

Effects of a Single Bout of Exercise on Memory and Attention Following One Night of Sleep Loss: Results of a Randomised Controlled Pilot Study

Johannes Fleckenstein (✉ johannes.fleckenstein@sport.uni-frankfurt.de)

Goethe University <https://orcid.org/0000-0003-3442-0380>

Sina Gerten

Goethe University Frankfurt: Goethe-Universität Frankfurt am Main

Winfried Banzer

Goethe University Frankfurt: Goethe-Universität Frankfurt am Main

Research

Keywords: insomnia, sleep deprivation, exercise therapy, mental performance, shift-work

Posted Date: January 4th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-136362/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background

Sleep-loss is a severe problem in night-shift workers. It causes fatigue and a decrease in awareness that may be counter-acted by exercise. This randomised controlled study in 22 university students investigated the effects of exercise on cognitive and physical performance following sleep deprivation.

Methods

We were comparing a single bout of a 20-minutes circuit training to control in an experimental setting of overnight sleep loss. Outcomes included memory, cognitive tasks, and physical parameters. The occurrence of false memories was considered being the main outcome.

Results

Exercise did not exert significant effects on false memories ($p = 0.456$). We could detect a trend to significance ($p < 0.01$) assessing cognitive dimensions, i.e. selective and sustained attention, and visual scanning speed. This revealed strong effects of exercise on attention ($p = 0.091$; Cohen's $d = 0.76$; $\Delta 14\%$), cognitive performance, performance speed, and perceived sleepiness ($p = 0.008$; $d = 0.60$; $\Delta 2.4$ cmVAS).

Conclusions

This study failed to show effects of exercise on memory function. Still, medium to strong effects on attention and consciousness can be considered clinically relevant. The results of this study encourage further research to determine its practicability and meaningfulness among night-shift workers.

Trial registration

German Clinical Trials Register, DRKS00010655, registered 21. June 2016.

Background

Sleep deprivation and sleep loss negatively impact our quality of life, mood, cognitive function, and health [1]. Insomnia increases the use of health care resources and is a risk factor for cardiovascular diseases. Studies show an association between short sleep duration, sleep disturbances, and circadian desynchronization of sleep with adverse metabolic traits, i.e. obesity and type 2 diabetes [2]. Recently an animal study hypothesized, that shift work-induced pathophysiologic changes go beyond the transcriptomic cellular level, regulating the circadian rhythm [3]. As within shift workers [4], bad sleep is common in jobs with high estimated levels of distress, such as truck drivers [5], railroad employees [6], or jet lags when crossing several time zones [7].

Besides illness, sleep deprivation limits our mental performance. Sleep loss results in the choice of low-effort behaviour [8]. In consequence this may reduce decision-making in physicians [9], impair the

cognitive performance of nurses [10], and shooters show a degraded marksmanship performance [11]. A study in polysomnography technicians showed one 12 hours night shift to be already sufficient to increase perceived sleepiness, reaction time and the number of lapses of attention [12].

Exercise has been emphasized being an approach to motivate tired populations and to improve the quality of sleep. Among workers with work-related fatigue, a 6 weeks exercise intervention improves employees' well-being, and reduces the degree of emotional exhaustion [13]. This is in line with a trial showing effects on study-related fatigue among university students [14]. Exercise and physical activity seem suitable to improve the quality of sleep in a variety of specific indications, e.g. pregnancy [15], concerned parents of children with cancer [16], or female university students [17]. There is one study, showing 16 weeks of aerobic exercise to improve daytime function and reduce depressive symptoms besides improving sleep in older adults with insomnia [18]. Finally, in the elderly, physical activity has been suggested to improve cognition [19] and to prevent people from cognitive decline [20].

In summary, literature suggests general benefits of exercise on symptoms following sleep loss [21]. Exercise is easily applicable and would thus be a valuable option for shift-workers to be performed after the shift before being exposed to decision-making and cognitive tasks in their daily life. This exploratory pilot study was designed to determine if a single exercise intervention is able to address both, functional and mental skills in healthy subjects following sleep loss.

Methods

Study Design

A single-centre randomised controlled study investigating the effects of a 20-minutes moderate-to-vigorous circuit training on parameters of cognitive performance when compared to a passive control. The study took place in the summer term 2016 at the Sports Campus of the Goethe-University Frankfurt am Main, Germany. The study was approved by the Ethics Committee FB05 of the Goethe-University of Frankfurt, Germany (reference 2016-23) and is in agreement with the Declaration of Helsinki (Version Fortaleza 2012). The study was registered on June 21st 2016 at the German Clinical Trials Register (DRKS00010655). Written informed consent was achieved by all participants

Participants checked in at 18:00 the day of the experiment, starting with a collective standardised Mediterranean dinner (grilled chicken, salad, vegetables, water). Eating was stopped at 20:00 and after two hours of digestion, baseline parameter were assessed at 22:00 (see Fig. 1). In the following night, sleep loss of the participants was assured by the study team. The participants watched two mainstream movies, were allowed to talk, to play cards or other board games that did not require physical activity or high intellectuality. Slices of vegetables (cucumber, peppers, and tomatoes) were offered till 4:00. At 6:30 participants were randomised into two groups with the "exercise group" leaving to a nearby gym where they participated in an exercise program, whereas the "control group" remained passively seated in the common area. At 7:30 all outcomes were re-assessed and the study ended thereafter.

