The influence of an afternoon nap on the endurance performance of trained runners

Blanchfield, Anthony W.; Lewis-Jones, Tammy M.; Wignall, James R.; Roberts, James B.; Oliver, Samuel J.

European Journal of Sport Science

DOI:
10.1080/17461391.2018.147718

Published: 01/01/2018

Peer reviewed version

Dyfyniad o'r fersiwn a gyhoeddwyd / Citation for published version (APA):
Blanchfield, A. W., Lewis-Jones, T. M., Wignall, J. R., Roberts, J. B., & Oliver, S. J. (2018). The influence of an afternoon nap on the endurance performance of trained runners. *European Journal of Sport Science*, *18*(9), 1177-1184. https://doi.org/10.1080/17461391.2018.147718

This article was accepted in its current form to European Journal of Sport Science on 10th May 2018. The full journal version is available at https://doi.org/10.1080/17461391.2018.1477180

The influence of an afternoon nap on the endurance performance of trained runners

Authors:

Anthony W. Blanchfield, Tammy M. Lewis-Jones, James R. Wignall, James B. Roberts & Samuel J. Oliver.

Corresponding author address:

Samuel J. Oliver
Extremes Research Group,
School of Sport, Health and Exercise Sciences,
Bangor University,
Bangor,
LL57 2PZ, UK
s.j.oliver@bangor.ac.uk

The affiliation and postal address of all authors listed is the same as the corresponding author. All research was conducted at this affiliation.

Running head: Endurance performance after napping

Manuscript word count: 4219

Abstract

The effectiveness of a nap as a recovery strategy for endurance exercise is unknown and therefore the present study investigated the effect of napping on endurance exercise performance. Eleven trained male runners completed this randomized crossover study. On two occasions runners completed treadmill running for 30 min at 75% $\dot{V}O_{2max}$ in the morning, returning that evening to run for 20 min at 60% $\dot{V}O_{2max}$, and then to exhaustion at 90% $\dot{V}O_{2max}$. On one trial, runners had an afternoon nap approximately 90-min before the evening exercise (NAP) whilst on the other runners did not (CON). All runners napped (20 ± 10 min), but time to exhaustion (TTE) was not improved in all runners (NAP 596 ± 148 s vs. CON 589 ± 216 s, P=0.83). Runners that improved TTE after the nap slept less at night than those that did not improve TTE (nighttime sleep 6.4 ± 0.7 h vs. 7.5 ± 0.4 h, P<0.01). Furthermore, nightime sleep predicted change in TTE, indicating that runners sleeping least at night improved TTE the most after the nap compared to CON (r^2 = -0.76, P=0.001). In runners that improved TTE, ratings of perceived exertion (RPE) were lower during the TTE on NAP than CON compared to runners that did not improve (-0.4 ± 0.6 vs. 0 ± 0, P=0.05). Reduced exercising sense of effort (RPE) may account for the improved TTE after the nap. In conclusion, a short afternoon nap improves endurance performance in runners that obtain less than 7 h nighttime sleep.

Key words: recovery, fatigue, sleep, training, time to exhaustion, RPE

Introduction

It is common for athletes to perform multiple exercise sessions on the same day and work obligations mean this training is often completed early in the morning and late in the evening (Sargent, Lastella, Halson, & Roach, 2014; Seiler, 2010). In addition to its physical and psychological demands, athletic training can therefore also curtail nighttime sleep (Sargent, Halson, & Roach, 2014; Sargent, Lastella, Halson, & Roach, 2014). For example, it was recently reported that sleep averaged only 6.5 h per night on training days in 70 national ranked athletes (Sargent, Halson, & Roach, 2014). A particular concern of this research was that the athletes reported increased fatigue pre-training (Sargent, Lastella, Halson, & Roach, 2014). Moreover, the athletes' sleep is not consistent with recommendation of 7-9 h of sleep per day to be a healthy adult with optimal neurocognitive functioning (Hirshkowitz et al., 2015). As insufficient sleep has been shown to reduce physical capacity, increase sense of effort (RPE) during exercise and decrease mood (Oliver, Costa, Laing, Bilzon, & Walsh, 2009; Bonnet, 1985), performance may be compromised in athletes that do not obtain the recommended night-time sleep. Accordingly, strategies that enable athletes to increase total daily sleep could benefit exercise performance and training. For example, extending nighttime sleep may improve athletic performance in collegiate basketball players (Mah, Mah, Kezirian, & Dement, 2011). Unfortunately, due to early morning and late evening training, extending night sleep time is not feasible for many athletes, and therefore, it is necessary to develop and assess the effectiveness of alternative methods to increase total daily sleep; for instance, daytime napping.

