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BRIEF REPORT

Sleep Deprivation Training to Reduce the Negative Effects of Sleep Loss on Endurance Performance: A Single Case Study

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Purpose: Sleep deprivation (SD) is very common during ultraendurance competitions. At present, stimulants such as caffeine and naps are the main strategies used to reduce the negative effects of SD on ultraendurance performance. In this case study, the authors describe the application of a novel strategy consisting of the intermittent repetition of SD (SD training [SDT]) during the weeks preceding an ultraendurance competition. ***Methods:*** A male ultraendurance runner underwent a 6-week SDT program (consisting of 1 night SD every Sunday) in addition to his regular physical training program before taking part in a 6-day race. Before and after SDT, the participant performed 5 consecutive days of daily 2-hour constant-pace running with SD on the first and third night. Psychological and physiological responses were measured during this multiday test. ***Results:*** SDT was well tolerated by the athlete. A visual analysis of the data suggests that including SDT in the weeks preceding an ultraendurance competition may have beneficial effects on sleepiness and perceived mental effort in the context of 5 consecutive days of prolonged running and 2 nights of SD. This multiday test seems a feasible way for assessing ultraendurance athletes in the laboratory. ***Conclusions:*** The results provided some encouraging initial information about SDT that needs to be confirmed in a randomized controlled trial in a group of ultraendurance athletes. If confirmed to be effective and well tolerated, SDT might be used in the future to help ultraendurance athletes and other populations that have to perform in conditions of SD.

Keywords: perception of effort, fatigue, EEG, aerobic exercise, mental effort

Sleep deprivation (SD) is very common during ultraendurance competitions,[1] and it is known to reduce endurance performance.[2] At present, naps[1] and caffeine[3] are the most common strategies used to reduce the negative effects of SD on ultraendurance performance. Here we propose and apply a novel strategy called SD training (SDT).

SDT consists in the systematic and intermittent repetition of isolated bouts of SD interspersed by adequate recovery periods to avoid the negative effects of chronic sleep restriction. We hypothesize that the addition of intermittent SD into a typical physical training program would counteract the negative effects of SD on endurance performance.

The aim of the current study was to implement, for the first time, SDT in an athlete preparing for the French 6-Day Race to assess its initial feasibility and tolerability. We also developed a novel multiday laboratory test to investigate the effects of SDT in ultraendurance runners.

Methods

Participant

A 63-year-old male ultraendurance runner of international standing participated in the current case study. The participant was a good sleeper (Pittsburgh Sleep Quality Index score: 3)[4] and a definite morning person (Morning–Evening Questionnaire score: 73).[5] Prior to taking part in the experiment, he was informed about the experimental protocol and signed an informed consent. All procedures used were approved by the University of Kent ethics committee and were conducted in conformity with the Declaration of Helsinki. The participant could not be blinded from the real aim of the study as he personally contacted our research team to try new training strategies.

Study Design

The participant visited the psychobiology laboratory at the School of Sport and Exercise Sciences (SSES), University of Kent, before and after 6 weeks of SDT. On both occasions, after an incremental running test and a day of rest, the subject performed a multiday test consisting of 5 consecutive days of sleepiness and prolonged running tests (days 1–5), conducted after alternated nights of normal sleep (nights 0, 2, and 4) and SD (nights 1 and 3).

All visits commenced at 8:00 AM and were completed by 11:00 AM. The participant was instructed to maintain his habitual diet and to drink 35 mL/kg body weight of water per day. The participant was not allowed to consume any caffeine and alcohol in the 12 hours before each visit.

Procedures

Incremental Running Test. The participant performed submaximal 4-minute increments for lactate threshold determination on a motorized treadmill (Pulsar 3P; h/p/cosmos Sports and Medical, Nußdorf, Germany). After 30-minute recovery, the participant completed 1-minute increments until volitional exhaustion to determine maximal oxygen uptake. Pulmonary gas exchange was measured breath-by-breath (MetaLyzer 3B; Cortex Biophysik GmbH, Leipzig, Germany). Heart rate (HR) was collected throughout the entire testing (Polar V800; Polar Electro Oy, Kempele,

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Table 1 Anthropometric and Physiological Characteristics of the Ultraendurance Runner Before and After 6 Weeks of SDT

Characteristic	Pre-SDT	Post-SDT
Height, m	1.66	1.66
Body mass, kg	56	58
BMI, kg/m^2	20	21
Peak velocity, km/h	16.2	16.5
$\dot{V}O_{2\,max}$, mL/kg/min	46.0	43.6
HR_{max}, beats/min	164	156
2 mmol/L $[La^-]_b$ threshold, km/h	12.5	13.1
4 mmol/L $[La^-]_b$ threshold, km/h	13.7	14.3

Abbreviations: BMI, body mass index; HR_{max}, maximal heart rate; SDT, sleep deprivation training; $\dot{V}O_{2\,max}$, maximal oxygen uptake; $[La^-]_b$, blood lactate concentration (in millimoles per liter).