Participants

Participants (> 18 < 36 years) with good sleep (6 to 8 hours/night) and no abuse of substances were assessed for study eligibility using the following exclusion criteria: pregnancy or lactation, intake of neuroenhancers, ability for smoking cessation less than 24 hours, suffering from diabetes, severe illness influencing the quality of life, or severe illness influencing the mental or physical performance. All participants signed a written informed consent prior to enrolment.

All participants have been recruited advertising at the Campus two weeks prior to the experiment.

Randomised treatment allocation, blinding and sample-size estimation

Participants were randomly assigned to one of the two study groups using the smartphone-based application Certified True Randomizers (Integer Generator, Random.org, Dublin, Ireland).

Sample size was estimated a priori using the software G*Power (Version 3.15, University of Düsseldorf, Germany). With α set at 5%, 22 participants are required to have 90% power to detect a decreased number of false memories in the intervention group (estimated 10%) as described for the use of caffeine.[22]

Exercise Intervention

The exercise intervention was performed after sleep deprivation at approx. 7:00. Participants exercised together and performed a 20-minutes lasting circuit training under the guidance of two trainers. First, Warm-Up was performed for 5 minutes and consisted of a series of five movements, each for 60 seconds, i.e. marching on the spot, side to side weight stabilising, step touches, double step touches, and V-steps. Second, the main exercise was performed for 10 minutes, including 10 exercises, 30 seconds each, with a 30 sec break – where participants shook their extremities out- between: 1) Air Squats, 2) Linear Lunges, 3) Side Lunges, 4) Push Ups, 5) Hip Lifts, 6) Plank + Push Ups, 7) Mountain Climber, 8) Swimming WoMan, 9) Pec Fly in push-up position, 10) Bird Dog. Warm-Up and Exercise was accompanied by music at 128 bpm. Third, Cool-Down was performed for 5 minutes including five different moves, 60 sec each. Two of the included elements derived from Yoga, i.e. sun salutation and the warrior, the other three were rotation of the vertebra, and stretching of chest and the quadriceps muscles. An internal assessment of this program among Master students of exercise physiology prior to this study revealed the exercise to be of vigorous intensity (60–80% HRR).

Outcome measures

Demographics included information on smoking, drinking behaviour (alcohol, coffee, caffeine, energy drinks), the extent of physical activity, and the quality of sleep (Pittsburgh Sleep Quality Inventory PSQI, German version) [23]. The PSQI ranges from 0 to 21 with higher scores indicating a decreased quality of sleep, and a PSQI > 5 being a cut-off value for good and bad sleepers.

Main Outcome Measure

Based on the sample size calculation the rate of false memories dating from the Dese, Roediger and McDermott (DRM) paradigm [24] were chosen as primary outcome, and implemented as an experimental False Memory Task by Diekelmann et al. [22]. Participants learned 18 DRM lists the evening prior to sleep loss. Each list consisted of 15 semantically associated words (e.g. apple, vegetables, orange, juice, ...). The list words were presented sequentially by a human female voice with a delay of ten seconds between lists and 750 ms between words, at the end of the baseline assessments in the evening previous to sleep deprivation. Retrieval took place the next morning in the common area, 108 words were projected in white letters on a black background at the wall. Half of these words originated from the evening before, 36 words were distractors not matching the list topics, and 18 words were theme words that had never been presented before (so called false memories). Participants gave an old/new judgment for each word (i.e. to indicate whether the word had been presented during learning or not), a confidence rating for their answer on a 4-point scale ranging from 1 ("I had to guess") to 4 ("absolutely sure"), and a Remember/Know/Guess judgment for words judged as "old". The ratios of false memories, true recognition and false alarms were calculated according to Diekelmann [22].

Secondary outcome measure

Secondary outcomes included psychologic as well as physical parameters. The d2 test of attention was used to assess selective and sustained attention, and visual scanning speed [25]. It consists of a general attention score (total errors per total task, in %), with lower scores indicating higher performance. Subindices include performance speed (total number processed, max. 299), and concentration performance (speed minus error count), with higher scores indicating improvement.

The severity of sleep deprivation was assessed using the Stanford Sleepiness Scale, ranging from 0 to 10 cm (with 0 cm being "fully awake", and 10 cm "sleeping") [26].

The German version of the Multidimensional Mood Questionnaire (MDBF; [27]) was used to assess three different dimensions of stress and anxiety, i.e. good-bad mood, awake-tired and calm-nervous, which are supposed to be expressions of mood, mental fatigue, and feelings of restlessness. Higher scores indicate a positive attitude.

Physical parameters included grip strength using a manual dynamometer (JAMAR, Homecraft Ltd, Nottinghamshire, UK), pressure pain threshold (PPT) with a mechanical pressure algometer (pdt, Rome, Italy; range 2–20 kg/cm², diameter 1 cm) upon the belly of the transversal trapezius muscle, as well as the Balance Error Scoring System (BESS; [28]). The BESS is a standardised battery investigating balance in three different stances (double-leg, single leg, and tandem stance) on first a firm and second a foam surface (range 0–60 points, with 60 indicating worst balance).

The sequence of assessments was in the order as described above, with the exception that the D2-test and the test for false memories were performed as the last two assessments.