Defined as a sleep that is distinct from and substantially shorter than an individual's normal night-time sleep (Dinges, 1989), napping has been shown to maintain physical, psychological, and perceptual performance in persons involved in shift work or early morning rising (Caldwell et al., 2009; Ruggiero & Redeker, 2014). While athletes nap sometimes during training (Sargent, Lastella, Halson, & Roach, 2014), experimental evidence exploring the effect of napping on exercise performance is limited to two studies that report disparate effects. Moreover, these studies investigated anaerobic exercise performance (Petit, Mougin, Bourdin, Tio, & Haffen, 2014; Waterhouse, Atkinson, Edwards, & Reilly, 2007). The effect of napping on endurance exercise performance is therefore unknown. The primary aim of this study was to investigate the effect of a short afternoon nap, after morning exercise, on evening endurance exercise performance in trained runners.

As napping has previously been shown to reduce subjective daytime fatigue, and maintain preferable mood profiles in occupational settings (Petrie, Powell, & Broadbent, 2004; Schweitzer, Randazzo, Stone, Erman, & Walsh, 2006), it was hypothesised that endurance exercise performance, as assessed by running time to exhaustion (TTE), would be longer after the nap because of a reduced sensation of pre-exercise fatigue. The two previous studies that report equivocal effects of a nap on short-term anaerobic exercise performance may be explained by the different sleep duration the night before the exercise test was performed. That is, a nap benefitted anaerobic exercise performance in those that slept 4 h the night before (Waterhouse et al., 2007) but not in those that slept 8 h the night before (Petit et al., 2014). A secondary aim of the study was therefore to determine whether nighttime sleep influences the effectiveness of a nap on endurance performance. It was hypothesised that the nap would benefit endurance performance of runners with the least nighttime sleep.

Methods

Participants

Eleven healthy, trained male runners (mean ± SD; age 35 ± 12 years, height 176 ± 4 cm, body mass 72.7 ± 10.0 kg, $\dot{V}O_{2max}$ 60 ± 11 ml·kg·min^{-1}, weekly training distance 72 ± 37 km) volunteered for this study having been recruited through local advertisements at running clubs and race events. Sleep questionnaires identified the runners as intermediate chronotype (56.7 ± 8.1, Horne-Östberg Morningness-Eveningness Questionnaire; Horne & Östberg, 1976) and having typical going to bed and rising times (23:24 ± 00:48 and 07:21 ± 01:01 h), nighttime sleep duration (6.9 ± 0.9 h) and sleep quality (4.7 ± 1.9, Pittsburgh Sleep Quality Index; Buysse, Reynolds 3rd, Monk, Berman, & Kupfer, 1989). Runners' also completed the Epworth Sleepiness Scale (ESS; Johns, 1991) scoring 5.9 ± 2.5, which is below the threshold of 10 for clinically meaningful daytime sleepiness. The study received local University Ethics Committee approval for testing human participants and was completed with ethical standards in accordance with the Declaration of Helsinki. Runners gave written informed consent after receiving verbal and written information about the study. To be eligible to complete the study runners were required to have completed a 5 km running race in less than 23 min in the previous 12 months. We also requested that runners maintain a consistent sleep-wake pattern for the entire study. Exclusion criteria included an alcohol intake of greater than 20 g (2.5 units) per day.

Design

Runners visited the laboratory on three occasions. The first visit was to establish maximal oxygen uptake ($\dot{V}O_{2max}$) and running speeds for the treadmill runs during the experimental trials in Visits 2 and 3. The study was a repeated-measures crossover design where participants completed either a control (CON) or nap (NAP) trial in a randomised order. The randomisation was completed by SJO using www.randomization.com. The experimental trials were separated by a minimum of 5 and a maximum of 9 days. All visits and exercise tests were conducted on the same motorised treadmill (h/p/ cosmos mercury med 4.0, Nussdorf, Germany), in the same laboratory, under the same environmental conditions (19.7 ± 0.6ºC, 59 ± 7% relative humidity, wind speed 2.3 $m \cdot s^{-1}$ generated by a fan placed 2 m in front of the treadmill).

Preliminary testing

During Visit 1, anthropometric measures of height and nude body weight were recorded and then an incremental exercise test to volitional exhaustion was completed on a treadmill to establish $\dot{V}O_{2max}$. The test started at 10 $km \cdot h^{-1}$ with a 0% treadmill gradient. Increments were achieved by increasing the treadmill speed by 1 $km \cdot h^{-1}$ every minute until16 $km \cdot h^{-1}$. Thereafter the gradient was increased by 1% every minute until exhaustion. Oxygen consumption was recorded continuously throughout this test by a metabolic cart (Metalyser, Cortex, Leipzig, Germany) with $\dot{V}O_{2max}$ defined as the highest 30 s average at any given time point. Additionally, during the final 15 s of each incremental stage recordings of heart rate (HR) and RPE were made by remote transmitter (FT3, Polar, Kempele, Finland) and the CR10 scale (Borg, 1998). After active recovery until HR decreased to less than 100 beats·min^{-1}, $\dot{V}O_{2max}$ was verified by runners returning to the treadmill to complete running at one intensity greater than at exhaustion (i.e. 1% greater gradient). After a further 10-min rest, runners re-mounted the treadmill, set at a gradient of 1% to reflect the energy cost of road running (Jones & Doust, 1996), to determine the running speeds equivalent to 60, 75 and 90% $\dot{V}O_{2max}$ for the subsequent experimental trials.

