The association between sleep efficiency and physical performance in taekwondo athletes
Asociación entre la eficiencia del sueño y el rendimiento físico en atletas de taekwondo

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Abstract. Sleep is considered as a part of the recovery process from training, and it is an integral feature in the athlete's continuous training control and monitoring. There is still limited evidence regarding the association between sleep and athletic performance. The purpose of the study was to determine the association between sleep efficiency and physical performance in taekwondo university athletes monitored throughout a training macrocycle. Eight males and four females (age = 20.9 ± 3.3 years.) trained 13-weeks divided in ten overload and three tapering or reduction of the training load phases. During tapering, 50% of the participants reduced their training linearly by 50% from the previous overload phase. The other 50% of participants maintained the same training volume. Physical performance measures were kicking movement time, kicking response time, muscular strength, and squat-, countermovement-, drop-, and arm counter-movement jumps. Sleep efficiency was recorded by accelerometry and all dependent variables were measured before training, at the end of the first mesocycle, and twice per week during the three weeks of tapering. Group analyses showed no significant associations between sleep efficiency and physical performance. Individual analysis showed that three participant's performance was related to sleep efficiency. The current evidence does not support the general contention that sleep efficiency is related to physical performance.
Keywords: Actigraphy, exercise physiology, biological rhythms, athletes, combat sports.

Resumen. El sueño es considerado como parte del proceso de recuperación del entrenamiento, y es una característica integral en el control y monitoreo continuo del entrenamiento del atleta. No obstante, todavía hay evidencia limitada respecto a la asociación entre el sueño y el rendimiento atlético. El propósito del estudio fue determinar la asociación entre la eficiencia del sueño y el rendimiento físico en atletas universitarios de taekwondo monitoreados a lo largo de un macrociclo de entrenamiento. Ocho hombres y cuatro mujeres (edad = 20.9 ± 3.3 años) entrenaron durante 13 semanas, de este periodo diez semanas fueron de sobrecarga y tres de puesta a punto o disminución de la carga de entrenamiento. Durante la puesta a punto, el 50% de los participantes redujo su entrenamiento de forma lineal en un 50% respecto a la fase de sobrecarga anterior. El otro 50% de los participantes mantuvo el mismo volumen de entrenamiento. Las medidas de rendimiento físico fueron el tiempo de movimiento de pateo, el tiempo de respuesta de pateo, la fuerza muscular y los saltos desde sentadilla, con contramovimiento, con caída y contramovimiento con brazos. La eficiencia del sueño se registró por acelerometría y todas las variables dependientes se midieron antes del entrenamiento, al final del primer mesociclo y dos veces por semana durante las tres semanas de puesta a punto. Los análisis de grupo no mostraron asociaciones significativas entre la eficiencia del sueño y el rendimiento físico. El análisis individual mostró que el rendimiento de tres participantes estaba relacionado con la eficiencia del sueño. La presente evidencia no respalda la premisa de que la eficiencia del sueño está relacionada con el rendimiento físico.
Palabras clave: Actigrafía, fisiología del ejercicio, ritmos biológicos, atletas, deportes de combate.

Introduction

The control and evaluation of the bodily responses and adaptations to training stimuli are essential to determine the effectiveness of an athlete's preparation process. Based on a timely assessment, modifications and fine-tuning of the orientation and magnitude of the training loads are warranted. This practice facilitates the optimal development of physical and technical-tactical capabilities, and therefore, the expected sports performance outcome (Borresen & Lambert, 2009; DeWeese, Gray, Sams, Scruggs, & Serrano, 2013; Viru & Viru, 2001).

Sleep is considered a homeostatic controlled behavior in which there is a reduced state of movement and sensory response capacity, and has been related with cognitive and physiological processes, especially with recovery. Therefore, coaches have included sleep as a training variable given its potential to generate relevant information in the control of the training process (Fullagar, Duffield, et al., 2015; Fullagar, Skorski, et al., 2015).

Deleterious physical performance and muscle recovery has been reported with sleep restriction and deprivation

(Knowles, Drinkwater, Urwin, Lamon, & Aisbett, 2018; Mougin et al., 1991; Pilcher & Huffcutt, 1996). Recently, partial (4-h) and total (0-h) sleep deprivation did not affect aerobic performance or blood lactate concentrations compared to regular sleep time condition (8-h) (Aburto, Miranda, Bárcenas, Espinoza, & Arrayales, 2018).