Statistical Analysis

Statistical analysis was conducted for comparison of the primary and secondary outcome measures between the two study groups. No evidence was found that the parametric tests used were inappropriate. Baseline characteristics and single time point data were analysed with unpaired t-test (for continuous measures) and chi-square test (for nominal data) to assess for differences among the two study groups. Longitudinal data were analysed using a time x group repeated measures ANOVA (2 × 2), followed by an unpaired t-test of change scores for post-hoc comparisons. Effect sizes according to Cohen were calculated for all relevant outcomes. Significance with $\alpha < 10\%$ was considered showing a statistical trend (pilot study), whereas $< 5\%$ indicated significant differences. Data are presented as mean \pm standard deviation.

Data analysis was performed with the SPSS statistical software system, version 24.0 (SPSS Inc., Chicago, IL, USA).

Results

Twenty-two participants (8 female and 14 male, age 29.0 ± 3.0 years, weight 71.6 ± 10.7 kg, height 175.6 ± 8.7 cm) were included in the study and no dropouts occurred during the trial. After randomisation we could observe in each group three left-handed participants, and three participants with a PSQI score > 5 (range 6-11) indicating mild sleeping disorders. There were no differences between groups regarding the intake of alcohol, coffee, caffeine products, energy drinks and cigarettes. Time spent with exercise was similar in both groups. Handiness revealed. There was no significant difference of any outcome between groups at baseline (Table 1).

We could not detect significant differences between intervention and control regarding the occurrence of the false memory rate (0.80 ± 0.12 vs. 0.76 ± 0.16 , unpaired t-test $p = 0.456$), false alarm rate (0.40 ± 0.12 vs. 0.43 ± 0.08 , $p = 0.40$), or true recognition rate (0.70 ± 0.13 vs. 0.67 ± 0.15 , $p = 0.56$, see Table 2). Effect sizes do not suggest only small effects between groups, i.e. false memories (Cohen's $d = 0.32$, effect size correlation $r = 0.16$), false alarms ($d = 0.36$, $r = 0.18$), and recognition ($d = 0.25$, $r = 0.12$).

Time x group analysis of the d2 test showed a trend ($p < 0.1$) towards an improved cognition. Posthoc t-tests for inner-subject effects sustained this trend for all d2 items in the exercise group, i.e. attention ($p < 0.001$), as well as concentration performance ($p < 0.001$), and performance speed ($p < 0.001$). The attention score improved within the exercise group by $17.22 \pm 15.21\%$ versus $3.53 \pm 20.57\%$ in the control group (Table 2, Figure 2). The magnitude indicates a strong effect ($d = 0.76$, $r = 0.35$). This effect was consistent for performance ($d = 0.78$, $r = 0.36$) and speed ($d = 0.71$, $r = 0.34$).

Time x group analysis of sleepiness, the dimensions of mood, balance, grip strength, and pressure pain revealed no significant effects (see Table 2).

There were inner-subject effects on sleepiness ($p = 0.019$), with an increase of 0.59 ± 4.30 cm VAS in the intervention and 2.97 ± 3.54 cm VAS in the control group, with no significance between groups (posthoc unpaired t-test $p = 0.171$). The magnitude corresponds to a strong effect ($d = 0.60$, $r = 0.29$).

Subgroup analysis dependent on a PSQI > 5 (cut-off for sleeping disorders) did not alter the observed trends. However, improvements in attention in the exercise group were significantly more pronounced in participants with a PSQI ≥ 5 ($\Delta -32.43 \pm 18.29\%$) versus PSQI < 5 ($\Delta -11.51 \pm 32.43\%$; $p = 0.033$). The PSQI did not affect other outcomes.

Covariate analysis including gender did not reveal differences in the time x group analysis. Female gender led to decreased errors in the balance test ($\Delta -8.25 \pm 5.44$ versus $\Delta +2.71 \pm 7.27$, $p = 0.029$) in the intervention group. Pressure pain threshold was significantly reduced in female participants in the exercise group ($p = 0.038$), and grip strength in both female groups, exercise ($p = 0.004$) and control ($p = 0.011$). Gender had no effects on attention and false memories.

No harms have been observed within this study.

Discussion

Our study indicates strong effects of a single exercise intervention on the d2 cognitive and attention scores, as well as sleepiness following one night of sleep deprivation. The power of these assumptions is restricted due to the pilot character of the study, and as the global statistical test did only indicate trends but not a statistical difference based on an α -error < 0.05 . The study was designed in line with the sleep loss experiment described by Diekelmann [22], outcome measures were all established and validated, and we controlled for important influencers such as the incidence of sleeping disorders and the standardisation of meals.

Generalisability of effects

The experimental induction of sleep deprivation was successful, as demonstrated by an increase on the sleepiness scale in the control group by 3.0 points. This in line with other experimental set ups [22, 29]. Perceived sleepiness in the exercise intervention group did not relevantly increase (0.59 points). Although this corresponds to a strong effect size (Cohen's $d = 0.6$) favouring the exercise group, we could not detect statistical significance. From a clinical perspective our results are comparable to a study, showing exercise to significantly decrease feelings of lethargy, a sensation that might be similar to sleepiness [30].

Exercise showed small effects on memory, however without being significant. It is to doubt that this effect is of clinical importance. Sleep is the best remedy for memory consolidation [31].

In contrast, the effects on cognitive attention in our paradigm indicate strong influence by exercise and are of clinical relevance (mean improvement 15% in attention). One night on sleep deprivation is suggested to rather impact implicit but not explicit learning of serial-response time tasks [32]. This may

be corroborated by our findings in the d2 test, suggesting a higher performance speed. However, reduced errors as reflected in the d2 global score as well as an increased concentration performance could indicate that acute exercise-induced effects on memory and cognition are not only limited to this improved automatization. This is in accordance with a recent study showing acute exercise to improve executive cognitive functions in young adults [33].

