Diurnal Variations in Physical Performance: Are There Morning-to-Evening Differences in Elite Male Handball Players?

by

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The purposes of this study were to determine: 1) morning-to-evening differences in physical performance with and without a ball; and 2) associations between sleep outcomes (duration and quality) and physical performance in handball players. Sixteen elite, male handball players (25.4 ± 5.8 yr, 94.0 ± 7.4 kg, 193.5 ± 7.5 cm) completed physical performance tests without a ball (a zig-zag test assessing closed-skill agility, linear sprints, and countermovement (CMJ) and squat jumps) and with a ball (a zig-zag test and linear sprints) in the morning and evening. In addition, sleep quality and quantity during the night before testing were obtained using self-reported measures. Superior physical performance was evident in all tests during the evening compared to the morning hours (p < 0.003). Specifically, jump height was moderately (effect size (ES) = 0.73 to 1.02) higher during the evening. Similarly, moderate (ES = 1.17) and large (ES = 1.67) improvements in zig-zag test performance were apparent during the evening with and without the ball, respectively. Also, large to very large (ES = 1.29 to 2.09) increases in sprint performance with and without the ball were evident in the evening. No significant correlations (p > 0.05) were apparent between sleep duration and quality and physical performance in both the morning and evening sessions. Diurnal variations in physical performance were apparent in elite male handball players with enhanced performance with and without the ball in the evening compared to morning hours. These findings indicate that morning-to-evening differences in physical performance should be considered when developing conditioning plans or preparing for competition in handball.

Key words: : speed, agility, jumping performance, team sport, sleep.

Introduction

Handball has increased in popularity across recent decades with more than 19 million players in 167 member federations worldwide (Nikolaidis and Ingebrigtsen, 2013). Consequently, professional competitions are held in many countries requiring players to complete heavy match and training schedules. In turn, handball matches and training sessions are often administered at different times of the day. Many professional handball teams train twice per day at least several times per week, with training and

competition scheduled in the morning and evening. Thus, it is important to establish if diurnal variations in performance exist for optimal training approaches and match preparation strategies to be implemented. Chtourou and Souissi (2012) concluded training in the morning could improve morning performance and reduce diurnal fluctuations in performance across the morning and evening. Furthermore, in some cases morning training increases physical performance more than training in the evening

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(Chtourou et al., 2012). In contrast, chronic training in the evening leads to higher daily variations in physical performance (Chtourou et al., 2012).

Previous studies (Chtourou and Souissi, 2012; Mhenni et al., 2017; West et al., 2014; Zarrouk et al., 2012) confirmed maximal short-term performances depend on the time of day completed with morning nadirs and afternoon peaks. For example, high-intensity short duration performance is usually higher in the afternoon (16:00-20:00 h) compared to the morning (6:00-10:00 h) (Zarrouk et al., 2012). This variation in muscle power, strength and sprint ability ranges from 3 to 21% depending on the muscle group and athlete sample investigated (Chtourou and Souissi, 2012). Specifically in handball players, Mhenni et al. (2017) reported maximal handgrip strength of the dominant hand (19.4%, effect size (ES) = 0.73), ball throwing velocity (5.4%, ES = 0.50) and change-of-direction speed (12.1%, ES = 1.59) were higher in the evening compared to the morning. However, in addition to strength, throwing and change-of-direction attributes, handball players also undergo extensive sprinting activity with and without a ball over 5-20 m as well as they need to respond to extensive jumping demands during match-play (Wagner et al., 2014). Thus, more research is needed to examine diurnal variations in a wider range of performance measures specifically encountered during handball match-play.

Diurnal variations in physical performance have been partly attributed to the natural fluctuations in core temperature (Chtourou and Souissi, 2012; Mhenni et al., 2017; West et al., 2014). For instance, West et al. (2014) concluded small morning-to-evening changes in core temperature (1.3%, ES = 0.98) decreased physical performance (peak power) by 5.1% (ES = 0.45) in elite athletes. In addition, diurnal enhancements in muscle force are related to improvement of muscle contractile properties in the evening due to a higher mechanical response to motor neuron stimulation (Guette et al., 2005). However, diurnal variation in short-term physical performance may be influenced by many factors such as the age, training level, experience, nutritional status, and sleeping behaviour of the athlete (Chtourou and Souissi, 2012; Mhenni et al., 2017). Sleeping behaviour is an especially

important factor to be considered in affecting short-term performance in handball players as it is recognised as the single most efficacious recovery strategy due to its physiological and psychological restorative effects (Halson, 2008; Leeder et al., 2012). Loss of sleep has been linked with overtraining syndrome and has negative effects on maximal muscle function (Jurimae et al., 2004) and motor performance (Pilcher and Huffcutt, 1996). A recent review of the literature (Malhotra, 2017) confirmed sleep deprivation has a substantial negative effect on motor and cognitive performances such as decision making, reaction time, fine motor coordination, and imprinting memories and skills that were practiced. Therefore, consideration of sleep quality and quantity is necessary to understand mechanisms underpinning diurnal variations in physical performance in handball players.