Experimental procedures

For the main experimental trials runners attended the laboratory on two separate occasions within the same day. This consisted of a morning exercise session (08:48 ± 01:09 h) and an evening exercise session (17:03 ± 00:50 h). To control for circadian variation runners attended the laboratory at the same time of day for both of their experimental trials; these exercise sessions replaced the runners' normal morning and evening exercise sessions in their scheduled training plan. To standardise diet and activity, 24 h before each visit runners recorded and replicated a diet and activity diary, consumed water equal to 35 ml·kg^{-1} body mass and avoided alcohol (Oliver, Laing, Wilson, Bilzon, & Walsh, 2007). Between the morning and evening exercise runners continued their normal daily obligations. The night before each experimental trial, and the day of each experimental trial, runner sleep-wake activity was monitored by a diary and wristwatch accelerometer worn on the non-dominant arm (GT1M, ActiGraph LLC, Florida, USA). The sleep diary was used to calculate time in bed from the difference between time asleep and time awake. Time asleep was calculated from time in bed minus sleep latency and interrupted sleep as determined by accelerometry (Ancoli-Israel et al., 2003). Sleep efficiency was determined by dividing time asleep by time in bed.

At the beginning of the morning exercise session runners completed two subjective sleep questionnaires: The Karolinska Sleepiness Scale (KSS; Akerstedt & Gillberg, 1990) and the St Mary's Sleep Questionnaire (Ellis et al. 1981). The KSS assesses current sleepiness on a single 10-point likert-type scale ranging from (1) "extremely alert" to (10) "extremely sleepy, can't keep awake". The St Mary's Sleep Questionnaire is a 14-item questionnaire that assesses prior night's sleep duration and quality. Sleep quality was determined from the sum of the seven likert-type items permitting an overall score of between 6 and 38, with higher scores representative of better sleep quality. Runners then completed a 30-min treadmill run at a speed equivalent to 75% $\dot{V}O_{2max}$. During this, HR and RPE were recorded at 1-min intervals. Runners did not consume food or fluids during the run. Upon completion of this exercise protocol, runners showered, fitted the accelerometer wristwatch, and were free to leave the laboratory with instructions to continue their normal daily obligations with or without an afternoon nap, depending on the assigned experimental condition. Runners were also reminded to avoid alcohol and strenuous exercise during this time.

On NAP trial, approximately 90 min before re-visiting the laboratory for the second exercise bout, runners commenced the afternoon nap (mean clock time of 15:20 ± 1:00 h, range 14:00 to 16:50 h). To commence the nap, runners rested on a bed, in a familiar, quiet, darkened room until they fell asleep. Runners were instructed to rest for no longer than 40 minutes and to set an alarm to indicate the end of this 40-minute period. On waking all runners immediately completed the KSS before returning to the laboratory.

At the beginning of the evening exercise session, runners completed questionnaires to assess current sleepiness (KSS) and mood (Brunel Mood Scale (BRUMS); Terry, Lane, & Fogarty, 2003). Total mood disturbance was calculated by the sum of BRUMS fatigue, anger, tension, confusion and depression subscales minus vigour. A constant of 100 was added to prevent negative numbers (Lastella, et al, 2015). To assess hydration status before exercise, a urine sample was collected to determine urine specific gravity (Atago Uricon-Ne, New York, USA) and nude body mass was measured. As napping was previously shown to reduce core body temperature (Waterhouse et al., 2007), which may benefit endurance performance, runners also fitted a rectal thermistor for core body temperature monitoring (YSI 4000A, Daytona, FL). Runners then performed a treadmill run for 20-min at a speed equivalent to 60% $\dot{V}O_{2max}$. During the run, HR and core body temperature were recorded every minute, whilst RPE was recorded at 2-min intervals. Runners did not consume food or fluids during the run. After the 20-min run, runners removed the rectal thermistor and completed the BRUMS and the KSS during a standardised 13-min rest period before beginning the treadmill run TTE, which was completed at a speed equivalent to 90% $\dot{V}O_{2max}$. Runners TTE was defined as the time elapsed between the onset of running at 90% $\dot{V}O_{2max}$ and volitional exhaustion. HR and RPE were recorded every minute during the TTE test, and finally at exhaustion. During the TTE, runners received no encouragement and they were blind to their elapsed running time. Results of all tests were only provided to the runners once they had completed both experimental trials.