Grip strength was assessed according to current principles, and the baseline force of the dominant hand of women (31.0 ± 4.0 kg) and man (48.2 ± 6.9 kg) is in agreement with German normative reference values [34]. Our data suggest an increase (2 kg) of maximal hand-grip strength. Even though grip strength measures have been validated to be robust in regard to test-retest settings, we cannot exclude effects of habituation. Still, an increase in grip strength could only be observed with in the exercised participants, in the control group, grip strength was reduced. Today, no link between sleep loss and grip strength has been reported. Consequently, effects of exercise on grip strength following sleep loss might be possible.

We could show that sleep deprivation mediates a decrease in pressure pain threshold in both groups, which is an indicator of facilitated pain perception. This is in line with previous findings of sleep disorders and pain sensitivity [35]. Training studies have shown that acute resistance exercise [36] as well as 12 weeks of aerobic exercise [37] are able to increase the pressure pain thresholds in general, effects we could not confirm following sleep loss.

We did not detect differences in mood as assessed by the MDBF. Our intervention phase may have been too short to cause significant effects. There is one study reporting a single session of 40 min aerobic exercise ($70\% \text{VO}_{2\text{max}}$) to cause improvements in morning subjective mood states [30]. A study investigating a multimodal 8month program in caregivers including exercise sessions could observe positive effects on stress and negative affection [38].

Implications of the exercise program

The participants in our study performed a single bout of exercise. Studies dealing with the effects of acute exercise on cognition have usually not been performed adding sleep-loss as an additional factor. As described above, Lluch et al. found acute exercise to improve mood and motivation [30]. It has been reported, that an acute bout of exercise improves the performance on an executive function task in individuals with schizophrenia [39]. High-intensity resistance exercise is more likely to reduce interference and improve reaction time in the evaluation of executive functions immediately after exercise, whereas low (40%) and moderate (70%) intensity improves performance on plus-minus tasks three hours after exercise [40]. The plus-minus task is a test for switching attention and is slightly comparable to the d2. As we did not assess the 3-hours follow-up period we are not aware if the effects of a single bout of vigorous exercise were even more pronounced at this time. An extended follow-up measurement should therefore be considered for future studies. A meta-analysis suggests acute bouts of exercise to reduce state anxiety [36], an outcome we did not assess in our study.

Finally, the timing of the exercise intervention possibly had an impact on the observed motor skills. It might be possible that exercise elicits larger effects when followed shortly after sleep, and not after sleep deprivation [31].

Limitations

We are aware that the lack of significances between groups limits the generalisability of findings. Effect-sizes are a well-established method to detect meaningful group differences, and effects found appear quite impressive. In addition with the small sample size and the character of the study design –i.e. a pilot study-, one should be aware that findings are only hints and will need confirmation.

As detailed above, this study did not cover the complete range of psychological cognition tests. It was designed to get a first insight into a complex understanding. Our study only observed one sleepless night in healthy and physically fit participants, but we did not extend sleep loss to several nights to display more realistic scenarios of daily life.

In addition, we did not control for cardiovascular fitness, as all of our participants were young academics at the sports campus, and their hand grip - correlating with oxygen uptake- was in the expected age-related group. However, fitness may moderate the interaction of acute exercise and cognition [41], and should be assessed on an individual level.

Conclusions

Acute circuit training following sleep loss seems to exert effects on attention and consciousness. These effects are small on the basis of a single bout of exercise, and it remains unclear whether they are meaningful for e.g. night-shift worker, or not. On the basis of this pilot study, it will be possible to perceive larger and longer-lasting prospective studies to evaluate the health impact of continuous exercise on physical and mental outcomes.

Abbreviations

BESS Balance Error Scoring System; BMI: body mass index; d effect size; DRM Dese, Roediger and McDermott paradigm; MDBF Multidimensional Mood Questionnaire; PPT: pressure pain threshold; PSQI Pittsburgh Sleep Quality Inventory; WHO: World Health Organization.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee FB05 of the Goethe University of Frankfurt am Main and was in agreement with the Declaration of Helsinki (Version Fortaleza 2013).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request (in compliance with data privacy).

Competing interests

All authors declare no conflict of interest.

Funding

There was no funding.

Authors' Contributions

JF: conception and design, data collection, analysis and interpretation of data, manuscript writing and final approval of the manuscript. SG: data collection, manuscript writing and final approval of the manuscript. WB: conception and design, financial support, manuscript writing, final approval of manuscript. All authors read and approved the final manuscript.