Finland). Rating of perceived exertion (RPE) was taken at the end of each increment using the Borg 15-point RPE scale.[6] The participant was then familiarized with the sleepiness and prolonged running tests.

Sleepiness and Prolonged Running Tests. After verifying that the participant followed all the instructions, a standardized light breakfast was provided. The participant subsequently performed the alpha attenuation test,[7] an objective measure of sleepiness based on 12-minute eyes-closed eyes-open electroencephalography (EEG). Finally, the participant ran for 2 hours on the treadmill at a constant speed of 11 km/h (corresponding to the average speed adopted during his last competitions). Perception of effort and affective valence were measured every 10 minutes using the Borg 15-point RPE scale[6] and the Feeling Scale.[8] HR was collected continuously during the test. The participant was allowed to see the remaining time. No verbal encouragement was given. Immediately after the 2-hour run, the participant completed the NASA Task Load Index,[9] a subjective measure of workload.

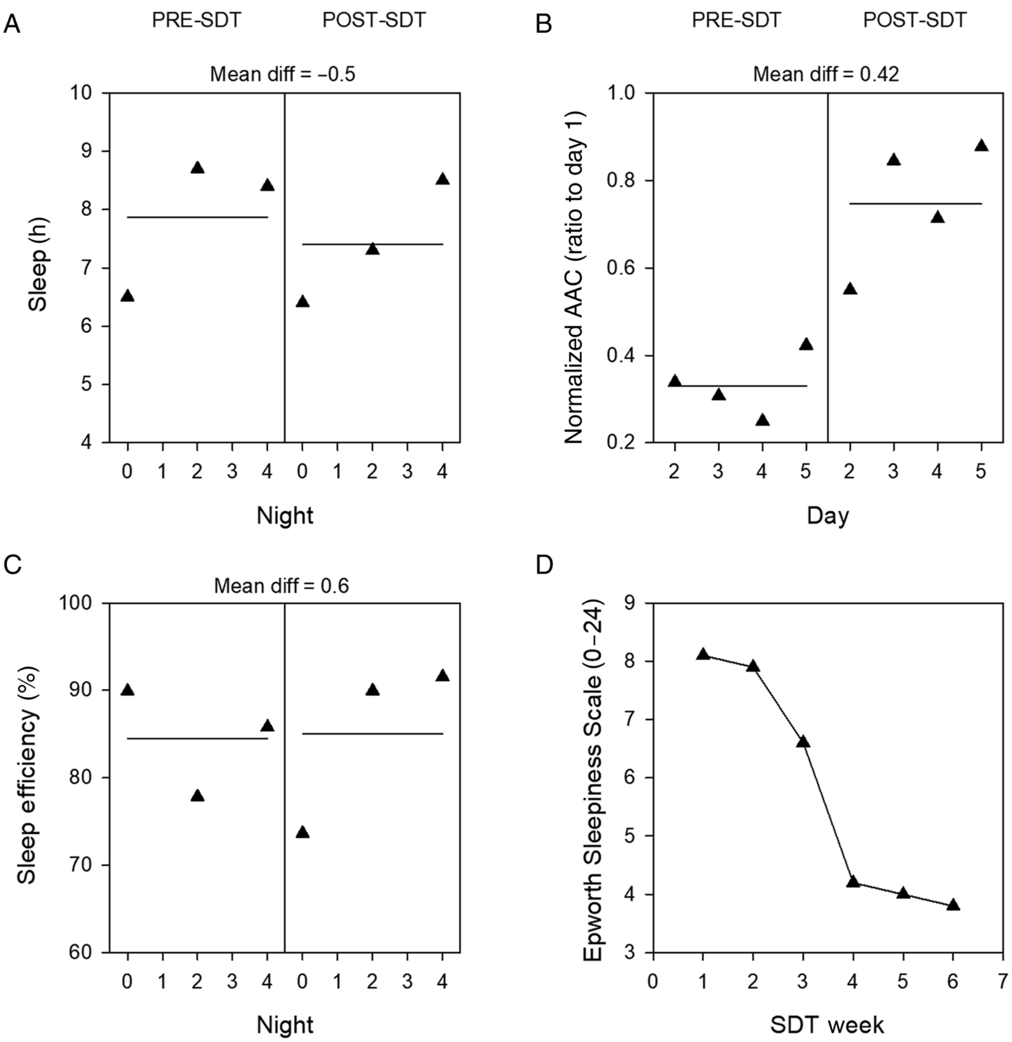

Figure 1 — Changes and mean level lines in the hours of sleep (A) and sleep efficiency (percentage of time spent asleep/total amount of time in bed) at night 0 to 4 (C) and in the alpha attenuation coefficient at days 2 to 5 normalized as ratio to day 1 (B), pre-SDT (right side of the panel) and post-SDT (left side of the panel). The difference between mean post-SDT and mean pre-SDT (mean diff) is also reported. (D) Changes in the subjective sleepiness over the 6-week SDT. SDT indicates SD training.