To date, diurnal variations in short-term maximal physical performance have been investigated in female handball players (Mhenni et al., 2017), judo athletes (Souissi et al., 2013), and rugby players (West et al., 2014). The existing studies have primarily focused on short-term physical performance using test protocols non-specific to actual match demands. However, morning-to-evening variations using sprint distances (5-20 m), closed-skill agility tasks, and jump protocols representative of movement patterns performed across matches as well as manoeuvres with a ball are yet to be examined in handball players. Furthermore, there is a distinct lack of data detailing morning-to-evening differences in physical performance in male handball players. While some studies have investigated mechanisms related to diurnal variations in physical performance including core temperature (Chtourou and Souissi, 2012), circadian rhythms (Souissi et al., 2004; West et al., 2014), peripheral (intramuscular contractile state of the muscle) and central neural mechanisms (Castaingts et al., 2004) and muscle architecture (Onambele-Pearson and Pearson, 2007), the impact of sleep (quality and quantity) remains somewhat limited, given Souissi et al. (2013) restricted sleeping time to 3 h. Therefore, the purposes of this study were to determine: 1) morning-to-evening differences in physical performance with and without a ball; and 2) associations between sleep outcomes (quality and

quantity) and physical performance in male handball players.

Methods

Participants

Sixteen elite male handball players (age: 25.4 ± 5.8 yr, body mass: 94.0 ± 7.4 kg, body height: 193.5 ± 7.5 cm) from the same team competing in the National Handball Superleague volunteered to participate in this study. Participants had at least 5 yr of professional handball experience and held similar acute training histories prior to study commencement, completing 4 weeks of baseline conditioning during the general preparatory phase. Participants were free of injury, illness and disease as determined by a team physician prior to study participation. All participants were informed of the study aims and gave informed written consent to participate prior to testing. To avoid potential bias, participants were not informed about the theoretical background of diurnal variations in performance and did not receive any feedback from the testers. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Ethics Committee of the Faculty of Sport and Physical Education before commencement.

Procedures

Testing was completed 1 week before the beginning of the competitive season. Prior to performance testing, sleep quality and quantity during the previous night were obtained using the modified wellness questionnaire (Buchheit et al., 2013). The questionnaire consisted of questions related to perceived sleep quality scored on a 10-point Likert scale with 1 representing poor and 10 representing excellent sleep quality. Participants also provided estimation of sleep duration (hh:mm) from the previous night including the latency period. This approach had been previously confirmed as valid for assessment of sleep outcomes (Caia et al., 2017). Morning and evening heart rates were measured before physical performance testing in the non-dominant arm using a validated automated measuring device (Omron-M7) (Coleman et al., 2008). Prior to physical performance testing, participants completed a standardised warm-up consisting of moderate-intensity jogging (8 min), static stretching (5 min),

and brief bouts of high-intensity running (2 min). All participants completed seven physical performance tests without a ball (a zig-zag test assessing agility, 5-m, 10-m and 20-m linear sprints, a countermovement jump (CMJ) with and without an arm swing, and a squat jump) and four tests with a ball (a zig-zag test and 5-m, 10-m and 20-m linear sprints) at two separate testing sessions in the morning (8:00-9:30 h) and in the evening (18:00-19:30 h). Time of the morning and evening testing sessions was similar to previous studies (Chtourou and Souissi, 2012; Mhenni et al., 2017; Zarrouk et al., 2012). Participants were informed to avoid any type of exercise as well as afternoon napping or sleeping between morning and evening testing sessions and to continue with their usual lifestyle activities. All testing was carried out in similar environmental conditions (20-25°C) on the same official handball court in an indoor facility in the following order: a CMJ without an arm swing, a CMJ with an arm swing, a squat jump, a zig-zag test without a ball, a zig-zag test with a ball, 5-m, 10-m and 20-m sprints without a ball, and 5-m, 10-m and 20-m sprints with a ball.

