NTNU
Kunnskap for en bedre verden

The effect of sleep deprivation on muscular strength performance

Bachelor's Thesis in Human Movement Science

BEV2900 - Spring 2019

Department of Neuromedicine and Movement Science, NTNU

Candidate number: 10024, 10048

Number of words abstract: 162/144

Number of words in thesis: 4065

Abstract

Objective: The aim of this literature review was to evaluate the effect of sleep deprivation (SD) on muscular strength performance.

Method: A literature search was conducted in PubMed, Scopus, Google Scholar and MedLine. Studies were chosen based on title, abstract and content. The inclusion criteria were; injury free male and females, experimental studies, measures of maximal- and submaximal strength, and all types of muscle contractions. Seven studies were included, all in English and peer reviewed.

Results: Three studies showed that SD decrease strength performance, further, two of these applied complex movements for testing and all three used partial SD. In contrast, four studies showed small but non-significant negative effects, three of them applied total SD, whereas three out of four used simple movements. Further, two small, non-significant results also indicated positive effect on strength performance after SD.

Conclusion: Our findings show that SD may have a negative effect on strength performance. However, there are inconsistencies in the literature, making further studies required.

Abstrakt

Formål: Målet med denne litteraturgjennomgangen var å evaluere effekten av søvnmangel (SM) på muskelstyrke.

Metode: Et litteratursøk ble utført i PubMed, Scopus, Google Scholar og MedLine. Studier ble valgt ut fra tittel, abstrakt og innhold. Inkluderingskriteriene var; skadefrie menn og kvinner, eksperimentelle studier, måling av maksimal- og submaksimal styrke og alle typer muskelkontraksjoner. Syv studier ble inkludert, alle var på engelsk og fagfellevurdert.

Resultater: Tre studier viste at SM reduserer muskelstyrken, to av disse brukte komplekse bevegelser for testing og brukte delvis SM. I kontrast viste fire studier små, men ikke signifikant negativ effekt, hvor tre av dem anvendte total SM og tre brukte enkle bevegelser. To små ikke-signifikante resultater indikerte også positiv effekt på styrkeprestasjon etter SM.

Konklusjon: Våre funn viser at SM kan ha negativ effekt på muskelstyrke. Imidlertid er det uoverensstemmelser i litteraturen, noe som gjør det nødvendig med flere studier.

Content

Key words: *Performance; strength; strength training; force; force production; sleep; sleep restriction; sleep deprivation; sleep disturbance.*

Introduction

Elite sport competition may represent a substantial challenge for athlete's sleep quality (1, 2). For instance, some evidence indicates that sleep deprivation (SD) is common among athletes (1), possibly explained by anticipation before competition (3), jet lag due to travelling (4), sleeping in unfamiliar surroundings (5), personal life stressors (6) or high training load (7). It has been suggested that increasing total sleep time improves physical performance (8) and that sleep and recovery play a large role in athletic adaption to training and ultimately performance (6, 9), indicating that sufficient sleep is vital for optimal sports performance in both competition and training (10, 11).

Further, an important factor for optimal sport performance is muscular strength, as it has shown to have a positive effect on sprinting, jumping, and change of direction (12). Previous findings have shown that SD may affect strength, (2, 13) but conflicting results have been reported (14). The explanation behind these inconsistent results remain uncertain, but may be linked to sample sizes, different testing methods or other distorting factors. For instance, a skill-based effect has been suggested, with less response from SD for single joint movements (e.g. bicep curl), compared to a skill based, complex, multi joint movement (e.g. deadlift) (15). An alternative factor may be timing of sleep restriction, as early rising may be more detrimental to muscular strength than late bedtime and normal rising (1, 10), furthermore a time of day effect has been reported with strength increasing towards the evening (14). Moreover, motivation decrease caused by SD is proposed to be one of the most important factors in reduced strength performance (6, 7, 13, 14, 16, 17). Correspondingly, motivation has been found to be affected through increased fatigue (17, 18).

Several previous reviews have included aerobic endurance, balance and power, whilst few have been focused on strength alone. Further, the uncertainty about the influence of SD on muscular strength performance emphasizes the importance of summarizing the literature on this topic.