Acknowledgements

This study has been conducted in parts with the assistance of the student class 'Scientific Skills Lab Summer Term 2016', Master of Sports Medical Training & Clinical Exercise Physiology, Institute of Sports Sciences, Goethe-University Frankfurt, Germany

References

1. Khan MS, Aouad R: The Effects of Insomnia and Sleep Loss on Cardiovascular Disease. *Sleep Med Clin* 2017, 12:167-177.
2. Schmid SM, Hallschmid M, Schultes B: The metabolic burden of sleep loss. *Lancet Diabetes Endocrinol* 2015, 3:52-62.
3. Marti AR, Patil S, Mrdalj J, Meerlo P, Skrede S, Pallesen S, Pedersen TT, Bramham CR, Gronli J: No Escaping the Rat Race: Simulated Night Shift Work Alters the Time-of-Day Variation in BMAL1 Translational Activity in the Prefrontal Cortex. *Front Neural Circuits* 2017, 11:70.
4. Jensen HI, Larsen JW, Thomsen TD: The impact of shift work on intensive care nurses' lives outside work: A cross-sectional study. *J Clin Nurs* 2018, 27:e703-e709.
5. Guglielmi O, Magnavita N, Garbarino S: Sleep quality, obstructive sleep apnea, and psychological distress in truck drivers: a cross-sectional study. *Soc Psychiatry Psychiatr Epidemiol* 2018, 53:531-536.

6. Dorrian J, Baulk SD, Dawson D: Work hours, workload, sleep and fatigue in Australian Rail Industry employees. *Appl Ergon* 2011, 42:202-209.
7. Reid KJ, Abbott SM: Jet Lag and Shift Work Disorder. *Sleep Med Clin* 2015, 10:523-535.
8. Engle-Friedman M, Riela S, Golan R, Ventuneac AM, Davis CM, Jefferson AD, Major D: The effect of sleep loss on next day effort. *J Sleep Res* 2003, 12:113-124.
9. Castro EAS, de Almondes KM: Sleep pattern and decision-making in physicians from mobile emergency care service with 12-h work schedules. *Int J Neurosci* 2018, 128:530-539.
10. Kaliyaperumal D, Elango Y, Alagesan M, Santhanakrishanan I: Effects of Sleep Deprivation on the Cognitive Performance of Nurses Working in Shift. *J Clin Diagn Res* 2017, 11:CC01-CC03.
11. Smith CD, Cooper AD, Merullo DJ, Cohen BS, Heaton KJ, Claro PJ, Smith T: Sleep restriction and cognitive load affect performance on a simulated marksmanship task. *J Sleep Res* 2019, 28:e12637.
12. Narciso FV, Barela JA, Aguiar SA, Carvalho AN, Tufik S, de Mello MT: Effects of Shift Work on the Postural and Psychomotor Performance of Night Workers. *PLoS One* 2016, 11:e0151609.
13. de Vries JD, van Hooff ML, Guerts SA, Kompier MA: Exercise to reduce work-related fatigue among employees: a randomized controlled trial. *Scand J Work Environ Health* 2017, 43:337-349.
14. de Vries JD, van Hooff ML, Geurts SA, Kompier MA: Exercise as an Intervention to Reduce Study-Related Fatigue among University Students: A Two-Arm Parallel Randomized Controlled Trial. *PLoS One* 2016, 11:e0152137.
15. Rodriguez-Blanke R, Sanchez-Garcia JC, Sanchez-Lopez AM, Mur-Villar N, Aguilar-Cordero MJ: The influence of physical activity in water on sleep quality in pregnant women: A randomised trial. *Women Birth* 2018, 31:e51-e58.
16. Halliday GC, Miles GCP, Marsh JA, Kotecha RS, Alessandri AJ: Regular exercise improves the well-being of parents of children with cancer. *Pediatr Blood Cancer* 2017, 64.
17. Hurdiel R, Watier T, Honn K, Peze T, Zunquin G, Theunynck D: Effects of a 12-week physical activities programme on sleep in female university students. *Res Sports Med* 2017, 25:191-196.
18. Reid KJ, Baron KG, Lu B, Naylor E, Wolfe L, Zee PC: Aerobic exercise improves self-reported sleep and quality of life in older adults with insomnia. *Sleep Med* 2010, 11:934-940.
19. Koscak Tivadar B: Physical activity improves cognition: possible explanations. *Biogerontology* 2017, 18:477-483.
20. Matura S, Fleckenstein J, Deichmann R, Engeroff T, Fuzeki E, Hattingen E, Hellweg R, Lienerth B, Pilatus U, Schwarz S, et al: Effects of aerobic exercise on brain metabolism and grey matter volume in older adults: results of the randomised controlled SMART trial. *Transl Psychiatry* 2017, 7:e1172.
21. Kredlow MA, Capozzoli MC, Hearon BA, Calkins AW, Otto MW: The effects of physical activity on sleep: a meta-analytic review. *J Behav Med* 2015, 38:427-449.
22. Diekelmann S, Landolt HP, Lahl O, Born J, Wagner U: Sleep loss produces false memories. *PLoS One* 2008, 3:e3512.

