priming exercise. *Am J Physiol Heart Circ Physiol* 2010;299:H1832–42.
 41. Bambaeichi E, Reilly T, Cable NT, Giacomoni M. Influence of time of day and partial sleep loss on muscle strength in eumenorrhic females. *Ergonomics* 2005;48:1499–511.
 42. Sedliak M, Haverinen M, Hakkinen K. Muscle strength, resting muscle tone and EMG activation in untrained men: interaction effect of time of day and test order-related confounding factors. *J Sports Med Phys Fitness* 2011;51:560–70.
 43. Souissi H, Chtourou H, Chaouachi A, Dogui M, Chamari K, Souissi N, et al. The effect of training at a specific time-of-day on the diurnal variations of short-term exercise performances in 10- to 11-year-old boys. *Pediatr Exerc Sci* 2012;24:84–99.
 44. Lericollais R, Gauthier A, Bessot N, Sesboue B, Davenne D. Time-of-day effects on fatigue during a sustained anaerobic test in well-trained cyclists. *Chronobiol Int* 2009;26:1622–35.
 45. Edwards BJ, Pullinger SA, Kerry JW, Robinson WR, Reilly TP, Robertson CM, et al. Does raising morning rectal temperature to evening levels offset the diurnal variation in muscle force production? *Chronobiol Int* 2013;30:486–501.
 46. Sedliak M, Finni T, Cheng S, Lind M, Hakkinen K. Effect of time-of-day-specific strength training on muscular hypertrophy in men. *J Strength Cond Res* 2009;23:2451–7.
 47. Sedliak M, Finni T, Peltonen J, Hakkinen K. Effect of time-of-day-specific strength training on maximum strength and EMG activity of the leg extensors in men. *J Sports Sci* 2008;26:1005–14.
 48. Chtourou H, Zarrouk N, Chaouachi A, Dogui M, Behm DG, Chamari K, et al. Diurnal variation in Wingate-test performance and associated electromyographic parameters. *Chronobiol Int* 2011;28:706–13.
 49. Zarrouk N, Chtourou H, Rebai H, Hammouda O, Souissi N, Dogui M, et al. Time of day effects on repeated sprint ability. *Int J Sports Med* 2012;33:975–80.
 50. Chtourou H, Driss T, Souissi S, Gam A, Chaouachi A, Souissi N. The effect of strength training at the same time of the day on the diurnal fluctuations of muscular anaerobic performances. *J Strength Cond Res* 2012;26:217–25.
 51. Souissi N, Bessot N, Chamari K, Gauthier A, Sesboue B, Davenne D. Effect of time of day on aerobic contribution to the 30-s Wingate test performance. *Chronobiol Int* 2007;24:739–48.
 52. Gauthier A, Davenne D, Martin A, Cometti G, Van Hoecke J. Diurnal rhythm of the muscular performance of elbow flexors during isometric contractions. *Chronobiol Int* 1996;13:135–46.
 53. Brisswalter J, Bieuzen F, Giacomoni M, Tricot V, Falgairette G. Morning-to-evening differences in oxygen uptake kinetics in short-duration cycling exercise. *Chronobiol Int* 2007;24:495–506.
 54. Lericollais R, Gauthier A, Bessot N, Davenne D. Diurnal evolution of cycling biomechanical parameters during a 60-s Wingate test. *Scand J Med Sci Sports* 2011;21:e106–14.
 55. Edwards BJ, Edwards W, Waterhouse J, Atkinson G, Reilly T. Can cycling performance in an early morning, laboratory-based cycle time-trial be improved by morning exercise the day before? *Int J Sports Med* 2005;26:651–6.
 56. Port K. Serum and saliva cortisol responses and blood lactate accumulation during incremental exercise testing. *Int J Sports Med* 1991;12:490–4.
 57. Paccotti P, Minetto M, Terzolo M, Ventura M, Ganzit GP, Borriero P, et al. Effects of high-intensity isokinetic exercise

- on salivary cortisol in athletes with different training schedules: relationships to serum cortisol and lactate. *Int J Sports Med* 2005;26:747–55.
58. Wirtz PH, von Kanel R, Emini L, Ruedisueli K, Groessbauer S, Maercker A, et al. Evidence for altered hypothalamus-pituitary-adrenal axis functioning in systemic hypertension: blunted cortisol response to awakening and lower negative feedback sensitivity. *Psychoneuroendocrinology* 2007;32:430–6.
59. West DW, Burd NA, Phillips SM. Comment and reply on: Interactions of cortisol, testosterone, and resistance training: influence of circadian rhythms. *Chronobiol Int* 2010;27(4):675–705. Author reply: *Chronobiol Int* 27, 2010: 1943–1945.
60. Hayes LD, Bickerstaff GF, Baker JS. Interactions of cortisol, testosterone, and resistance training: influence of circadian rhythms. *Chronobiol Int* 2010;27:675–705.
61. Bahrke MS, Yesalis CE. Abuse of anabolic androgenic steroids and related substances in sport and exercise. *Curr Opin Pharmacol* 2004;4:614–20.
62. Ferrando AA, Tipton KD, Doyle D, Phillips SM, Cortiella J, Wolfe RR. Testosterone injection stimulates net protein synthesis but not tissue amino acid transport. *Am J Physiol* 1998;275:E864–71.
63. Holmang A, Bjorntorp P. The effects of testosterone on insulin sensitivity in male rats. *Acta Physiol Scand* 1992;146:505–10.
64. Wendelaar Bonga SE. The stress response in fish. *Physiol Rev* 1997;77:591–625.
65. Florini JR. Hormonal control of muscle growth. *Muscle Nerve* 1987;10:577–98.
66. Timon R, Olcina G, Tomas-Carus P, Munoz D, Toribio F, Raimundo A, et al. Urinary steroid profile after the completion of concentric and concentric/eccentric trials with the same total workload. *J Physiol Biochem* 2009;65:105–12.
67. Touitou Y, Haus E. Alterations with aging of the endocrine and neuroendocrine circadian system in humans. *Chronobiol Int* 2000;17:369–90.
68. Kraemer WJ. Endocrine responses to resistance exercise. *Med Sci Sports Exerc* 1988;20:S152–7.
69. Atkinson G, Coldwells A, Reilly T, Waterhouse J. A comparison of circadian rhythms in work performance between physically active and inactive subjects. *Ergonomics* 1993;36:273–81.
70. Wyse JP, Mercer TH, Gleeson NP. Time-of-day dependence of isokinetic leg strength and associated interday variability. *Br J Sports Med* 1994;28:167–70.
71. Martin A, Carpentier A, Guissard N, van Hoecke J, Duchateau J. Effect of time of day on force variation in a human muscle. *Muscle Nerve* 1999;22:1380–7.
72. Callard D, Davenne D, Gauthier A, Lagarde D, Van Hoecke J. Circadian rhythms in human muscular efficiency: continuous physical exercise versus continuous rest. A crossover study. *Chronobiol Int* 2000;17:693–704.
73. Souissi N, Sesboue B, Gauthier A, Larue J, Davenne D. Effects of one night's sleep deprivation on anaerobic performance the following day. *Eur J Appl Physiol* 2003;89:359–66.
74. Castaingts V, Martin A, Van Hoecke J, Perot C. Neuromuscular efficiency of the triceps surae in induced and voluntary contractions: morning and evening evaluations. *Chronobiol Int* 2004;21:631–43.
75. Bessot N, Moussay S, Clarys JP, Gauthier A, Sesboue B, Davenne D. The influence of circadian rhythm on muscle activity and efficient force production during cycling at different pedal rates. *J Electromyogr Kinesiol* 2007;17:176–83.