Thus, the aim of this review is to examine the effect of sleep deprivation on muscular strength performance.

Methods

We collected literature in the period between 28.01.2019 and 12.02.2019. The following databases were used: PubMed, Scopus, Google Scholar and MEDLINE. The search words were:

[*Performance; strength; strength training; force; force production; sleep; sleep restriction; sleep deprivation; sleep disturbance*].

The search words were used in combination with either "AND" or "OR". The selection process of studies began with screening of titles and abstracts. Second, the whole study was read to make sure they met the inclusion criteria (table 1). All studies were examined thoroughly by both authors. Studies before 2005 were excluded to focus on up-to-date information about this topic. All studies were peer-reviewed and written in English.

A total of seven studies were included for this literature review.

Table 1 – the inclusion and exclusion criteria.

Category	**Inclusions**	**Exclusions**
Study populations	Injury free males and females. Strength and sports athletes.	Children (average of ≤16 years), elderly (average of >40) sickness, drugs*, medicine-users.
Study design	Experimental studies.	Observational studies, systematic review, meta-analysis.
Results	Maximal strength, sub-maximal strength, all types of muscle contractions.	Blood samples (testosterone, cortisol etc.), power output.

*Four smokers in Vaara et al. (16), were included as they were categorized as healthy and physically active subjects.

Results

Bambaeichi et al. (2005). The influence of time of day and partial sleep loss on muscle strength in eumenorrheic females. (17)

Study population (average ± standard deviation): 8 voluntary females with a normal menstrual cycle (age 30 ± 6 years; body mass 67 ± 5.0 kg; height 162 ± 6 cm). They were injury free and had normal sleeping schedules.

Protocol: Used a counterbalanced experimental study design. The SD-group had 2.5 hours of sleep, from 3:00 to 5:30. In the no sleep deprivation (NSD)-group they went to sleep between 22:30 to 23:30 and woke up at 5:30. The testing was performed at 6:00 and 18:00. They had 24 hours between the NSD night and SD night. Subjects attended two practice sessions. They measured both isometric and isokinetic strength using an isokinetic dynamometer (Lido Active, Loredan, Davis, Ca, USA). The isokinetic measures were performed at 1.05 and 3.14 radian/seconds giving results in Newton meter (Nm). To control for motivation, on the voluntary isometric contraction of the extensor muscle, electrodes were fitted to deliver 250 volts with pulses of 200 microseconds. They had three attempts. The tests were followed by three minutes rest period, before next attempt.

Results: There were small differences between SD and NSD with some results indicating higher force production for SD than NSD (dynamic knee extension, both speeds and both times of day) and vice versa (The electrode tests resulted in higher strength for SD (06:00: NSD; 146 ± 28 Nm, SD; 151 ± 20 Nm, 18:00: NSD; 145 ± 33 Nm, SD; 155 ± 23 Nm). However, no significant effect were found between the two groups ($p > 0.05$).

Blumert et al. (2007): The Acute Effects of Twenty-Four Hours of Sleep Loss on the Performance of National-Caliber Male Collegiate Weightlifters. (6)

Study population (average ± standard deviation): 9 voluntary collegiate national-caliber male weightlifters (age 20.7 ± 1.2 year; body mass 102,3 ± 28,1 kg; height 178.6 ± 7.2 cm). All subjects slept habitually 8 ± 1 hours/night and had minimum one-year experience with weight lifting.

Protocol: Used a randomized counterbalanced design. The SD-group got instructions to meet at the laboratory at 23:30 where they would be monitored by researchers to obtain total SD. NSD-group got instructions to go to bed at 24:00 and wake up at 08:00 at home. They were instructed to show up for testing at 09:00. First test determined their 1 repetition maximum (1RM) in snatch, clean and jerk, and front squat through a modified 1RM protocol where they performed maximal attempts with progressive resistance until there were two consecutive misses. For test two they performed the 1RM protocol again, test three was identical to test two, except that all the subjects switched group. The tests were separated by seven days. ANOVA tests compared groups.