A good sleep quality or efficiency has been related to better mood states (Lastella, Lovell, & Sargent, 2014), improved cognitive performance (Taheri & Arabameri, 2012; N. F. Watson et al., 2015), faster recovery time in damaged muscle tissues (Skein, Duffield, Minett, Snape, & Murphy, 2013), and enhanced immune response (Fondell et al., 2011; Vgontzas et al., 2004). Indeed, it has been reported that by increasing the period in which athletes stay in bed relates to improved performance in specific sports (Juliff, Halson, Hebert, Forsyth, & Peiffer, 2018; Mah, Mah, Kezirian, & Dement, 2011).

Current evidence suggests a potential association between training load and sleep habits. For example, swimmers chronically performing distances greater than 200 m reported a higher number of episodes of pain during sleep and getting up earlier than those swimming shorter distances (Stavrou et al., 2019); however, acute intense exercise in rugby players was associated to increased sleep duration and quality (Saidi et al., 2019). Therefore, new recovery strategies based on sleep duration and quality are being tested. For

instance, Abdessalem et al. (2019), designed an experiment in which 18 athletes performed an aerobic exercise test following 25-min napping in the afternoon (1:00, 2:00, and 3:00pm) or a control condition (i.e., no napping). The exercise performance was better after napping at 2:00 and 3:00 pm compared to no napping at all or napping at 1:00 pm.

To date, only one study has evaluated the effect of manipulating training loads on sleep during a competitive season (Taylor, Rogers, & Driver, 1997). Sleep quality was measured in seven female swimmers before training season, at peak training season and during tapering. The number of movements during sleep was higher at the beginning of the training season (10.3%, p < .05) and during peak training (11%, p < .01) compared to tapering. In addition, slow-wave sleep was higher at the beginning of the training season (26%, p < .01) and during peak training load (31%, p < .05) phases compared to tapering (16%). This sleep pattern supports the theory of reduced restorative slow-wave sleep during periods of diminished physical needs (Taylor et al., 1997).

A recent report showed that nearly 16% of elite athletes show clinically relevant sleep problems (Biggins et al., 2019), which are likely responsible for impaired mood states and eventually poor performance. Although both athletes and coaches recognize the importance of sleep for potential optimal sports performance, it is peculiar that there have been only a few studies investigating the influence of the quantity and quality of sleep on performance in cohorts of athletes (Aburto et al., 2018; Fullagar, Duffield, et al., 2015; Fullagar, Skorski, et al., 2015; Juliff et al., 2018; Knufinke et al., 2018; Staunton, Gordon, Custovic, Stanger, & Kingsley, 2017; N. F. Watson et al., 2015). Therefore, the purpose of this study was to determine the immediate correlation between sleep efficiency and physical performance throughout a training season in taekwondo athletes.

Methods

Participants

Volunteers were eight males and four females taekwondo athletes competing for the University of Costa Rica (UCR) team. Male participants were 21.2 ± 3.6 years of age, 75.5 ± 16.3 kg body weight, 174.4 ± 7.0 cm body height, 17.5 ± 8.4 body fat mass (%), and a VO$_2$max of 53.5 ± 5.0ml·kg^{-1}·min^{-1}. Female participants were 19.5 ± 1.3 years of age, 51.7 ± 2.2 kg body weight, 160.6 ± 5.1 cm body height, 26.5 ± 6.1 body fat mass (%) and a VO$_2$max of 45.5 ± 4.1 ml·kg^{-1}·min^{-1}.

Athletes were allowed to participate in the study if they met the following inclusion criteria: a) had between 18 and 29 years of age, b) belong to the UCR taekwondo team, c) had time availability to participate in the study, and e) had no recognized sleep disturbance. Volunteers were not allowed to participate in the study if they were sick, injured, or consumed any sleep medication. Participants read and signed an informed consent approved by the Scientific Ethics Committee of the University of Costa Rica.

