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

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Title: Sleep Deprivation Training (SDT) to reduce the negative effects of sleep loss on endurance performance: a single case study.

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Abstract

Purpose
Sleep deprivation (SD) is very common during ultra-endurance competitions. At present stimulants such as caffeine, and naps are the main strategies used to reduce the negative effects of SD on ultra-endurance performance. In this case study, we described the application of a novel strategy consisting of the intermittent repetition of SD (Sleep Deprivation Training, SDT) during the weeks preceding an ultra-endurance competition.

Methods
A male ultra-endurance runner underwent a 6-week SDT programme (consisting of one-night SD every Sunday) in addition to his regular physical training programme before taking part in a 6-day race. Before and after SDT, the participant performed five consecutive days of daily 2-h constant-pace running with SD on the first and third night. Psychological and physiological responses were measured during this multi-day test.

Results
SDT was well tolerated by the athlete. A visual analysis of the data suggests that including SDT in the weeks preceding an ultra-endurance competition may have beneficial effects on sleepiness and perceived mental effort in the context of five consecutive days of prolonged running and two nights of SD. This multi-day test seems a feasible way for assessing ultra-endurance 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 ultra-endurance athletes. If confirmed to be effective and well-tolerated, SDT might be used in the future to help ultra-endurance athletes and other populations that have to perform in conditions of SD.

Keywords

Perception of Effort, Fatigue, EEG, Aerobic Exercise, Mental Effort

Introduction

Sleep deprivation (SD) is very common during ultra-endurance 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 ultra-endurance performance. Here we propose and apply a novel strategy called Sleep Deprivation 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 programme 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 multi-day laboratory test to investigate the effects of SDT in ultra-endurance runners.

Methods

Participant

A 63-year-old male ultra-endurance runner of international standing participated in the current case study. The participant was a good sleeper (PSQI 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 local 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, University of Kent, before and after 6 weeks of SDT. In both occasions, after an incremental running test and a day of rest, the subject performed a multi-day test consisting of five consecutive days of sleepiness and prolonged running tests (Day 1-5), conducted after alternated nights of normal sleep (Night 0, 2, 4) and SD (Night 1, 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 a submaximal 4-min incremental step test for lactate threshold determination on a motorised treadmill (Pulsar 3P; h/p/cosmos Sports and

Medical, Germany). After 30-min recovery, the participant completed a 1-min incremental step test until volitional exhaustion to determine VO_{2max}. Pulmonary gas exchange was measured breath-by-breath (MetaLyzer 3B, Cortex Biophysik GmbH, Germany). HR was collected throughout the entire testing (Polar V800, Polar Electro Oy, Finland). RPE was taken at the end of each step in both tests using the Borg's 15-point scale[6]. The participant was then familiarised with the sleepiness and prolonged running tests.

Sleepiness and Prolonged Running Tests

After verifying that the participant followed all the instructions, a standardised light breakfast was provided. The participant subsequently performed the AAT[7], an objective measure of sleepiness based on 12-min eyes-closed eyes-open electroencephalography (EEG). Finally, the participant ran for 2 hours on the treadmill at a constant speed of 11 km/h (i.e. average speed adopted during his last competitions). RPE and affective valence were collected every 10 minutes using the Borg's 15-point scale[6] and the Feeling Scale (FS)[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-TLX[9], a subjective measure of workload.

EEG

EEG data were collected using a dual 2.4 GHz band wireless system (1000 Hz sampling frequency) (BioNomadix, Biopac, California, USA), with two gel-based Ag/AgCl electrodes (Ambu Neuroline 720, Ambu A/S, 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 Acknowledge Software (v4.1, Biopac) was used for data acquisition.

EEG data were analysed using EEGlab (v2020.0, SCCN, California, USA). 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 (FFT) was used to calculate the power spectral density (PSD) of each 4-sec overlapped epoch (50% overlapped Hanning windows). The Alpha Attenuation Coefficient (AAC)[7] was then computed per each channel and averaged. The Matlab software (R2016a, Mathworks, Massachusetts, USA) 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, Pennsylvania, USA) was used to monitor and quantify his sleep-wake activity.

SDT

In addition to his physical training programme, the participant did not sleep once per week (Sunday night) for six consecutive weeks. The day after the one-night 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 non-functional overreaching or overtraining, the participant was monitored for the entire duration of the training programme through a GPS watch as well as through the completion of the Epworth Sleepiness Scale[10] (daily) and the BRUMS[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 multi-day test were slightly lower post-SDT (Figure.1A). The sleep efficiency during the multi-day test was high both pre- and post-SDT (Figure.1C). The AAC during the multi-day test normalised for Day 1 was higher post-SDT (Figure.1B). Subjective sleepiness decreased over the 6-week intervention (Figure.1D). TMD did not substantially change over the 6-week intervention (range: 162-167). Weekly average running/walking training volume was 62 km and session-RPE 13.