Results: The 1RM snatch showed no effect (NSD; 97.78 ± 17.87 kg, SD; 97.78 ± 17.43 kg, $p > 0.05$) for the clean and jerk 1RM it decreased slightly (NSD; 116.67 ± 17.85 kg, SD; 115.56 ± 16.99 kg, $p > 0.05$). For the front squat 1RM, the SD group lifted more (NSD; 134.44 ± 22.43 kg, SD; 137.5 ± 22.43 kg, $p > 0.05$). Total volume load decreased as well (NSD; 4272.78 ± 1077.87 kg, SD; 4032.5 ± 843.05 kg, $p > 0.05$). However, no significant effect was found.

Brotherton et al. (2019): Effect of two nights partial sleep deprivation on an evening submaximal weightlifting performance; are 1 h powernaps useful on the day of competition? (1)

Study population (average ± standard deviation): 15 voluntary male weightlifters (age 22.7 ± 2.5 years; body mass 89.0 ± 13.8 kg; height 182.4 ± 7.5 cm). All subjects slept ~ 8 hours/night, reported no sleep problems and had minimum 2-year experience in strength training.

Protocol: Used a counterbalanced experimental design. Subjects were randomized into three different groups with one week between testing; NSD-group, SD-group and SD with nap. SD with nap was excluded. NSD-group, retiring to sleep at 23:00, rising at 06:30. SD-group, retiring to sleep at 03:30, rising at 06:30, this took course over two consecutive nights. The subjects completed a 1RM protocol for bench press and leg press and had four familiarization sessions prior to the experiment. In the period between trials the subjects were informed to live like normal. Testing was done using one repetition at 40%, 60% and 80% of their 1RM for bench press and leg press. A force-velocity linear encoder (Muscle Lab, Ergotest version 4010, Norway) measured the force in newton (N). Hand grip strength measured with hand dynamometer (Takei Kiki Kogyo, Japan). The highest of three attempts were further analyzed. ANOVA was used for comparing groups.

Results: There was significant effect of SD for hand grip strength (NSD; 43.9 ± 3.8 N, SD; 42.47 ± 3.1 N, p=0.019) and for bench press (NSD; 567 ± 140 N, SD; 548 ± 138 N, p=0.003). There was no significant effect of SD for leg press (NSD; 1894 ± 518 N, SD; 1762 ± 476 N, p=0.062).

Cook et al. (2012): Acute Caffeine Ingestion's Increase of Voluntarily Chosen Resistance-Training Load After Limited Sleep. (7)

Study population (average ± standard deviation): 16 voluntary male rugby players (age 20.9 ± 0.9 years; body mass 97 ± 8 kg; height 185 ± 6 cm), minimum of two years of training experience.

Protocol: Used a randomized, double blind, placebo-controlled, balanced trial study design. Participant logged their nightly sleep and were asked to show up for testing two times when they had logged 8 or more hours of good sleep (NSD), and two times when they had less than 6 hours (SD), with minimum 3 days apart. All subjects tested their 1RM for squat, bench press and barbell rows in the week preceding the experiment. Testing was done at the gym they normally trained at. Testing was done with 85% of the previous measured 1RM for 4 sets. Each set consisted of as many reps as possible without failing with 90 seconds of rest between. T-test for analysis.

Results: Showed SD significantly lower than NSD for total repetitions and load (Effect size: 2.33, p < .001). Significant negative effect was seen in all three lifts, but more so in the squat, compared to bench press and row.

Ridha et al. (2016): Effects of one-night sleep deprivation on selective attention and isometric force in adolescent karate athletes. (11)

Study population (average ± standard deviation): 12 voluntary karate athletes (age 16.2 ± 2.5 years; body-mass 61.7 ± 11.5 kg; height 170.5 ± 5.4 cm). All subjects had minimum three years of experience.

Protocol: Used an experimental crossover study design. They first did a reference night, where the athletes slept at home, bedtime between 23:00-00:00 and wake up time 07:00-08:00. Then they did tests at 08:00-09:00, 12:00-13:00 and 16:00-17:00. The next night they spent awake in a laboratory and they did tests at the same time as the previous day, therefore corresponding to 24, 28 and 32 hours of total SD. An isometric dynamometer (Ergo System, Globus, Codogne, Italy) was used to measure strength and isometric force in dominant arm biceps for three seconds.