Measurement instruments

Anthropometric measures body height (cm) and body weight (kg) were measured with a stadiometer and an electronic scale, respectively. Body fat (%) was determined by dual X-ray absorptiometry (DXA, Lunar Prodigy Advance, General Electric, Madison, WI, USA), with enCORE 2011 software, version 13,60,033.

Aerobic capacity was determined by the maximal oxygen consumption (VO$_2$max) and it was measured with the Bruce protocol using a treadmill COSMOS (Care Fusion, Germany), and a breath-by-breath Jaeger CPX metabolic cart (CareFusion Corporation, San Diego, CA). The VO$_2$max was recorded as ml·kg^{-1}·min^{-1}.

Leg strength was measured with a digital dynamometer MicroFet 2™ (Hoggan Health Industries, UT). Participants performed a knee extension on a biomechanical machine, and the highest score was recorded in kg. Appropriate reliability has been reported for this test; the intraclass correlation coefficient (ICC) for intra-observer ranged from .82 to .93, for inter-session from .70 to .92 and inter-observer reliability was .77 (Kelln, McKeon, Gontkof, & Hertel, 2008). Leg power was measured on a Kistler® force plate (Kistler Instrumente, Winterthur, Switzerland).

The jump tests performed were the counter-movement jump (CMJ), counter-movement jump with free arms (ACMJ), squat jump (SJ), and the drop jump (DJ). For the CMJ, the athlete started from an upright standing position and hands in the hips, made a preliminary downward movement by flexing at the knees and hips, then immediately extended the knees and hips again to jump vertically up off the ground. For the ACMJ, the athlete repeated the same movement as for the CMJ; however, the arms were free at all times, allowing the athlete to swing them to reach a higher impulse off the ground. The SJ started on a standing position, body erect, feet slightly narrower than shoulder width, hands in the hips, and head forward. The athlete was instructed to squat down, bending the hips with back straight and looking forward. With a quick pause at the bottom, the athlete pushed up with feet into a jumping motion. Finally, for the DJ, the athlete stood still on top of a wooden box (40 x 35 x 30 cm), and then performed a drop on the force plate and then a vertical push-off action as quickly and as explosively as possible in order to reach the highest possible height. Three attempts were allowed on each jump type and the best performance was recorded in cm and used for statistical analyses.

Taekwondo-specific drills were assessed using a Fitlight Trainer System® (Fitlight Sports Corp., Ontario, Canada). Two kicking response time drills were measured, the kicking movement time (KMT) and the kicking response time (KRT). The automated system consisted of circular sensors placed conveniently according to the drill evaluated, and these sensors were activated and deactivated when a beam of light was interrupted by the performer's kick. For the KMT drill, the athlete was instructed to use the dominant leg in a circu-lar kick (i.e., *«Bandal Chagui»*) to hit a single focus paddle target placed at 1.10 m height and then place the foot in the floor; then immediately, use the same leg in a circular kick to the head (i.e., *«Tolio Chagui»*) to hit another single focus paddle target placed at 1.60 m height. Three attempts were allowed and the best performance in seconds was recorded for further statistical analyses. For the KRT drill, two single focus paddle targets were located at 1.10 m height and two at 1.60 m height. Sensors were placed next to each paddle and

randomly programmed (i.e., left, right, up, down) to be activated 0.05 s after a target was deactivated. Thus, when one of the four sensor lights was randomly turned on, the athlete had to kick the paddle to turn the light off, and 0.05 s later, a second light was randomly turned on, and so forth, until 10 lights were turned on and off. Three attempts were allowed and the best performance in seconds was recorded for further statistical analyses.

Sleep efficiency was measured by accelerometry using an ActiGraph device, model wGT3X-BT and the ActiLife 6 (ActiGraph™, Pensacola, FL) software. Athletes slept wearing an accelerometer on their wrist the night before testing. Sleep efficiency was defined as the percentage of time between the sleep onset and final awakening, which was spent asleep (de Souza et al., 2003).