23. Buysse DJ, Reynolds CF, 3rd, Monk TH, Berman SR, Kupfer DJ: The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res* 1989, 28:193-213.
24. Roediger HL, McDermott KB: Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1995, 21:803-814
25. Brickenkamp R: *Aufmerksamkeits-Belastungs-Test (Test d2). [The d2 Test of attention.]* Göttingen, Germany: Hogrefe; 1962.
26. MacLean AW, Fekken GC, Saskin P, Knowles JB: Psychometric evaluation of the Stanford Sleepiness Scale. *J Sleep Res* 1992, 1:35-39.
27. Hinz A, Daig I, Petrowski K, Brahler E: [Mood in the German population: norms of the Multidimensional Mood Questionnaire MDBF]. *Psychother Psychosom Med Psychol* 2012, 62:52-57.
28. Bell DR, Guskiewicz KM, Clark MA, Padua DA: Systematic review of the balance error scoring system. *Sports Health* 2011, 3:287-295.
29. Blumert PA, Crum AJ, Ernsting M, Volek JS, Hollander DB, Haff EE, Haff GG: The acute effects of twenty-four hours of sleep loss on the performance of national-caliber male collegiate weightlifters. *J Strength Cond Res* 2007, 21:1146-1154.
30. Lluch A, Hubert P, King NA, Blundell JE: Selective effects of acute exercise and breakfast interventions on mood and motivation to eat. *Physiol Behav* 2000, 68:515-520.
31. Tucker MA, Morris CJ, Morgan A, Yang J, Myers S, Pierce JG, Stickgold R, Scheer F: The Relative Impact of Sleep and Circadian Drive on Motor Skill Acquisition and Memory Consolidation. *Sleep* 2017, 40.
32. Heuer H, Spijkers W, Kiesswetter E, Schmidtke V: Effects of sleep loss, time of day, and extended mental work on implicit and explicit learning of sequences. *J Exp Psychol Appl* 1998, 4:139-162.
33. Chu CH, Kramer AF, Song TF, Wu CH, Hung TM, Chang YK: Acute Exercise and Neurocognitive Development in Preadolescents and Young Adults: An ERP Study. *Neural Plast* 2017, 2017:2631909.
34. Steiber N: Strong or Weak Handgrip? Normative Reference Values for the German Population across the Life Course Stratified by Sex, Age, and Body Height. *PLoS One* 2016, 11:e0163917.
35. Smith MT, Wickwire EM, Grace EG, Edwards RR, Buenaver LF, Peterson S, Klick B, Haythornthwaite JA: Sleep disorders and their association with laboratory pain sensitivity in temporomandibular joint disorder. *Sleep* 2009, 32:779-790.
36. Ensari I, Greenlee TA, Motl RW, Petruzzello SJ: Meta-Analysis of Acute Exercise Effects on State Anxiety: An Update of Randomized Controlled Trials over the Past 25 Years. *Depress Anxiety* 2015, 32:624-634.
37. Henriksen M, Klokke L, Graven-Nielsen T, Bartholdy C, Schjodt Jorgensen T, Bandak E, Danneskiold-Samsoe B, Christensen R, Bliddal H: Association of exercise therapy and reduction of pain sensitivity in patients with knee osteoarthritis: a randomized controlled trial. *Arthritis Care Res (Hoboken)* 2014, 66:1836-1843.

38. Sallon S, Katz-Eisner D, Yaffe H, Bdolah-Abram T: Caring for the Caregivers: Results of an Extended, Five-component Stress-reduction Intervention for Hospital Staff.*Behav Med* 2017, 43:47-60.
39. Subramaniapillai M, Tremblay L, Grassmann V, Remington G, Faulkner G: The effect of an acute bout of exercise on executive function among individuals with schizophrenia.*Psychiatry Res* 2016, 246:637-643.
40. Brush CJ, Olson RL, Ehmann PJ, Osovsky S, Alderman BL: Dose-Response and Time Course Effects of Acute Resistance Exercise on Executive Function.*J Sport Exerc Psychol* 2016, 38:396-408.
41. Chang YK, Chu CH, Wang CC, Song TF, Wei GX: Effect of acute exercise and cardiovascular fitness on cognitive function: an event-related cortical desynchronization study.*Psychophysiology* 2015, 52:342-351.

Tables

Table 1 Demographics. Data is reported as mean \pm standard deviation, or in counts (n). Statistics between continuous variables was calculated with unpaired t-tests (all parametric), and between categoric variables with chi square tests.

		Exercise Group	Control Group	p-value*
		(n = 11)	(n = 11)	
<i>age (years)</i>		23.64 ± 1.8	24.18 ± 1.89	0.496
<i>gender (female/male)</i>		4/7	4/7	0.670
<i>height (cm)</i>		175.91 ± 9.51	175.18 ± 8.35	0.702
<i>weight (kg)</i>		72.27 ± 9.45	70.91 ± 12.3	0.851
<i>BMI</i>		23.37 ± 2.63	22.95 ± 2.35	0.774
<i>lifestyle factors</i>				
	alcohol (yes/no)	11/0	10/1	1.0
	irregularly	1	1	0.663
	1 day / week	7	8	
	2 days / week	2	1	
	3 days / week	1	0	
	4 days / week	0	1	
	5 days / week	0	0	
	caffeine products (yes/no)	3/8	3/8	0.682
	coffee			0.554
	never	7	3	
	<1 cup / day	1	2	
	1 cup / day	1	2	
	2 cups / day	2	2	
	amount (l)	0.28 ± 0.2	0.25 ± 0.05	0.795
	caffeine-containing softdrinks			0.670
	never	5	7	
	<0.5l / day	6	4	
	energy drinks			0.214
	never	8	11	
	<1 tin / day	3	0	
	nicotine			1.0
	none	10	11	
	<5 cigarettes	1	0	
	training activity			
	hours / week			

	2-3	2	0	0.552
	4-5	3	5	
	6-7	2	3	
	8-9	2	2	
	10-11	0	0	
	>11	2	1	
<i>Handedness (left/right)</i>		3/8	3/8	1.0
<i>PSQI (0-21 points)</i>		4.45 ± 2.66	4.64 ± 1.63	0.849