Results: After total SD the maximal force production dropped slightly compared to NSD for the morning and midday test but increased for the evening test (8:00-9:00; NSD; 436 ± 52 N, SD; 428 ± 50 N. 12:00-13:00; NSD; 442 ± 57 N, SD; 425 ± 44 N. 16:00-17:00; NSD; 424 ± 45 N, SD; 454 ± 54 N, $p > 0.05$). The effects were however not significant. One subject did not make it to 12:00-13:00 SD test and 8 subjects did not make it to 16:00-17:00 SD test.

Souissi et al. (2013): Effects of Time-of-Day and Partial Sleep Deprivation on Short-Term Maximal Performances of Judo Competitors. (10)

Study population (average ± standard deviation): 12 voluntary male active judo competitors (age 18.6 ± 2.4 years; body-mass 77.1 ± 10.7 kg; height 177.8 ± 5.8 cm). Subjects had normal sleeping routines.

Protocol: Used a randomized crossover study design. For NSD, the participants slept in the lab from 22:30 to 06:00, in the next two parts, the participants were either deprived of sleep in the beginning of the night (SDb) or the end of the night (SDe). For SDb they came to the laboratory at 22:00, and were not allowed to sleep until 03:00, they then slept till 06:00. For SDe they came to the laboratory at 22:00 and went to sleep at 23:00, and was waken up at 02:00, and did not sleep thereafter. There was a week between each part, and it was organized in a random order. They had one session in the morning at 09:00-10:00 and one in the afternoon at 16:00-17:00. They were tested before and after 5 minutes of judo combat on each occasion. They had 3 attempts measuring hand grip strength with a hand dynamometer (T.K.K. 5401; Takei, Tokyo, Japan), and maximal voluntary contraction (MVC) of the elbow flexor of the dominant arm at 90 degrees measured by a strain gauge and further analyzed with available software (TCS-SUITE 400; Globus, Italy). The MVC was determined at the highest reading during the 5 seconds the test was performed. They had three attempts with a rest period of 2 minutes before each attempt.

Results: The study found that SDe had a significant effect on strength in the afternoon (3.1-8.4% decrease for hand grip strength, 15-24% decrease for MVC, $p < 0.001$) when compared to NSD. SDb showed no significant effect between the two groups.

Vaara et al. (2018): 60-hour sleep deprivation affects submaximal but not maximal physical performance. (16)

Study population (average ± standard deviation): 20 voluntary male cadets (age 26 ± 2 years; body mass 79.6 ± 11.1.kg; height 177 ± 1 cm). The study had four smokers, but they were categorized as “good health”. All subjects slept 6:52 ± 2:28 hours/night.

Protocol: Used a quasi-experimental one-group design. They were tested for maximal strength and electromyography (EMG) with bipolar surface electrodes (Blue sensor M, Ambu A7S, Ballerup, Danmark) of the knee extensors 3 days prior to the experiment and immediately after the 60 hours SD period, using a specifically constructed chair with strain gauge. Maximal isometric knee extension force was measured at knee joint angle of 107 degrees. Compatible Signal 4.0 (Cambridge Electronic design Ltd., Cambridge, England) was used for data recording, data reduction and analysis of the two highest attempts out of three. Confidence intervals was set to 95%. ANOVA was further used to test the effects of SD.

Results: Maximal isometric force did decrease after SD, but it was not significant (NSD; 778 ± 116 N, SD; 754 ± 162 N). There was no significant difference in time to peak force either. Confidence interval not given.

Discussion

General finding

This literature review summarizes the effect of SD on muscular strength performance. Three studies showed that SD decrease strength performance (1, 7, 10), two of these applied complex movements (1, 7) and all three used partial SD. In contrast, four studies showed small, yet non-significant negative effect (6, 11, 16, 17), with three applying total SD (6, 11, 16) and simple movements (11, 16, 17). Surprisingly, two studies (6, 17) found a weak positive effect on lower body strength after one night of SD, which may be due to study population or protocol. Further, one study used females, which was the only population that were not familiar with strength training (17), however, through our findings, level of training experience does not seem to affect the results. Amongst the remaining studies, two used subjects trained in mixed martial arts (10, 11), two used weight lifters (1, 6), one used rugby players (7) and one used military cadets (16). Although these findings indicate that SD may have a negative effect on strength performance, more studies are needed, as the existing studies have small populations and are inconsistent in their findings.