Data and statistical analyses

An analysis (G*Power, Version 3.1.2) using standard alpha (0.05), beta values (0.8) and typical coefficient of variation (8%) of high-intensity running TTE tests in trained runners (Billat, Renoux, Pinoteau, Petit, & Koralsztein, 1994) indicated a sample size of eleven would provide adequate statistical precision to detect a 8% or ~30 s difference between CON and NAP trials in the main outcome measure, TTE. To determine the effect of a nap on TTE, a paired sample t-test was used to compare TTE on the NAP and CON trials. To determine the effect of the nap on individual runners performance, the percentage change in individual runners performance was compared to the coefficient of variation of the TTE (8%). A paired sample t-test was used to determine if nighttime sleep and exercising responses were different between those runners that improved TTE after the nap compared to runners that did not improve TTE after the nap. In addition, simple regression was used to determine if time asleep the night before the trials, and time asleep the night before combined with the nap duration, predicted the effectiveness of a nap to improve TTE. Time asleep was calculated as the average of the night's sleep before both experimental trials. A paired sample *t*-test was used to determine if a difference existed between sleep duration the night before the experimental trials and a 4-day mean from the sleep diary that was completed one month prior. Paired sample *t*-tests were also used to assess for differences between the CON and NAP for: night sleep-wake activity and subjective sleep quality the night before each experimental trial; 30-min morning exercise responses (mean HR & RPE); responses 90-min after the nap and before evening exercise (urine specific gravity, nude body mass, core temperature, BRUMS subscales and total mood disturbance; and at the end of the TTE. In addition, a 2 x 4 (condition x time) fully repeated measures analysis of variance (ANOVA) was used to assess sleepiness throughout each trial day, and 2 x

3 (condition x time) ANOVA's were used to assess iso-time RPE and HR at 0% (first minute), 50%, and 100% (final full minute) of the TTE test (Blanchfield, Hardy, de Morree, Staiano, & Marcora, 2014). Bonferroni follow up tests were used where appropriate. Statistical significance was accepted at $P < 0.05$ (two-tailed). Unless noted otherwise, all data are shown as mean ± standard deviation.

Results

Nighttime sleep before each trial and morning exercise

Sleep duration the night before the experimental trials was similar to the 4-day mean that was recorded one month before the first experimental visit (419 ± 46 min before experimental trials vs. one-month prior 406 ± 62 min, $P = 0.53$). Runner's sleep-wake activity, including sleep duration and quality were also similar before each experimental trial (Table 1).

The 30-min morning treadmill exercise at 75% $\dot{V}O_{2max}$ elicited similar mean HR (NAP 153 ± 19 beats·min^{-1} vs. CON 150 ± 18 beats·min^{-1}, $P = 0.71$) and RPE (NAP 4.2 ± 1.0 vs. CON 4.5 ± 1.4, $P = 0.49$), indicating that runners completed the morning exercise in a similar physiological and perceptual state on each trial.

Nap intervention

All runners confirmed that they were able to nap on the NAP trial. Runners were in bed for 34 ± 12 min with 20 ± 10 min time asleep. As expected, our follow up tests for sleepiness revealed that it was increased immediately after the nap (Figure 1, NAP 5.5 ± 1.6 vs. CON 4.0 ± 1.4, $P = 0.001$).

On arrival to the laboratory, approximately 90-min after the nap period had commenced, there was no difference in urine specific gravity or nude body mass, which suggests that runners arrived for the evening exercise in a similar state of hydration on both trials. Sleepiness (Figure 1), core body temperature and total mood disturbance (Table 2) were also similar approximately 90-min after the nap and before the 60% $\dot{V}O_{2max}$ steady state run. Further, there was no difference in any of the mood subscales including fatigue and vigour, suggesting mood was not altered by the nap.

Evening exercise following an afternoon nap

As a whole group, running TTE was similar after the nap to the control trial (NAP 596 ± 148 s vs. CON 589 ± 216 s, $P = 0.83$). Similarly, isotime HR and RPE did not differ during the TTE (HR and RPE, $P = 0.88$ and $P = 0.81$, respectively). Examination of individual runner responses to the nap revealed that the nap improved TTE of five runners and impaired the TTE of three runners (Figure 2A).