Table 2 Outcome Measures. The table depicts all outcome measures between the exercise intervention group (EXE) and the control group (CON) at baseline and following one night of sleep loss. The main outcome measure was assessed only once, following sleep loss, applying an unpaired t-test between groups. All other statistics was performed as time x group (2x2) analysis. Inner-subject effects have been displayed calculating paired t-test within the groups. VAS visual analogue scale; MDBF multidimensional mood questionnaire; BESS balance error scoring system; D dominant side; ND non-dominant side; PPT pressure pain threshold

		At baseline	Following sleep loss	between subject effects [#]	inner-subject effects
Main outcome				unpaired t-test	
<i>false memory rate</i>	EXE (n = 11)		0.8 ± 0.12	0.456	
	CON (n = 11)		0.76 ± 0.16		
<i>false alarm rate</i>	EXE (n = 11)		0.4 ± 0.12	0.402	
	CON (n = 11)		0.43 ± 0.08		
<i>true recognition rate</i>	EXE (n = 11)		0.7 ± 0.13	0.565	
	CON (n = 11)		0.66 ± 0.15		
Secondary outcome				time x group analysis	
<i>Sleepiness (cm VAS)</i>	EXE (n = 11)	3.94 ± 2.98	4.53 ± 2.32	0.171	0.357
	CON (n = 11)	4.64 ± 1.83	7.61 ± 2.64		0.019
<i>Attention (%)</i>	EXE (n = 11)	44.84 ± 31.4	27.62 ± 17.53	0.091	<0.001
	CON (n = 11)	42.02 ± 21.52	38.48 ± 25.4		0.581
<i>Concentration performance (n)</i>	EXE (n = 11)	214.45 ± 43.65	237.91 ± 31.46	0.088	<0.001
	CON (n = 11)	214.27 ± 30.3	221.55 ± 38.01		0.365
<i>Performance speed (n)</i>	EXE (n = 11)	215.73 ± 43.87	239.00 ± 31.07	0.109	<0.001
	CON (n = 11)	215.91 ± 30.98	224.00 ± 38.44		0.314
<i>MDBF mood</i>	EXE (n = 11)	11.55 ± 0.69	11.82 ± 1.54	0.673	0.763
	CON (n = 11)	11.00 ± 1.55	10.91 ± 1.87		0.898

<i>MDBF mental fatigue</i>	EXE (n = 11)	11.45 ± 1.21	10.27 ± 0.9	0.335	0.923
	CON (n = 11)	10.45 ± 1.63	10.09 ± 2.21		0.629
<i>MDBF restlessness</i>	EXE (n = 11)	12.09 ± 1.38	10.82 ± 1.47	0.313	0.311
	CON (n = 11)	11.00 ± 1.55	11.09 ± 2.51		0.937
<i>BESS-Score (0-60)</i>	EXE (n = 11)	13.82 ± 9.03	12.55 ± 5.34	0.940	0.219
	CON (n = 11)	16.91 ± 7.03	15.36 ± 8.85		0.555
<i>Grip strength D (kg)</i>	EXE (n = 11)	41.27 ± 9.56	41.55 ± 11.42	0.699	<0.001
	CON (n = 11)	42.64 ± 11.47	41.09 ± 12.14		0.306
<i>Grip strength ND (kg)</i>	EXE (n = 11)	43.64 ± 10.89	43.00 ± 11.16	0.054	<0.001
	CON (n = 11)	44.27 ± 11.71	39.55 ± 12.09		0.098
<i>PPT D (kg/cm²)</i>	EXE (n = 11)	9.24 ± 4.31	9.05 ± 3.78	0.899	0.028
	CON (n = 11)	8.27 ± 3.19	7.95 ± 2.7		0.005
<i>PPT ND (kg/cm²)</i>	EXE (n = 11)	7.38 ± 2.45	6.87 ± 1.81	0.510	<0.001
	CON (n = 11)	6.27 ± 1.91	6.33 ± 1.96		0.005

Figures

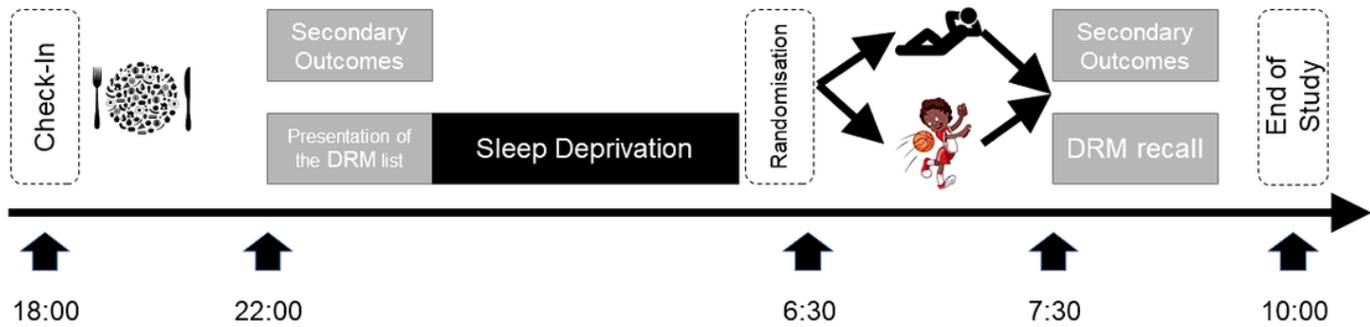


Figure 1

Study Design. A single-centre randomised controlled study investigating the effects of a 20-minutes moderate-to-vigorous circuit training (see icons) on parameters of cognitive performance when compared to a passive control. Participants checked in at 18:00 the day of the experiment, starting with a collective standardised Mediterranean dinner. Baseline parameter were assessed at 22:00 and thereafter the list of Desse, Roediger and McDermott (DRM) words was presented.²⁴ In the following night, sleep loss of the participants was assured by the study team. At 6:30 participants were randomised into two groups with the “exercise group” leaving to a nearby gym where they participated in an exercise program, whereas the “control group” remained passively seated in the common area. At 7:30 all outcomes were re-assessed, the DRM word were recalled, and the study ended thereafter.