This review shows that SD may negatively influence strength performance, and suggest that sleep hygiene and routines for sleeping is important (2). This finding may be particularly valuable for elite athletes, as the difference between failure and success may be miniscule (14).

The mechanisms behind these findings remains uncertain but may be related to several internal and external factors. For instance, some evidence shows a strong association between SD and fatigue (18) and that fatigue is associated with lower motivation and decreased recruitment of motor units and spinal cord transmission (17). Interestingly, subjective fatigue measuring methods were used in three of the studies included, which all found that rate of perceived exhaustion (RPE) increased after a night of SD (1, 6, 10). An increased state of fatigue may therefore impact the motivation of the subjects, causing them to perform worse. Correspondingly, several studies indicates that motivation may have a detrimental effect on tasks requiring sub-maximal or maximal effort (4, 6, 13). Some of the studies tried to control for motivation, e.g. Bambaeichi et al. (17) used superimposed electrical stimulation to “override” motivation, and found a positive effect on performance in MVC of the knee extensor after a night of SD compared to NSD, however the effect was not significant. In contrast, Cook et al. (7) found a significant negative effect of SD and did not control for motivation as the participants chose the weights and repetitions themselves. It should also be noted that a protocol where the participants came to the laboratory when they experienced a bad night of sleep was used (<6 hours), which may strengthen the nocebo effect. This suggest that motivation may represent an important mediator on the association between SD and decrements in strength performance. Furthermore, acute strength loss may be linked to cortisol and testosterone levels (6, 7). SD may give an elevation of cortisol levels, acting conversely of testosterone which is an anabolic hormone that decreases muscle degradation and increases muscle-protein synthesis, further, SD can decrease testosterone levels (19). This is supported by some studies, however, it remains uncertain whether these hormones influence the short-term effect of SD on strength performance (19). To summarize, sleep restriction may cause a decrement in strength performance, possibly explained by internal factors; cognitive changes, lack of motivation, greater levels of fatigue, and hormonal changes.

External factors in the various protocols may play a part of the connection between SD and strength. Three studies looked at time of day for exercising (10, 11, 17), indicating significant higher strength in the evening compared to morning (10, 17), this increase in strength may be due to body temperature reaching a peak in the evening (14). However Ridha et al. (11) found a slightly lower but non-significant value of strength during NSD tests between 16:00-17:00 compared to earlier in the day, it should be noted that 3 tests were performed on the same day, so fatigue may have occurred. Additionally, several studies have discussed the possibility of skill-oriented, multi-joint exercises being more affected by SD (6, 11, 14). Correspondingly, it has been found that SD affect maximal effort on deadlift, bench press and leg press, contrary to maximal effort biceps curl (15). In this review, three studies included complex movements (1, 6, 7). For instance, Cook et al. (7) found a significant effect on bench press, squat and barbell row. This is supported by Brotherton et al. (1) showing a significant negative effect of SD on bench press and hand grip; however the negative effect on leg press was not significant, these findings are in line with previous studies (20) showing that the motor tasks may be differently influenced by SD. In contrast to these findings Blumert et al. (6) found no significant effects on the snatch, front squat or clean and jerk. Thus, the type of exercise used may be an important determinant when assessing the effect of SD of acute strength performance. The complexity of the exercise is important for athletes, as sports mostly involve multi-joint, complex and skill-oriented tasks. Furthermore, strength performance seems to be less affected by total SD than partial. Vaara et al. (16) found no significant effect of SD on strength performance after 60 hours total SD, which has been found previously as well (14).

Further, all three studies that found a negative effect of SD on strength performance used a partial SD protocol. Another factor could be SD duration, for instance, Brotherton et al. (1) had SD for two consecutive nights, and found a significant negative effect. Hence; time of day, complexity of exercise, type of SD used and duration, may play a part in the various results found.