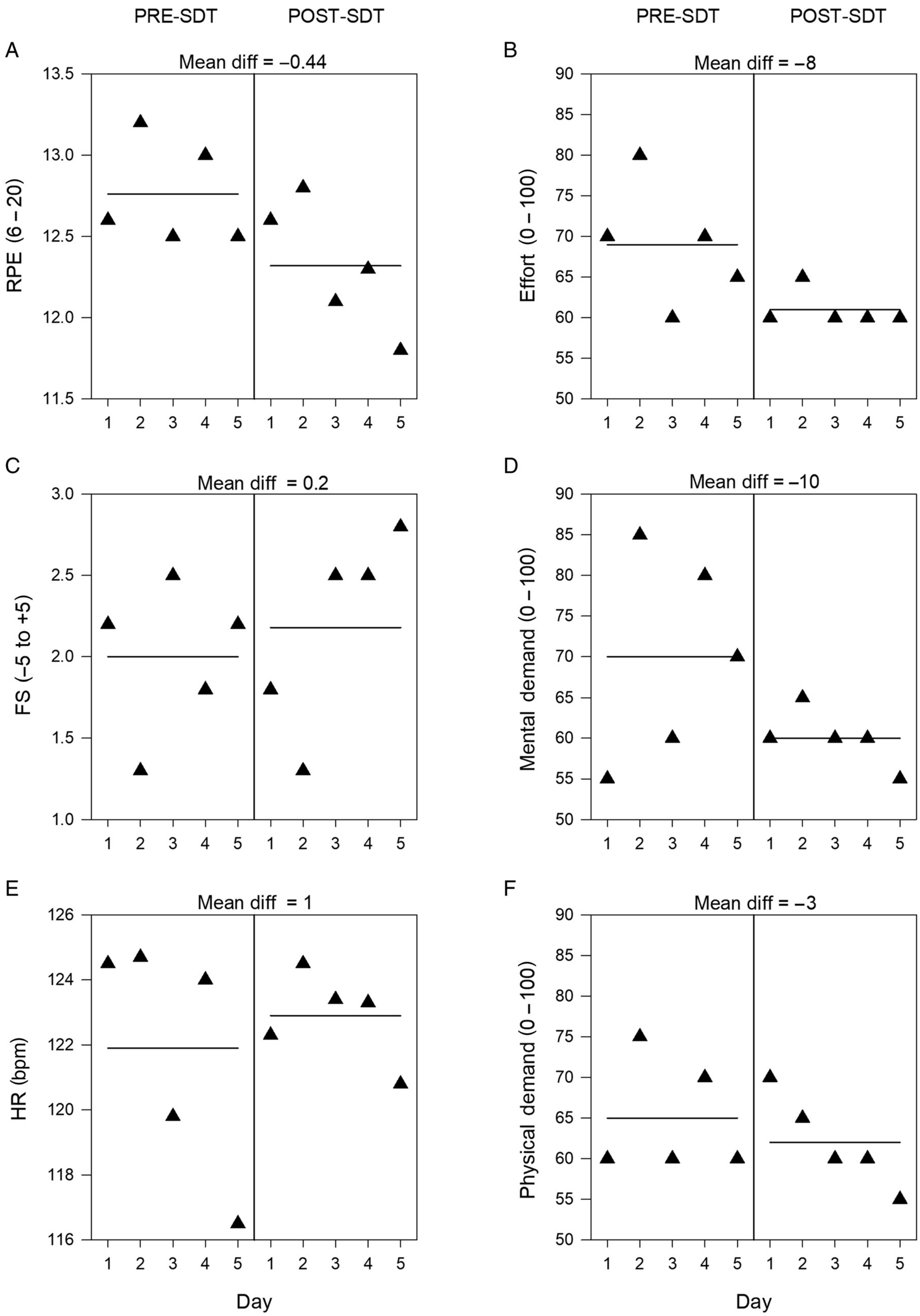

Figure 2 — Changes and mean level lines (bold lines) in RPE (A), FS (C), and HR (E) measured during the running tests and in mental demand (B), physical demand (D), and effort (F) dimensions of subjective workload measured immediately after the running tests. Data points refers to day 1 to 5 pre-SDT (left side of the panels) and day 1 to 5 post-SDT (right side of the panels). The difference between mean post-SDT and mean pre-SDT (mean diff) is reported for each variable. bpm indicates beats per minute; FS, Feeling Scale; HR, heart rate; mean diff, mean difference; RPE, rating of perceived exertion; SDT, SD training; SD, sleep deprivation.

Electroencephalography. The EEG data were collected using a dual 2.4 GHz band wireless system (1000-Hz sampling frequency) (BioNomadix; Biopac, Goleta, CA), with 2 gel-based Ag/AgCl electrodes (Ambu Neuroline 720; Ambu A/S, Ballerup, Denmark) placed in the frontal F3 and F4 positions (International 10–20 System). Reference and ground electrodes were placed on earlobes and forehead, respectively. Electrodes' impedance was checked prior to testing and maintained to <5 kΩ. The AcqKnowledge Software (version 4.1; Biopac) was used for data acquisition.

The EEG data were analyzed using EEGLAB (version 2020.0; SCCN, La Jolla, CA). Data were filtered using a passband Butterworth filter (0.5–30 Hz) and downsampled to 128 Hz. Eye-blinks and data artifacts were removed using artifact subspace reconstruction. Spectral analysis (fast fourier transform) was used to calculate the power spectral density of each 4-second overlapped epoch (50% overlapped Hanning windows). The alpha attenuation coefficient (corresponding to the alpha mean power ratio between eyes closed and eyes open)[7] was then computed per each channel and averaged. The MATLAB software (R2016a; MathWorks, Natick, MA) was used for data analysis.