Those runners that improved running TTE after the nap slept less the night before, and in the 24 hours before, the TTE than those that did not improve running TTE after the nap (nighttime sleep 382 ± 39 min vs. 449 ± 24 min, $P = 0.007$; total 24 h sleep (nighttime sleep plus nap) 401 ± 37 min vs. 469 ± 20 min, $P = 0.004$). Furthermore, time asleep the night before the TTE predicted change in TTE, indicating those that slept less at night improved TTE most after the nap ($r^2 = -0.69$, $P = 0.002$: Figure 2B). Total sleep in the 24 h before the TTE also predicted change in TTE ($r^2 = -0.76$, $P = 0.001$). Sleep efficiency ($P = 0.37$) and subjective sleep quality ($P = 0.08$) was however similar between those improving TTE and those that did not.

Runners that improved TTE after the nap reported a lower RPE at 100% TTE isotime on their NAP trial versus their CON trial (-0.4 ± 0.6) compared to runners who did not improve TTE after the nap (0 ± 0, $P = 0.05$). There also was a relationship between the change in RPE between NAP versus CON at 100% TTE isotime and change in TTE ($r = -0.64$, $P = 0.02$), indicating that where a nap lowered RPE it was associated with a longer TTE. In contrast, there was no difference between those runners that improved running TTE and those that did not in other resting or TTE physiological or psychological responses (i.e. sleepiness, fatigue, vigour, core temperature or HR, $P > 0.1$).

Discussion

Research on napping and athletic performance is limited. Accordingly, this study uniquely adds to the napping literature by providing the first experimental evidence into the effect of a nap on endurance exercise performance. As a strength, we included trained runners with typical sleep-wake schedules. Our primary aim was to determine the effect of a short afternoon nap on evening endurance exercise performance in trained runners. In contrast to our first hypothesis the nap did not reduce fatigue or improve endurance performance in all runners. A secondary aim of the study was to determine whether sleep duration influences the effectiveness of a nap to improve endurance performance. Consistent with our second hypothesis the nap improved endurance performance of runners that slept least the night before the trials. This was true regardless of whether sleep duration before the experimental trials was defined as nighttime sleep only or nighttime sleep plus the nap.

An additional strength of this study is that we confirmed that nighttime sleep before the experimental trials was similar to the sleep the runners typically experienced (419 ± 46 min before experimental trials vs. one-month prior 406 ± 62 min, $P = 0.53$). These data suggest that the nap improved endurance performance in those that typically sleep less, rather than improving runners that had poor sleep the night before the endurance performance tests. Poor sleep the night before the experimental trials might also be discounted as mood before each endurance performance test (Table 2) was similar to that typically reported by athletes (Lastella, et al, 2015; Terry, Lane, Lane & Keohane, 1999) as opposed to being indicative of poor mood which is a hallmark of sleep deprivation (Kahn, Fridenson, Lerer, Bar-Haim, & Sadeh, 2014; Lieberman et al., 2006; Scott, McNaughton, & Polman, 2006).

Our runners had typical sleep-wake patterns, sleeping as a group 7 h per day, which is consistent with the 7-9 h sleep recommendations for a healthy adult with optimal neurocognitive functioning set by the American Academy of Sleep Medicine, Sleep Research Society and National Sleep Foundation (Hirshkowitz et al., 2015; Watson et al., 2015). It is then perhaps not surprising that the nap did not improve endurance performance in all runners. Indeed, in this study we show that the benefits of a nap for endurance performance are dependent on typical sleep. Runners obtaining sleep recommendations did not improve endurance performance after the nap. In contrast, the endurance performance of runners that did not obtain the recommended sleep benefitted from the short afternoon nap. The observation that a nap aids athletic performance in those that sleep least is consistent with the only two other studies to investigate the effect of napping on athletic performance. These studies indicate a nap benefits sprint and strength (anaerobic) performance after sleep restriction (Waterhouse et al., 2007) but not after a normal night of sleep (Petit et al., 2014).

Previous studies have suggested that obtaining less than recommended sleep decreases mood and increases fatigue, which may negatively affect athlete training and competition performance (Sargent, Lastella, Halson, & Roach, 2014). We did not observe differences in mood following the nap. We also did not observe any alterations in resting or exercising physiological measures after the nap. After the nap however, ratings of perceived exertion (sense of effort) were lower at the end of the time to exhaustion exercise in those runners that improved endurance performance. As other mood and physiological measures were not altered before, during or after exercise, the nap most likely improved endurance performance in this study by lowering the sense of effort during exhaustive exercise. This explanation is consistent with the consensus of previous studies that propose altered sense of effort, rather than a physiological alteration, is responsible for altered endurance performance after sleep restriction (Oliver et al., 2009; Martin, 1981; Myles et al., 1985).