Procedures

The volunteers were required to complete a 5-week baseline where they avoided performing any type of structured physical training. Then, all the participants completed 13-week macrocycle comprised of 6-weeks of accumulation, 4-weeks transmutation, and 3-week realization mesocycles. All athletes underwent the same training sessions during the accumulation and transmutation mesocycles. The experimental setting continued at the beginning of the realization mesocycle (i.e., tapering), by matching athletes by gender and session attendance to finally randomly assign them to either an experimental condition where training volume was maintained (i.e., weekly training minutes) (Group with No Reduction, GNR), or an experimental condition where training volume was linearly-reduced daily 3.33% until the 50% from the original training volume was reached at the end of the taper (Group with 50% reduction, G50%) (Bosquet, Montpetit, Arvisais, & Mujika, 2007). Both groups (GNR and G50%), complete a tapering strategy, since from a physical and technical training the point of view, the work density decreased and the speed drills were emphasized over those of strength and power that had prevailed in the previous mesocycles.

Dependent variables were measured in nine different moments; at baseline, at the beginning of the accumulation mesocycle, at the beginning of the transmutation mesocycle, and finally, measures were obtained at the realization or tapering mesocycle, where two assessments per week were performed for a total of six measurements. The dependent variable measurement order was KMT, KRT, lower-body strength, SJ, CMJ, ACMJ, and DJ. The measurement of these variables was always completed before the respective training session (these variables were measured at each of the nine measurement times described before). A schematic summary of the research protocol is presented in figure 1.
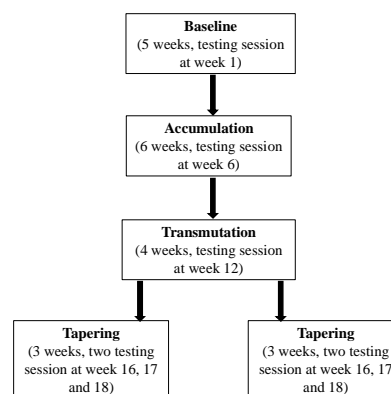

Figure 1. Research protocol schematic summary.

Statistical analysis

Statistical analysis was performed with the IBM-SPSS Statistics, version 21 (IBM Corporation, Armonk, New York). Descriptive statistics are presented as mean and standard deviation (M ± SD). Given the sample size, Spearman correlation coefficients were calculated between sleep efficacy and other variables across nine measurements. Group (nine measurements), subgroup (i.e., GNR vs. G50%) and individual correlation analyses were performed on the dependent variables (KRT, KMT, SJ, CMJ, ACMJ, DJ, VO$_2$max).

Results

In the group analysis, there were found significant negative correlations between sleep efficiency and KRT and all vertical jumps (Table 1), but only in the last measurement at end of tapering period. This correlation pattern showed that better sleep quality deteriorated some physical performance variables. In this regard, it must be interpreted that a longer KRT implies a worse performance since the movement is slower; therefore, although the correlation coefficient is positive, it should also be considered as a negative.

The GNR reported four significant correlation coefficients between sleep efficiency (79.0 ± 7.2%) and KRT (9.4 ± 1.5 s; r = -.83; p = .04) in the baseline, sleep efficiency during the sixth tapering (79.2 ± 10.1%) and KRT (9.6 ± 1.1 s; r = .94, p = .01), CMJ (31.2 ± 6.7 cm; r = -.83, p = .04) and DJ (29.9 ± 6.1 cm; r = -.93, p = .01). In the G50% during tapering only one significant correlation was observed between sleep efficiency (87.7 ± 5.3%) and KMT (1.3 ± 0.1 s; r = .90, p = .04) when measured at the fourth tapering measurement.

Individual analyses showed significant correlation coefficients between sleep efficiency and KRT and explosive strength in four participants. Participant 2 in the G50% showed a negative correlation between sleep efficiency (76.5

Table 1.
Correlation coefficients between sleep efficiency and physical performance variables for all participants.