Strengths and weaknesses

Strengths that should be highlighted; all studies used an experimental protocol. An advantage with experimental studies is using an experimental group and a control group, which is considered a high tier for validity. Furthermore, most studies applied a crossover design, which are suited for studies including short-lived symptoms and reversible (21), however a weakness is risk of carry-over effect if time between measurements are short. Another strength however is the validity and reliability in measuring, for instance four studies (10, 11, 16, 17) used isokinetic tests, which is considered more accurate than dynamic movements (22). In contrast, the remaining three studies used experimental weight lifting protocols based of the subjects 1RM, which may not be as reliable, causing a possible loss of technique (1). However compound movements are more applicable for sports compared to isokinetic dynamometers. Another limitation is the validity of sleep measurement (1), for instance, only two studies specify that the subjects had both nights at a laboratory (1, 10), one having both nights at home (7). Further, the precision of sleeping,- training- or nutrition-logs acquired may cause inaccurate results due to misreporting, and therefore influence factors, such as; recovery, total work load and energy balance (23). However, keeping a diary may also be a strength as they get an indication of behavior. Further five of the studies used a self-assessment questionnaire to assess morning- and eveningness-types in their screening procedure, only two of the studies (7, 11), did not use any type of questionnaire to check their subjects, this may impact the performance. Furthermore, the study populations were small (8 to 20 subjects), which gives weak statistical power. A weakness of our interpretation is a lack of reported non-significant p-values/confidence intervals in some studies. Moreover, only Bambaeichi et al. (17) performed tests on females, meaning that applying our findings to different sexes is uncertain, further the study should be mentioned as a weakness, being the only study on non-athletic subjects. Moreover, in Vaara et al. (16) a possible limitation is the lack of a control group. Ridha et al. (11) had 8 out of 12 subjects drop out before the last test. Lastly, our inclusion criteria may be a limitation, for instance we only included studies with a population under 40. Due to the selection process of the studies conducted in this review, only studies from the year 2005 and onwards were included.

Future directions

Future studies should include larger samples, to diminish effect of individual differences. Further, sex differences should be explored, as few studies have been done on females. Different ages could play a role, as youth may have different sleep needs or patterns than adults. Complexity of movements may also be given more focus as it pertains better to athletes, having better carry-over to sports compared to single joint exercises, therefore we suggest testing sport specific movements, to better understand how SD affects sports. Furthermore, focus may be directed to partial SD as it represents a more realistic scenario for athletes compared to total SD. Moreover, future studies could be performed in a laboratory for preferably three nights to potentially limit the effect of first-night effect (5) and control sleep amount. However, at home testing may be advantageous as some subjects may not sleep as well in a laboratory setting, sleep quality and duration should be measured with actigraphy or at-home polysomnography for assessing transitions between states of awake and asleep at home. Measuring sleep quality can help in understanding the relationship between sleep duration and sleep quality and how both affect strength performance. Actigraphy could also be used in daytime to assess the energy expenditure during the day and control for other behavior patterns. We advise to check all subjects for chronotypes by using morningness-eveningness questionnaire.

An interesting topic that should be further explored is the possibility of negating effect of SD, for instance; caffeine has been associated to significantly eliminate the effect SD on strength performance (7), and a 1 hour power-nap was found to have significant positive effect on strength compared to a SD group (1), although this is not an universal finding.

Conclusions

This literature review summarizes the effect of SD on muscular strength performance. Three studies showed that SD decrease strength performance, further, two of these applied complex movements for testing and all three used partial SD. In contrast, four studies showed small but non-significant negative effects, three of them applied total SD and three used simple movements. This suggests that SD may have a negative effect on strength, however, further studies are needed. This finding indicate that elite athletes should maintain a good sleep routine, to perform at the highest levels.