To develop the long-term implications of napping for athletes it is important that the constraints of the present study are considered. We intentionally selected a short (~20 min) afternoon nap so our findings would be comparable to previous exercise studies (Petit et al. 2014; Waterhouse et al. 2007) and because this is a practical duration for athletes to adopt. It is possible however that the benefit of napping interventions for endurance athletes would become more apparent with alternative nap durations and scheduling. Further research should therefore examine the effects of different nap durations and alternative napping schedules on exercise performance. In the present research, we also did not asses our participants for recent travel. This is something that should be considered in future napping research; as should the capture of participant sleep-wake data throughout the experimental period. As well as these considerations future studies may wish to investigate the effect of chronic daily napping on athletic performance. As sleep extension has been shown to improve athletic performance (Mah et al., 2011) chronic napping may also benefit athlete training and competition performance. Given the demands of training early in the morning and/or late in the evening, daytime napping is likely a more practical strategy than extending nighttime sleep for most athletes.

In summary, this study investigated for the first time the effect of a nap on endurance exercise performance, revealing that a short afternoon nap improved endurance performance in runners with least sleep. The runners that improved running performance after the nap slept typically less than the 7-9 h sleep recommendations. These findings have important applied implications for endurance athletes; indicating a nap may benefit training and competition performance in athletes that struggle to obtain recommended sleep due to training, work, social and domestic demands. Further, athletes should consider napping as a strategy to adopt when travel and training causes sleep duration or quality to be compromised e.g. long-haul flights, intensified or altitude training. As the first investigation to test the effects of napping on endurance performance, this study provides an important point of reference for future research that seeks to develop napping. In an ever more 24/7 society napping represents a promising strategy to optimise work, domestic and social performance of athletes and non-athletes alike.

Conflict of interest

The authors declare they have no conflict of interest.

References

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C, P. (2003). The role of actigraph in the study of sleep and circadian rhythms. *Sleep, 26*, 342-392. doi: 10.1093/sleep/26.3.342

Akerstedt. T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience, 52*, 29-37. doi: 10.3109/00207459008994241

Banks, S., & Dinges, D, F. (2011). Chronic sleep deprivation. In: M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine* (4th ed). (pp. 67-75). Philadelphia: Elsevier.

Billat, V., Renoux, J. C., Pinoteau, J., Petit, B., & Koralsztein, J. P. (1994). Reproducibility of running time to exhaustion at VO2max in subelite runners. *Medicine and Science in Sports and Exercise, 26,* 254-257.

Blanchfield, A. W., Hardy, J., De Morree, H. M., Staiano, W., & Marcora, S. M. (2014). Talking yourself out of exhaustion: the effects of self-talk on endurance performance. *Medicine and Science in Sports and Exercise, 46,* 998-1007. doi: 10.1249/MSS.0000000000000184

Bonnet, M. H. (1985). Effect of sleep disruption on sleep, performance, and mood. *Sleep 8*, 11-19.

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign IL: Human Kinetics:

Buysee, D. J., Reynolds, C. F 3rd., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research, 28*, 193-213.

Dinges, D. F. (1989). Napping patterns and effects in human adults. In: D. F. Dinges & R. J. Broughton (Eds) *Sleep and alertness: Chronobiological, behavioural and medical aspects of napping* (pp. 171-204). New York: Raven Press.

Ellis, B. W., Johns, M. W., Lancaster, R., Raptopoulos, P., Angelopoulos, N., Priest, R. G. (1981). The St. Mary's Hospital sleep questionnaire: a study of reliability. *Sleep, 4*, 93-97.

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., … Adams Hillard, P. J. (2015) National Sleep Foundation's sleep time recommendations: methodology and results summary. *Sleep Health, 1*, 40-43. http://dx.doi.org/10.1016/j.sleh.2014.12.010

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology, 4*, 97-110.

Johns, M. W. (1991). "A new method for measuring daytime sleepiness: The Epsworth sleepiness scale". *Sleep*, *14*, 540-545.

Jones, A. M., & Doust, J. H. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sports Sciences, 14*, 321-327.

Kahn, M., Fridenson, S., Lerer, R., Bar-Haim, Y., & Sadeh, A. (2014). Effects of one night of induced night-wakings versus sleep restriction on sustained attention and mood: a pilot study. *Sleep Medicine*, *15*, 825-832. doi: 10.1016/j.sleep.2014.03.016.

Lastella, M., Roach, G. D., Halson, S. L., Martin, D. T., West, N P., & Sargent, C. (2015). The impact of a simulated grand tour on sleep, mood, and well-being of competitive cyclists. *Journal of Sport, Medicine and Physical Fitness*, *55*, 1555-1564.

Lee, K. A. (1992). Self-reported sleep disturbances in employed women. *Sleep*, *15*, 493-498.

Lieberman, H. R., Niro, P., Tharion, W. J., Nindl, B. C., Castellani, J. W., & Montain, S. J. (2006). Cognition during sustained operations: comparison of a laboratory simulation to field studies. *Aviation, Space, and Environmental Medicine*, *77*, 929-935.