Jump assessments.

Explosive power of the lower body was assessed using a vertical CMJ with and without an arm swing, and a squat jump. All jumps were performed on a photocell mat (Optojump, Microgate, Bolzano, Italy) which measures flight time between take-off and subsequent landing to calculate jump height (cm). Validity and reliability of the Optojump system has been confirmed in previous research (Glatthorn et al., 2011). Each trial was validated by a visual inspection to ensure that each landing was without any leg flexion; furthermore, participants were instructed to maintain their hands on their hips during the CMJ (without an arm swing) and squat jump and to use the arm swing in the CMJ free arms. The CMJ was performed starting from a standing position after which participants were asked to jump as high as possible with a rapid, preparatory downward eccentric action. The depth of the CMJ was self-selected. Participants performed the squat jump starting from a standing position, bending the knees to 90°, stopping for 3 s, and then jumping as high as possible to avoid any knee or trunk countermovement. Each test was performed three times, separated by 1 min of

passive recovery, and the best jump was recorded and used for analysis. Participants wore athletic shoes during all jumps.

Zig-zag test (with and without a ball).

Closed-skill agility with and without a ball was evaluated using a zig-zag test (Sekulic et al., 2013). This test required participants to run a course of four 5-m sections set out at 100° angles in the shortest possible time. Electronic timing gates used to record performance times (Witty, Microgate, Bolzano, Italy) were placed 1 m above the ground. Participants commenced each test 20 cm before the initial timing gate to avoid triggering timing early. The test was completed with and without dribbling a ball. Participants performed two trials of each test, with at least 2 min rest between trials. The best time recorded with and without a ball was used for analysis as previously described (Al Haddad et al., 2015).

5-m, 10-m and 20-m sprints (with and without a ball).

Sprint ability was evaluated with participants performing a standing-start all-out maximal running effort across 20 m. Time was recorded using electronic timing gates (Witty, Microgate, Bolzano, Italy) placed 1 m above the ground at the start line, 5 m, 10 m, and at the finish line (20 m). Participants commenced each sprint 20 cm before the initial timing gate. Three sprints were performed with 2 min rest between trials and 5-m, 10-m and 20-m split times recorded during each trial. Sprints were completed with and without dribbling a ball. The dribbling sprints involved players tapping the ball in conjunction with the first step over the start line, and continuing dribbling the ball during the whole sprint. The fastest trial for each split in each test, irrespective of the trial they occurred, was recorded for further analysis (Al Haddad et al., 2015). In the event of failed attempts (e.g. hitting a cone, dropping the ball), participants repeated the test following an appropriate recovery period.

Statistical analysis

All data are presented as means ± standard deviation with corresponding 95% confidence intervals (CI). Since normality of data distribution was confirmed by the Kolmogorov–Smirnov test, any systematic diurnal changes in jump (a CMJ with and without an arm swing and a squat jump), zig-zag test (without and with dribbling a ball) and sprint (5-m, 10-m, and 20-without and with a ball) performance were assessed using analysis of variance (ANOVA) with repeated measures. The magnitude of difference between morning and evening performances was measured using Hopkins' effect size (ES) and interpreted using previously established criteria: *trivial = < 0.20; small = 0.2–0.59; moderate = 0.60–1.19; large = 1.20–1.99; very large = >* 2.0 (Hopkins et al., 2009). Further, magnitude-based inferences were determined by quantifying the chances that true differences in all pairwise comparisons were greater than, similar to, or smaller than the smallest worthwhile difference (0.2 multiplied by the between-participant deviation) and interpreted qualitatively as: *almost certainly not = < 0.5%; very unlikely = 0.5-5%; unlikely = 5-25%; possible = 25-75%; likely = 75-95%; very likely = 95-99.5%; almost certain = > 99.5%* (Hopkins et al., 2009). The relationships between performance in each test and sleep quality and quantity were calculated using the Pearson's correlation coefficient. All statistical analyses were performed using SPSS 24.0 software (SPSS Inc., Chicago, IL). The alpha level was set at < 0.05 to indicate statistical significance.