RPE during the multi-day 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 multi-day test post-SDT. The physical demand during the multi-day 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 multi-day test.

Discussion

The AAT revealed a reduction in sleepiness during the multi-day 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 six weeks concurrently with the rigorous physical training required for an ultra-marathon without inducing non-functional 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 multi-day 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 multi-day test. Considering that his fitness level and the HR and physical demand during the multi-day 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 multi-day test.

Although more work is needed to validate it and assess its reliability, the novel multi-day test we developed for this case study seems a feasible way to assess in the laboratory runners that participate in multi-day ultra-endurance 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 five consecutive days of prolonged running and two nights of SD. These preliminary findings need to be corroborated by a randomized controlled trial before SDT can be recommended to ultra-endurance athletes preparing for a multi-day event.

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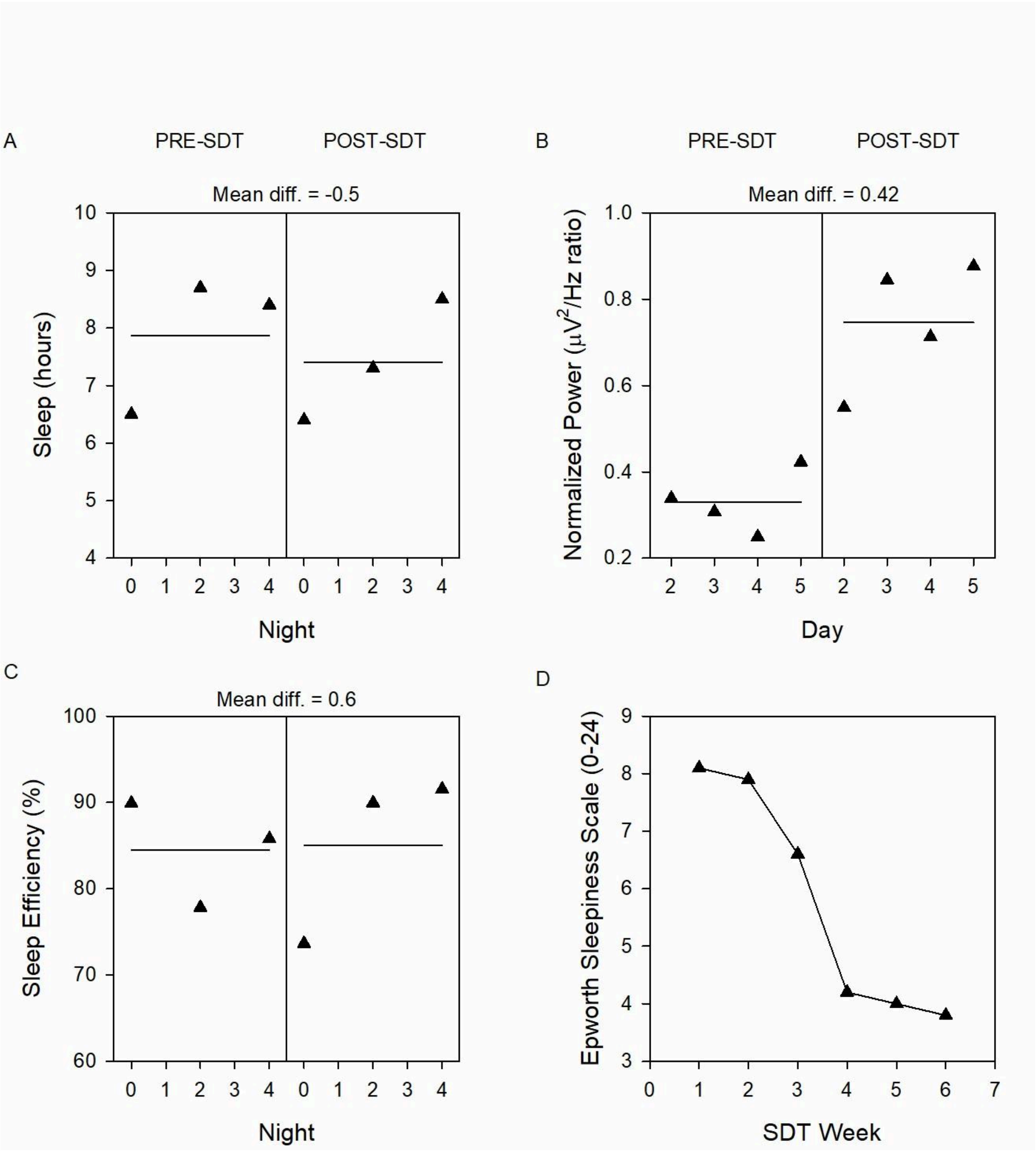

Figure 1. Changes and mean level lines in the hours of sleep (panel A) and sleep efficiency (% of time spent asleep/total amount of time in bed) at Night 0-4 (panel C), and in the normalised AAC at Day 2-5 (panel B), pre-SDT (right side of the panel) and post-SDT (left side of the panel). The mean difference (Mean diff.) computed as the difference between [mean post-SDT] and [mean pre-SDT] is also reported. Panel D shows changes in the subjective levels of sleepiness over the 6-week SDT.