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep, 34*, 943-950.

Martin, B. J. (1981). Effect of sleep deprivation on tolerance of prolonged exercise. *European Journal of Applied Physiology and Occupational Physiology, 47*, 345-354.

Myles, W. S. (1985). Sleep deprivation, physical fatigue, and the perception of exercise intensity. *Medicine and Science in Sports and Exercise*, *17*, 508-584.

Oliver, S. J., Costa, R. J. S., Laing, S. J., Bilzon, J. L. J., & Walsh, N. P. (2009). One night of sleep deprivation decreases treadmill endurance performance. *European Journal of Applied Physiology, 107*, 155-161. doi: 10.1007/s00421-009-1103-9

Oliver, S. J., Laing, S. J., Wilson, S., Bilzon, J. L. J., & Walsh, N. P. (2007). Endurance running performance after 48 h of restricted fluid and/or energy intake. *Medicine and Science in Sports and Exercise, 39*, 316–322.

Petit, E., Mougin, F., Bourdin, H., Tio, G., & Haffen, E. (2014). A 20-min nap in athletes changes subsequent sleep architechture but does not alter physical performances after normal sleep or 5-h phase-advance conditions. *European Journal of Applied Physiology, 114*, 305-315. doi: 10.1007/s00421-013-2776-7

Petrie, K. J., Powell, D., & Broadbent, E. (2004). Fatigue self-management strategies and reported fatigue in international pilots*. Ergonomics, 47*, 461-468. doi: http://dx.doi.org/10.1080/00140130310000085653

Ruggiero, J. S., & Redeker, N. S. (2014). Effects of napping on sleepiness and sleep-related performance deficits in night-shift workers: a systematic review. *Biological Research for Nursing, 16*, 134-142. doi: 10.1177/1099800413476571

Sargent, C., Halson, S. L., & Roach, G. D. (2014). Sleep or Swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. *European Journal of Sport Science, 14*, S310-315. doi: 10.1080/17461391.2012.696711

Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2014). The impact of training schedules on sleep and fatigue of elite athletes. *Chronobiology International, 31*, 1160-1168. doi: 10.3109/07420528.2014.957306

Schweitzer, P. K., Randazzo, A. C., Stone, K., Erman, M., & Walsh, J. K. (2006). Laboratory and field studies of naps and caffeine as practical countermeasures for sleep-wake problems associated with night work. *Sleep, 29*, 39-50.

Scott, J. P., McNaughton, L. R., & Polman, R. C. (2006). Effects of sleep deprivation and exercise on cognitive, motor performance and mood. *Physiology and Behaviour*, *28*, 396-408. DOI: 10.1016/j.physbeh.2005.11.009

Seiler, S. (2010). What is best practice for training intensity and duration distribution in endurance athletes? *International Journal of Sports Physiology and Performance*, *5*, 276-291. https://doi.org/10.1123/ijspp.5.3.276

Terry, P. C., Lane, A. M., & Fogarty, G. J. (2003). Construct validity of the profile of mood states – adolescents for use with adults. *Psychology of Sport and Exercise,* *44*, 125-139. doi: https://doi.org/10.1016/S1469-0292(01)00035-8

Terry, P. C., Lane. A, M., Lane, H, J., & Keohane, L. (1999). Development and validation of a mood measure for adolescents. *Journal of Sports Sciences*, *17*, 861-872. DOI: 10.1080/026404199365425

Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2007). The role of a short post-lunch nap in improving cognitive, motor, and sprint performance in participants with partial sleep deprivation. *Journal of Sport Sciences, 25*, 1557-1566. doi: 10.1080/02640410701244983

Watson, N. F., Badr, M. S., Belenky, G., Bliwise, D. L., Buxton, O. M., Buysse, D., … Tasali, E. (2015). Joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society on the recommended amount of sleep for a healthy adult: methodology and discussion. *Sleep, 38*, 1161–1183. doi: 10.5665/sleep.4886

Tables with Captions

Table 1. Nighttime sleep duration and quality before each experimental visit

	Time in bed (min)	Time asleep (min)	Sleep latency (min)	Sleep efficiency (%)	Subjective sleep quality
CON	447 ± 35	416 ± 39	18 ± 15	93 ± 4	25 ± 6
NAP	459 ± 64	421 ± 64	22 ± 22	92 ± 6	25 ± 7
P	0.44	0.75	0.43	0.35	0.67

Abbreviations: CON, Control trial; NAP, Nap trial.