Results

Means ± standard deviation for each performance measure in the morning and evening are shown in Table 1. *Moderate* ($p < 0.001$) increases in jump height were observed in the evening for the CMJ without (ES = 0.78, *likely trivial*) and with an arm swing (ES = 1.02, *possibly beneficial*) and the squat jump (ES = 0.73, *likely trivial*). Comparisons between morning and evening performance showed *most likely moderate* and *large* improvements in the zig-zag test with (ES = 1.17, $p < 0.001$) and without a ball (ES = 1.69, $p < 0.001$) during the evening (Table 1). Similarly, *most likely large* to *very large* better ($p < 0.001$) sprint times (5-m, 10-m and 20-m sprint) were observed in the evening regardless of whether participants were dribbling the ball or not (Table 1).

Means ± standard deviation of sleep quality and quantity were 7.94 ± 1.44 and 7.70 ± 1.40 h, respectively. Sleep quality and quantity were not significantly related ($p > 0.05$) to any performance measure in the morning or evening (Table 2). In addition, there were no significant correlations ($p > 0.05$) between magnitude of diurnal variation in performance and sleep outcomes (quality and

quantity) in all tests. Variation in the heart rate was 5% ($p > 0.05$) between morning and evening hours.

Table 1

Mean ± standard deviation performance measures in the morning and evening with pairwise statistical comparisons in elite male handball players (N = 16).

Performance measure	Morning	Evening	p	Effect size		MBI
				Statistic (95% CI)	*Magnitude*	*Interpretation*
Without a ball						
Zig-zag test (s)	4.55 ± 0.16	4.28 ± 0.16	<0.001	-1.67 (-2.2 to -1.1)	*Large*	*Most likely*
5 m sprint (s)	1.19 ± 0.10	1.06 ± 0.07	<0.001	-1.69 (-2.3 to -1.1)	*Large*	*Most likely*
10 m sprint (s)	2.03 ± 0.13	1.80 ± 0.09	<0.001	-2.09 (-2.8 to -1.4)	*Very large*	*Most likely*
20 m sprint (s)	3.50 ± 0.25	3.18 ± 0.19	<0.001	-1.46 (-1.9 to -1.0)	*Large*	*Most likely*
CMJ without an arm swing (cm)	32.11 ± 4.33	35.75 ± 4.99	<0.001	0.78 (0.5 to 1.0)	*Moderate*	*Likely trivial*
CMJ with an arm swing (cm)	38.00 ± 4.52	42.66 ± 4.58	<0.001	1.02 (0.6 to 1.4)	*Moderate*	*Possibly benefical*
Squat jump (cm)	30.54 ± 4.12	33.52 ± 4.09	<0.001	0.73 (0.5 to 1.0)	*Moderate*	*Likely trivial*
With a ball						
Zig-zag test (s)	4.99 ± 0.37	4.58 ± 0.33	<0.001	-1.17 (-1.6 to -0.8)	*Moderate*	*Most likely*
5 m sprint (s)	1.20 ± 0.10	1.08 ± 0.08	<0.001	-1.34 (-1.8 to -0.9)	*Large*	*Most likely*
10 m sprint (s)	2.06 ± 0.10	1.90 ± 0.15	<0.001	-1.29 (-1.7 to -0.9)	*Large*	*Most likely*
20 m sprint (s)	3.65 ± 0.22	3.36 ± 0.20	0.003	-1.40 (-1.9 to -0.9)	*Large*	*Most likely*

Note: CI – confidence interval; MBI – Magnitude-based inferences; CMJ – countermovement jump; all comparisons are presented as evening vs. morning.

Table 2

Pearson correlations between sleep quality and duration and physical performance in elite male handball players (N = 16).

Performance measure	Morning		Evening		% changes in performance	
	Sleep quality	Sleep duration	Sleep quality	Sleep duration	Sleep quality	Sleep duration
Without a ball						
Zig-zag test (s)	-0.01	-0.30	0.07	0.39	0.06	0.624
5 m sprint (s)	-0.12	0.52	-0.26	-0.08	-0.05	-0.54
10 m sprint (s)	0.10	0.46	-0.18	0.02	-0.24	0.41
20 m sprint (s)	0.09	0.19	-0.21	0.15	-0.28	-0.03
CMJ without an arm swing	-0.05	-0.06	0.04	0.05	0.21	0.17
CMJ with an arm swing	-0.14	-0.20	0.04	0.00	0.24	0.21
Squat jump	0.15	0.01	0.25	0.00	0.08	0.01
With a ball						
Zig-zag test (s)	0.02	0.03	-0.25	-0.10	-0.23	-0.13
5 m sprint (s)	-0.39	0.37	-0.06	0.30	0.37	-0.12
10 m sprint (s)	-0.27	0.19	-0.25	0.26	-0.11	0.19
20 m sprint (s)	-0.20	0.05	-0.21	0.34	-0.03	0.25

Note: CMJ – countermovement jump.