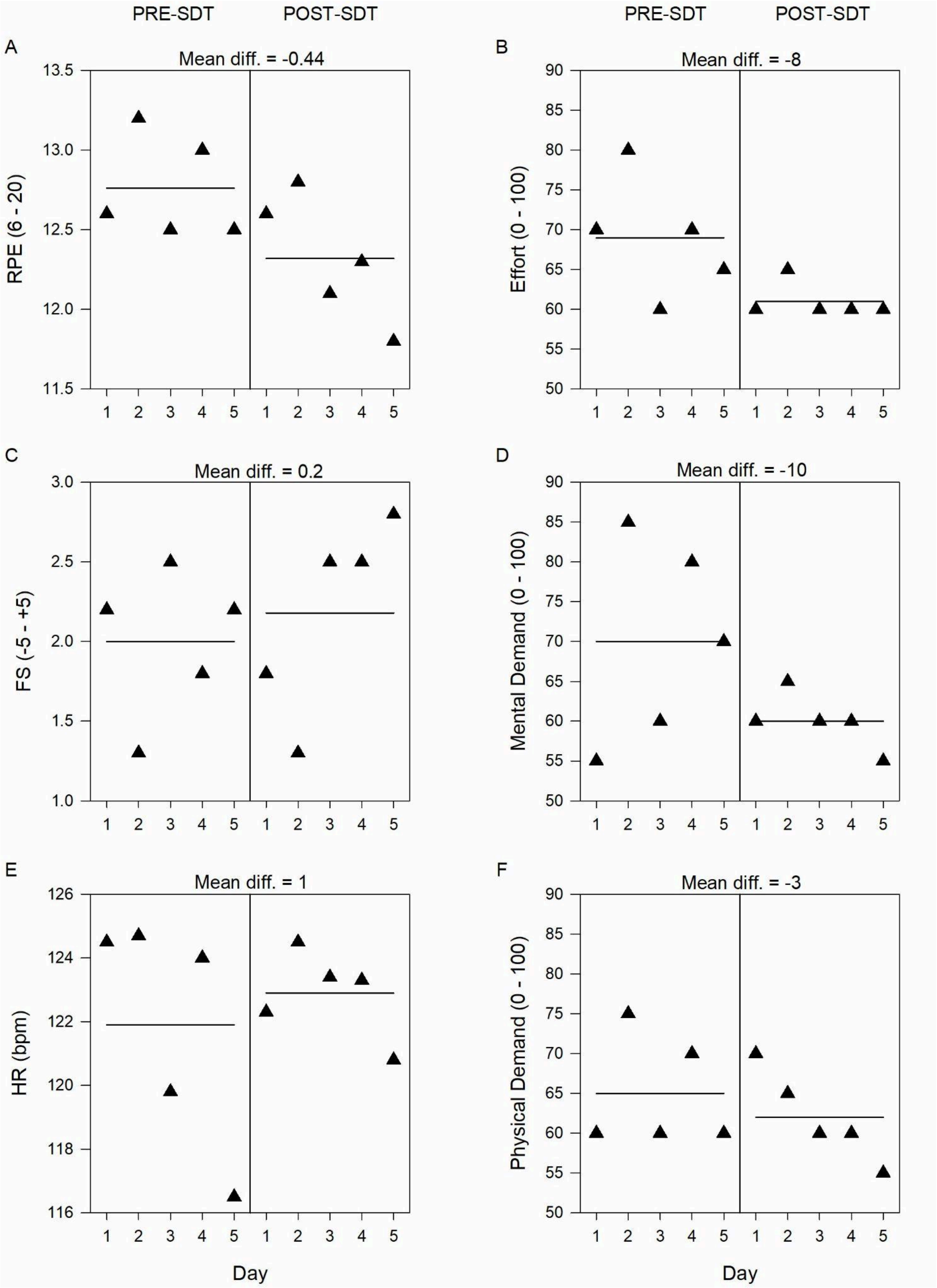

Figure 2. Changes and mean level lines (bold lines) in RPE (panel A), FS (panel C) and HR (panel E) measured during the running tests and in mental demand (panel B), physical demand (panel D) and effort (panel F) dimensions of subjective workload measured immediately after the running tests. Data points refers to Day 1-5 pre-SDT (left side of the panels) and Day 1-5 post-SDT (right side of the panels). The mean difference (Mean diff.) computed as the difference between [mean post-SDT] and [mean pre-SDT] is reported for each variable.