Sleep During Testing. The participant was required to spend the nights of normal sleep in a quiet hotel room and the nights of SD in the Student Hub of SSES (from 08:00 PM to 08:00 AM) under strict monitoring of one member of the research staff. The participant was not allowed to take any naps at any time of the day. A wrist actigraphy device (AW Spectrum PRO; Philips Respironics, Murrysville, PA) was used to monitor and quantify his sleep-wake activity.

Sleep Deprivation Training. In addition to his physical training program, the participant did not sleep once per week (Sunday night) for 6 consecutive weeks. The day after the night of SD, the participant performed a steady prolonged run (2.5/3.5 h at an average speed of 10 km/h) session in a sleep-deprived state and was instructed not to take any naps. The participant spent the SD nights at home and was monitored remotely. To prevent the development of a state of nonfunctional overreaching or overtraining, the participant was monitored for the entire duration of the training program through a global positioning system watch as well as through the completion of the Epworth Sleepiness Scale[10] (daily) and the Brunel Mood Scale[11] (weekly) from which the Total Mood Disturbance (TMD) score[11] was calculated.

Data Analysis

A systematic visual analysis of the data was used to enhance the interpretation of the present results.[12] Level lines corresponding to the mean of the data points pre-SDT and post-SDT were added to the relevant graphs to facilitate comparisons.

Results

Anthropometric and physiological characteristics of the participant before and after SDT are shown in Table 1.

The hours of sleep during the multiday test were slightly lower post-SDT (Figure 1A). The sleep efficiency during the multiday test was high both pre-SDT and post-SDT (Figure 1C). The alpha attenuation coefficient during the multiday test normalized for day 1 was higher post-SDT (Figure 1B). Subjective sleepiness decreased over the 6-week intervention (Figure 1D). Mood did not substantially change over the 6-week intervention (TMD score range: 162–167). Weekly average running/walking training volume was 62 km and session-RPE 13.