Discussion

This study investigated diurnal variations in short-term maximal physical performance as well as the temporal (morning-to-evening) relationships between self-reported sleep outcomes (quality and quantity) and performance in elite male handball players. *Most likely large* to *very large* diurnal differences were evident across all sprint (5 m, 10 m and 20 m) and zig-zag tests, while *moderate* diurnal variations were observed for the squat jump and the CMJ with and without an arm swing, with superior responses achieved in the evening in all tests. The highest magnitude of change in performance was observed for linear sprinting (5 m, 10 m and 20 m) with and without dribbling a ball. In contrast, handball-specific, short-term maximal performances in the morning and evening were not associated with prior sleep quality and quantity.

Moderate improvements (ES = 0.73 to 1.02; 10-12%) in the evening compared to the morning were observed in all vertical jump protocols in the present study. These findings contrast those reported by Mhenni et al. (2017) where no morning-to-evening difference in CMJ performance was evident in female handball players. Variations in vertical jump data reported across studies could be attributed to discrepancies in the warm-up approach applied (static vs. dynamic stretching) (Chtourou et al., 2013a). Namely, dynamic stretching performed in the morning as used by Mhenni et al. (2017) may enhance electromyographic activity and reduce diurnal variations in vertical jump height (Chtourou et al., 2013a). In contrast, participants in this study underwent static stretching prior to testing, which might have increased the temporal improvements in vertical jump performance. The strict mechanism for the decline in performance (or temporal improvements) induced by static stretching is still unclear, but several authors assumed that a decrease in muscle activation and musculo-tendinous stiffness could be the main causes (Chtourou et al., 2013a; Fletcher and Monte-Colombo, 2010). In turn, the diurnal fluctuations in jumping performance we observed were similar to those reported in soccer players (11% improvement in evening hours) (Reilly et al., 2007) and college students (7-10% improvement in evening hours) (Chtourou et al., 2012). Although, the exact underlying mechanisms are still unknown, this temporal change in jump performance could be explained by fluctuations in core temperature, peaking in the late afternoon (Gharbi et al., 2013; Mhenni et al., 2017). Indeed, previous authors hypothesised (Bernard et al., 1997; Chtourou et al., 2013b) concomitant rises in core temperature and gains in short-term maximal performances were causally related. In this regard, elevations in core temperature could exert a passive warm-up effect enhancing metabolic reactions, increasing the extensibility of connective tissue, reducing muscle viscosity, and increasing the conduction velocity of action potentials (Souissi et al., 2004). Furthermore, diurnal fluctuations in neuromuscular efficiency of postural muscles (*triceps surae)* have been related to variation in central (neural input to the muscles) and peripheral (contractile state of the muscle) mechanisms (Castaingts et al., 2004).

Morning-to-evening neuromuscular changes may also elucidate the improvement in change-of-direction speed we observed, given this physical attribute is influenced by a number of factors, such as linear sprinting speed as well as leg muscle qualities including eccentric and concentric strength, power and reactive strength (Young et al., 2015). Accordingly, the results revealed that zig-zag test performance with and without the ball was significantly better (ES = - 1.17 to - 1.67, *p* < 0.001) in the evening than in the morning. The same observations have been made in female handball players and male soccer players examining modified Agility T-Test and zig-zag test protocols with improvements of 12.1% (ES = -1.58, *p* < 0.001) and 6.3% (*p* < 0.001) (Gharbi et al., 2013; Mhenni et al., 2017) evident in the evening. In addition, *large* to *very large* enhancements in sprint performance were observed during the evening compared to the morning in our study. Similarities in temporal variations evident for the linear sprinting and closed-skill agility tests are not surprising given significant associations reported between linear and change-of-direction speed when measuring total performance times (Gabbett et al., 2008; Sheppard et al., 2006). Collectively, the obtained results demonstrated that time-of-day should be taken into account in the interpretation of the results of anaerobic tests including longitudinal and transversal studies, especially in elite athletes.