	Baseline	Accumulation	Transmutation	Tapering 1	Tapering 2	Tapering 3	Tapering 4	Tapering 5	Tapering 6
				Sleep efficiency					
KRT	-0.41	-0.35	0.02	0.02	-0.02	0.30	-0.45	-0.05	0.79*
KMT	0.02	-0.14	-0.08	0.28	0.03	0.38	0.09	0.16	0.42
Strength	-0.20	-0.09	-0.28	-0.03	-0.47	-0.38	-0.50	0.22	-0.54
SJ	-0.05	0.18	0.07	-0.05	-0.50	-0.36	0.16	-0.09	-0.72*
CMJ	-0.22	-0.01	-0.01	-0.43	-0.47	-0.36	0.05	-0.13	-0.81*
ACMJ	-0.15	0.08	-0.01	-0.42	-0.60	-0.30	-0.02	-0.10	-0.68*
DJ	-0.11	0.20	0.08	-0.49	-0.52	-0.27	0.13	-0.15	-0.82*
VO$_2$max	-0.07	-0.04							-0.27

Note 1: KRT: kicking reaction time; KMT: kicking movement time; SJ: squat jump; CMJ: counter-movement jump; ACMJ: counter-movement jump with arms; DJ: drop jump; VO$_2$max: maximal oxygen consumption.
Note 2: The VO$_2$max was not measured from the second mesocycle to the fifth tapering; therefore, open spaces are shown in the table.
Note 3: * p = 0.05.

± 5.3%) and performance in KRT (7.9 ± 0.6 s; r = .94, p = .01), CMJ (41.1 ± 2.1 cm; r = -.82; p = .04) and DJ (40.6 ± 1.2 cm; r = -.88; p = .02) respectively. For all variables, an optimal performance was correlated to low sleep efficiency. Participant 4 in the G50% showed a correlation between sleep efficiency (83.2 ± 6.6%) and KMT (1.3 ± 0.1 s; r = -.84; p = .01), showing better kicking times with increased sleep efficiency. Participant 11 in the GNR showed a correlation between sleep efficiency (89.0 ± 5.9%) and SJ (20.4 ± 1.4 cm; r = .96, p = .01), ACMJ (21.0 ± 1.6 cm; r = .82, p = .01) and DJ (20.1 ± 1.1 cm; r=.74; p = .04). Participant 12 in the GNR showed a correlation between sleep efficiency (82.1 ± 7.08%) and KMT (1.4 ± 0.0 s; r = -.71; p = .03). For participants 1, 3, 5, 6 in the G50% and participants 7, 8, 9, 10 in the GNR, sleep efficiency was unrelated to physical performance.

Discussion

Our aim was to determine the correlation between sleep efficiency and physical performance in taekwondo university athletes. The main finding of the study was that individual analyses showed correlations between physical performance and sleep efficiency only in some athletes. Sleep efficiency was unrelated to physical performance in the overall sample, with the exception of the second and last tapering measurements and inconsistently for some of the performance variables. Some participant's performance was unaffected by sleep efficiency.

It is important to take into consideration that the study was carried in a natural training setting, where only the training volume was manipulated during the tapering phase to intensify the reduction in training load in one of the groups. Therefore, there could be multiple factors capable of intervening in the athlete's sleep.

Group analysis showed an acute correlation between sleep efficiency and physical performance in some of the variables studied, especially during the sixth measurement of the tapering phase in the GNR. The individual analysis allowed us to identify that only for some competitors, sleep efficiency becomes relevant for improving performance. Recently, 98 elite athletes from different sports were monitored on sleep quantity and sleep stages on three non-consecutive nights within a 7-day monitoring period and results were related to performance tests (Knufinke et al., 2018). Results suggested that psychomotor vigilance was affected to a greater extent than athletic performance by natural sleep quantity. The authors presented the concept of «accumulated sleep debt» as a potential trigger for impaired physical performance, by suggesting that one night of compromised sleep may not be immediately deleterious to performance; however, extreme sleep loss may have more severe consequences to performance (Knufinke et al., 2018). At this point, more elaborated experimental research is required to confirm and investigate the causality of the correlations between sleep and performance.

The lack of a differentiated effect according to the tapering model followed is consistent with the results reported by Jafer, Mondal, Abdulkedir, and Mativananan (2019), who analyzed the effect of a tapering condition characterized by high intensity and a low volume and another strategy using a high intensity and a moderate volume. The runners in the study showed better red blood cell mass, hemoglobin and hematocrit values, regardless of the reduced volume during tapering. These findings support the relevance of a reduction in the training volume during tapering. However, Jafer et al. (2019), suggest that the way in which tapering is done is possibly irrelevant. This possibility might explain the similar response found in the present study between the GNR condition and the G50%.