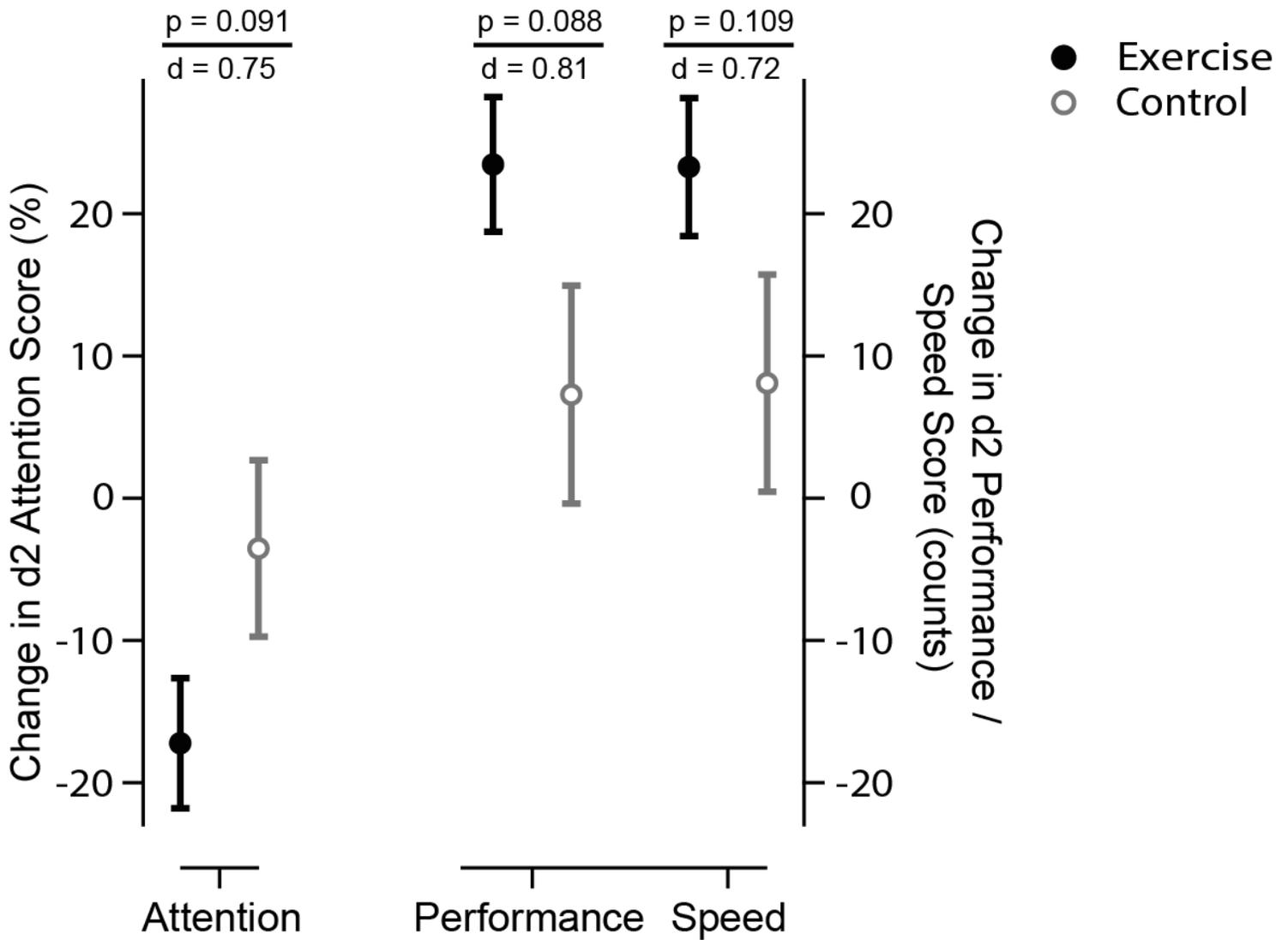


Figure 2

Selective and sustained attention (D2-Score). The circles display the changes to baseline for exercise (solid black) and control (open grey circles). The d2 test of attention consists of a general attention score and subindices including concentration performance and performance speed.²⁵ It consists of a general attention score (total errors per total task, in %), with lower scores indicating higher performance (left scale). Subindices (right scales) include performance speed (total number processed, max. 299), and concentration performance (speed minus error count), with higher scores indicating improved performance and speed. There is a statistical trend (time x group analysis, $p < 0.1$) that exercise (solid circles) improved attention (less errors), speed (more numbers processed), and performance (count of processed numbers minus errors) than control (open circles). p indicates the level of significance, d represents the effect size according to Cohen, suggesting that a $d = 0.2$ represents a 'small' effect size, $d = 0.5$ represents a 'medium' effect size and $d = 0.8$ represents a 'large' effect size.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [CONSORT2010Checklist.doc](#)