Tasks that required a greater degree of

motor control, such as those with a ball, tended to exhibit less temporal changes in performance than tests without a ball (zig-zag test: ES = -1.17 vs. -1.67, 5-m sprint: ES = -1.34 vs. -1.69, 10-m sprint: ES = -1.29 vs. -2.09, 20-m sprint: ES = -1.40 vs. -1.46). Although this is the first study examining diurnal variations in change-of-direction and linear sprint tests with a ball in handball players, our findings are comparable to data reported in soccer players. Specifically, lower improvements in zig-zag test performance in the evening were observed while dribbling a ball with the feet than without dribbling in soccer players (6.7% vs. 4.6% improvement) (Gharbi et al., 2013). Another related study demonstrates no significant temporal effect for juggling performance (ball control with the body and head) and coordination tests (Gharbi et al., 2013). These collective findings may be expected given complex tasks with a higher level of cognitive processing are strongly correlated with psychomotor vigilance and arousal (Neri, 2004; Reilly and Ekblom, 2005; Van Dongen, 2004). Namely, it has been reported complex aspects of performance such as mental arithmetic and short-term memory peak in the early hours of the morning rather than in the evening (Malhotra, 2017). Therefore, short-term specific handball maximal performances requiring cognitive and physical components may have less diurnal variation across the day compared to performance involving mainly physical components.

The presence of circadian rhythm in short-term maximal performances may also depend on sleeping patterns (Drust et al., 2005; Souissi et al., 2013). Partial sleep deprivation has been suggested to affect the typical diurnal changes seen in short-term maximal performance (Souissi et al., 2013). More precisely, Souissi et al. (2013) noted greater temporal changes in anaerobic performance with shorter sleep durations. However, our results indicate short-term maximal performances were not associated with acute prior sleep outcomes (duration and quality). Variations across studies may be due to the wide disparities in sleep quantity as Souissi et al. (2013) restricted sleeping time to 3 h and we allowed participants to adopt regular sleeping behaviours. In addition, Pilcher and Huffcutt (1996) observed less than 5 h sleep in a 24–h period could significantly decrease motor performance. Given none of the participants in the present study reported less than 5 h of sleep, it appears the relatively consistent sufficient sleep duration across the sample may have countered any influence of sleep outcomes on performance. However, more intervention-based studies manipulating sleep behaviours are needed to definitively determine the impact of sleep outcomes on physical performance across the day.

Despite interesting outcomes in this study, some important limitations should be acknowledged. First, we made inferences using the heart rate as a proxy measure of core temperature responses despite responses increasing by 5% in the evening. Second, the nutritional status of participants was not controlled prior to morning and evening testing. Third, although our findings provide valuable insight into diurnal variation of elite male handball players, the applicability of these results remains limited to other ages, playing levels and females. Future studies should focus on determining the influence of nutritional interventions on morning short-term performance to reduce diurnal variations, such as caffeine supplementation. In addition, future studies should identify if training administered in the morning can reduce morning-to-evening differences in handball players.

Conclusion

Short-term maximal performance such as a linear sprint over 5 to 20 m with and without a ball *most likely* varied across the day, with superior performance observed in the evening compared to the morning in elite male handball players. Also, handball-specific closed-skill agility movement without a ball showed *large* diurnal variation, while the same movement pattern with a ball showed smaller (*moderate*) morning to evening changes. Explosive power in the lower-body presented *likely trivial* to *possibly moderate* diurnal variation with superior performance in the evening. These diurnal variations depended on the nature of the performed task, whereby complex skilled-based tasks with a ball exhibited less morning-to-evening variations in performance. Importantly, short-term maximal performance with or without a ball was not associated with sleep quality and quantity in handball players.

Practical application

The present study showed *moderate* to *very large* improvements in a range of vertical jump, change-of-direction, and linear sprint tests in the evening compared to the morning in elite male handball players. Coaching staff of professional handball teams should be aware of diurnal rhythms in players and plan training activities accordingly. In particular, it appears physical performance without a ball is more adversely affected in the morning than skill-based performance with a ball. Based on these results, early conditioning-based training, especially targeting explosive anaerobic tasks, might be appropriate to improve the diminished short-term maximal performance seen in the morning. In support of this notion, previous research shows training in the morning can improve poor morning performances to the same

or higher level as peak performance typically observed in the afternoon and decrease the amplitude of the diurnal rhythm (Chtourou and Souissi, 2012). Resistance training sessions should also be programmed in the morning to improve short-term maximal performances and counteract the diurnal variations and effect of time of day. Furthermore, handball coaching staff should consider physical performance variations across the day when interpreting results of anaerobic tests including longitudinal and transversal studies, especially in elite players. Although non-significant relationships were observed between sleep outcomes and short-term maximal performance across the day, it is important to achieve sufficient sleep quality and quantity during training phases and competition periods for optimal player recovery and health.

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