The RPE during the multiday test was slightly lower post-SDT (Figure 2A). This trend was confirmed by substantially lower effort (Figure 2B) and mental demand (Figure 2D) during the multiday test post-SDT. The physical demand during the multiday test did not differ substantially between pre-SDT and post-SDT (Figure 2F). Similarly, only small differences were observed for affective valence (Figure 2C) and HR (Figure 2E) measured during the multiday test.

Discussion

The alpha attenuation test revealed a reduction in sleepiness during the multiday test following SDT. The progressive decline in subjective sleepiness reported during the training period also confirms that SDT reduces sleepiness levels. Moreover, the small physiological/performance improvements post-SDT (Table 1) and the TMD scores suggest that SDT can be used for 6 weeks concurrently with the rigorous physical training required for an ultramarathon without inducing nonfunctional overreaching or overtraining.

Previous studies have demonstrated that acute SD impairs endurance performance by negatively affecting RPE.[2] In the present study, the participant reported slightly lower RPE during the multiday test after 6-week SDT, suggesting that this new form of training may reduce the negative effects of SD on perception of effort and endurance performance. This finding was corroborated by the substantial reduction in the effort dimension of subjective workload, which confirmed that the participant perceived less effort during the post-SDT multiday test. Considering that his fitness level and the HR and physical demand during the multiday test did not substantially change in response to 6-week SDT and physical training, the considerable reduction in mental demand could be the key factor mediating the positive effect of SDT on perception of effort during the multiday test.

Although more work is needed to validate it and assess its reliability, the novel multiday test we developed for this case study seems a feasible way to assess in the laboratory runners who participate in multiday ultraendurance competitions.

Practical Applications and Conclusions

The combination of 6-week SDT with physical training seems to be well tolerated and effective in reducing perception of mental effort in the context of 5 consecutive days of prolonged running and 2 nights of SD. These preliminary findings need to be corroborated by a randomized controlled trial before SDT can be recommended to ultraendurance athletes preparing for a multiday event.

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References

1. Martin T, Arnal PJ, Hoffman MD, Millet GY. Sleep habits and strategies of ultramarathon runners. *PLoS One*. 2018;13(5):e0194705. PubMed ID: 29742118 doi:10.1371/journal.pone.0194705
2. Fullagar HHK, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise.

Sports Med. 2015;45(2):161–186. PubMed ID: 25315456 doi:10.1007/s40279-014-0260-0
3. Getzin AR, Milner C, LaFace KM. Nutrition update for the ultra-endurance athlete. *Curr Sports Med Rep*. 2011;10(6):330–339. PubMed ID: 22071393 doi:10.1249/JSR.0b013e318237fcdf
4. Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Res*. 1989;28(2):193–213. PubMed ID: 2748771 doi:10.1016/0165-1781(89)90047-4
5. Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol*. 1976;4(2):97–110. PubMed ID: 1027738
6. Borg G. *Borg's Perceived Exertion and Pain Scales*. 1998;104. https://psycnet.apa.org/fulltext/1998-07179-000.pdf
7. Stampi C, Stone P, Michimori A. A new quantitative method for assessing sleepiness: the alpha attenuation test. *Work & Stress*. 1995;9(2–3):368–376. doi:10.1080/02678379508256574
8. Hardy CJ, Rejeski WJ. Not what, but how one feels: the measurement of affect during exercise. *J Sport Exerc Psychol*. 1989;11(3):304–317. doi:10.1123/jsep.11.3.304
9. Hart SG, Staveland LE. Development of NASA-TLX (task load index): Results of empirical and theoretical research. In: Hancock PA, Meshkati N, eds. *Human Mental Workload*. *Advances in Psychology*. Vol. 52. Amsterdam, North-Holland; 1988:139–183.
10. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep*. 1991;14(6):540–545. PubMed ID: 1798888 doi:10.1093/sleep/14.6.540
11. Terry PC, Lane AM. Normative values for the profile of mood states for use with athletic samples. *J Appl Sport Psychol*. 2000;12(1):93–109. doi:10.1080/10413200008404215
12. Krasny-Pacini A, Evans J. Single-case experimental designs to assess intervention effectiveness in rehabilitation: a practical guide. *Ann Phys Rehabil Med*. 2018;61(3):164–179. PubMed ID: 29253607 doi:10.1016/j.rehab.2017.12.002