The absence of a consistent correlation between sleep efficiency and physical performance is opposed to that reported by Brandt, Bevilacqua, and Andrade (2017), who demonstrated a correlation between sleep quality, sports performance and mood. However, in that study sleep quality was measured using a Likert-type scale and performance in a dichotomous way (win or lose), while in the present investigation, sleep quality and physical performance were analyzed with objective measurement instruments unaffected by external factors. Recently, a group analysis comparing top and bottom-performance netball teams showed no significant differences in sleep efficiency (Juliff et al., 2018). However, the best ranked teams slept longer, spent more time in bed and had better subjective sleep ratings than the worst ranked teams.

Sleep has been identified by researchers, elite athletes and coaches as a critical component for training and competition (Halson, 2014; Lastella, Roach, Halson, & Sargent, 2014; Simpson, Gibbs, & Matheson, 2017; Skein et al., 2013; A. M. Watson, 2017); however, the study of this psychophysiological variable and its correlation with sports performance is still in its initial stages (Fullagar, Skorski, et al., 2015; Halson, 2014). The equivocal findings reported by others on the acute association between sleep efficiency and physical performance are consistent with the present results (Staunton et al., 2017); there were correlation between these variables only at certain measurements periods during the intervention and only in some individuals, suggesting a large inter-individual variability between these variables.

When analyzing the report of 103 marathon runners on the characteristics of sleep on the night before a race (Lastella, Lovell, et al., 2014), it was possible to identify that negative mood such as fatigue and precompetitive tension correlated negatively with the quality of sleep and the total of the minutes that they slept. In addition, the vigor was positively correlated with the quality of the sleep. Nevertheless, individual's performance was unrelated to sleep quality.

Ten males performed maximum speed tests on a cycle ergometer following 8-h sleep and another day when they were sleep-deprived (Ritsche, Nindl, & Wideman, 2014). Results comparisons showed no significant mean differences in maximum power (p = .18), peak power (p = .68), fatigue index (p = .55), total work (p = .18), and VO$_2$peak (p = .43). Similar findings in anaerobic power have been reported in 18 college athletes following one-night of sleep deprivation or one night of normal 7- to 8-h sleep (Taheri & Arabameri, 2012). However, performance on a reaction time tests was impaired following sleep deprivation, which suggest that gross and fine motor skills might be affected differentially by sleep deprivation (Taheri & Arabameri, 2012). (Skein et al., 2013) showed an impaired CMJ and a color and word cognitive

recognition test results ($p < .01$) following one-night sleep deprivation compared to normal sleep time; however, maximal contraction strength was similar between both experimental conditions.

Patrick et al. (2017), also reported inconsistent results following one-night sleep deprivation in 24 participants who subsequently performed a submaximal test for 8-min on a cycle ergometer. Participants in the experimental condition increased their reaction time ($p = .003$) and systolic blood pressure ($p = .012$) compared to controls who did not have sleep deprivation; however, there were no group differences in heart rate ($p = .08$), lung function ($p = .30$), perceived exertion ($p = .56$), working memory ($p = .30$), and executive function ($p = .18$).

A methodological consideration is in order regarding research in sleep and human performance. First, most (or all) studies have used a group analysis approach; however, individual analysis might be more powerful and valid. It is likely that valuable information explaining the correlation between sleep and sports performance has not been identified yet. In other words, researchers and coaches need to identify individual athlete's features that might be related to their physical performance. In the context of the present study, the group and individual analysis represent a methodological contribution to the body of knowledge in the field.

Second, the majority of research in the field has used the sleep-deprivation vs. physical performance paradigm (Goh, Tong, Lim, Low, & Lee, 2001; Ritsche et al., 2014; Skein et al., 2013; Souissi et al., 2008; Taheri & Arabameri, 2012); thus, the study of the association between sleep quality vs. physical performance in athletes training on their natural context represents an important contribution to the scientific literature in the area and a promising line of study. This is a new paradigm that requires further inquiry.

In conclusion, sleep efficiency was unrelated to physical performance measures in a group of taekwondo university students. At an individual level, some students might improve or impair their performance depending on the sleep efficiency measured the night prior to a physical performance challenge. The mechanisms explaining these group and individual associations deserve further explanation.

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