References

1. Brotherton EJ, Moseley SE, Langan-Evans C, Pullinger SA, Robertson CM, Burniston JG, et al. Effects of two nights partial sleep deprivation on an evening submaximal weightlifting performance; are 1 h powernaps useful on the day of competition? Chronobiology International. 2019:1-20.
2. Kirschen G, J. Jones J, Hale L. The Impact of Sleep Duration on Performance Among Competitive Athletes: A Systematic Literature Review2018. 1 p.
3. Juliff LE, Halson SL, Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. Journal of Science and Medicine in Sport. 2015;18(1):13-8.
4. Reilly T, Edwards B. Altered sleep–wake cycles and physical performance in athletes. Physiology & Behavior. 2007;90(2):274-84.
5. Tamaki M, Bang Ji W, Watanabe T, Sasaki Y. Night Watch in One Brain Hemisphere during Sleep Associated with the First-Night Effect in Humans. Current Biology. 2016;26(9):1190-4.
6. Blumert P, J Crum A, Ernsting M, Volek J, Hollander D, E Haff E, et al. The Acute Effects of Twenty-Four Hours of Sleep Loss on the Performance of National-Caliber Male Collegiate Weightlifters2007. 1146-54 p.
7. Cook C, Beaven C, Kilduff L, Drawer S. Acute Caffeine Ingestion's Increase of Voluntarily Chosen Resistance-Training Load After Limited Sleep2012. 157-64 p.
8. Mah CD, Mah KE, Kezirian EJ, Dement WC. The Effects of Sleep Extension on the Athletic Performance of Collegiate Basketball Players. Sleep. 2011;34(7):943-50.
9. Halson SL. Nutrition, sleep and recovery. European Journal of Sport Science. 2008;8(2):119-26.
10. Souissi N, Chtourou H, Aloui A, Hammouda O, Dogui M, Chaouachi A, et al. Effects of Time-of-Day and Partial Sleep Deprivation on Short-Term Maximal Performances of Judo Competitors. 2013;27(9):2473-80.
11. Ridha B, Latiri I, Dogui M, Ben Saad H. Effects of one night sleep deprivation on selective attention and isometric force in adolescent Karate athletes2016.
12. Suchomel T, Nimphius S, Stone M. The Importance of Muscular Strength in Athletic Performance2016.
13. Knowles OE, Drinkwater EJ, Urwin CS, Lamon S, Aisbett B. Inadequate sleep and muscle strength: Implications for resistance training. Journal of Science and Medicine in Sport. 2018;21(9):959-68.
14. Thun E, Bjorvatn B, Flo E, Harris A, Pallesen S. Sleep, circadian rhythms, and athletic performance. Sleep Medicine Reviews. 2015;23:1-9.
15. Reilly T, Piercy M. The effect of partial sleep deprivation on weight-lifting performance. Ergonomics. 1994;37(1):107-15.
16. Vaara JP, Oksanen H, Kyröläinen H, Virmavirta M, Koski H, Finni T. 60-Hour Sleep Deprivation Affects Submaximal but Not Maximal Physical Performance. 2018;9(1437).
17. Bambaeichi E, Reilly T, Cable NT, Giacomoni M. The influence of time of day and partial sleep loss on muscle strength in eumenorrheic females. Ergonomics. 2005;48(11-14):1499-511.
18. Martin B. J. Effect of sleep deprivation on tolerance of prolonged exercise. European Journal of Applied Physiology & Occupational Physiology. 1981;47(4):345-54.
19. Crewther B, Cook C, Cardinale M, Weatherby R, Lowe T. Two emerging concepts for elite athletes: The short-term effects of testosterone and cortisol on the neuromuscular system and the dose-response training role of these endogenous hormones2011. 103-23 p.
20. Pilcher JJ, Huffcutt AI. Effects of sleep deprivation on performance: A meta-analysis. Sleep. 1996;19(4):318-26.
21. Mills EJ, Chan A-W, Wu P, Vail A, Guyatt GH, Altman DG. Design, analysis, and presentation of crossover trials. Trials. 2009;10:27-.

22. G. Hopkins W, Schabort E, Hawley J. Reliability of Power in Physical Performance Tests2001. 211-34 p.
23. Goldberg GR, Black AE. Assessment of the validity of reported energy intakes - review and recent developments. Näringsforskning. 1998;42(1):6-9.

Appendix:

Terms:

1RM – 1 repetition max

EMG – Electromyography

MVC – Maximal Voluntary Contraction

N – Newton

Nm – Newton meter

NSD – Not sleep deprived/deprivation

RPE – Rate of perceived exhaustion

SD – Sleep deprived/deprivation

SDb – Sleep deprivation beginning of night

SDe – Sleep deprivation end of night