Table 2. Resting physiological and psychological responses 90-min post-nap

	Urine specific gravity	Body mass (kg)	Core body temperature (°C)	Fatigue (BRUMS)	Vigour (BRUMS)	Total mood disturbance (BRUMS)
CON	1.005 ± 0.004	73.0 ± 10.0	37.10 ± 0.30	2.2 ± 1.9	7.7 ± 3.7	97.6 ± 6.9
NAP	1.004 ± 0.004	72.9 ± 10.0	37.05 ± 0.25	2.8 ± 1.8	7.0 ± 3.8	98.4 ± 6.0
P	0.55	0.80	0.11	0.36	0.30	0.62

Abbreviations: CON, Control trial; NAP, Nap trial; BRUMS, Brunel Mood Scale.

Figure Captions

Figure 1. Runner alertness and sleepiness during control and nap trials. Immediately after a nap runners reported increased sleepiness but this declined before evening exercise including the running time to exhaustion (TTE). * indicates greater sleepiness on the nap trial (NAP) vs. control trial (CON) (*P* = 0.001). Date are mean ± SD.

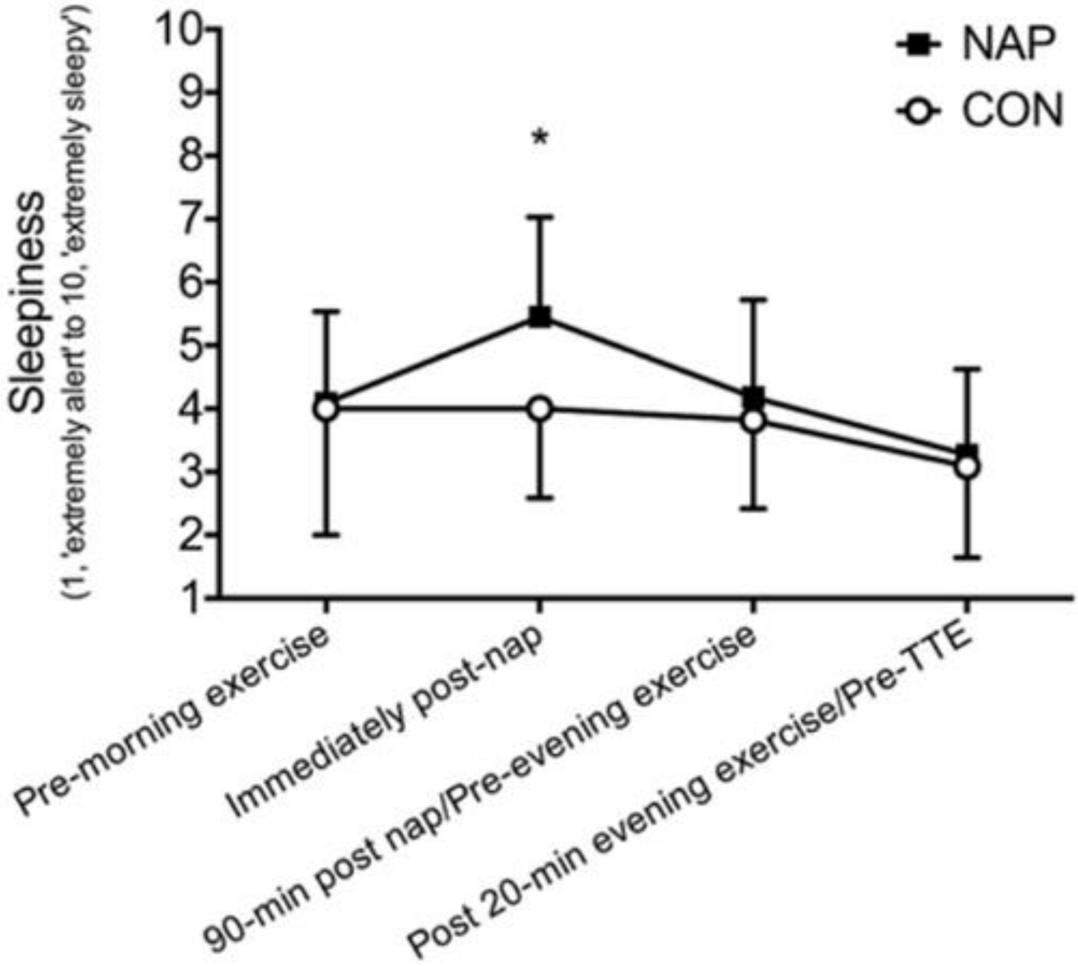

Figure 2. Running time to exhaustion (TTE) after a short afternoon nap (NAP) compared to a control trial (CON) in trained athletes. Data are individual (dot plots) and the TTE coefficient of variation (± 8%) is represented by the shaded area (A); Nighttime sleep predicted the change in running time to exhaustion (TTE) after a short afternoon nap. Data are individual (dot plots) (B).