One night of sleep deprivation impairs executive function but does not affect psychomotor or motor performance

AUTHORS: Albertas Skurvydas[1], Laura Zlibinaite[2], Rima Solianik[1], Marius Brazaitis[1], Dovile Valanciene[1], Neringa Baranauskiene[1], Daiva Majauskiene[3], Dalia Mickeviciene[2], Tomas Venckunas[1], Sigitas Kamandulis[1]

[1] Institute of Sports Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania
[2] Department of Applied Biology and Rehabilitation, Lithuanian Sports University, Kaunas, Lithuania
[3] Department of Health, Physical and Social Education, Lithuanian Sports University, Sporto str. 6, 44221 Kaunas, Lithuania

Corresponding author:
Dovile Valanciene
Institute of Sports Science and Innovations, Lithuanian Sports University, Sporto str. 6
LT-44221, Kaunas, Lithuania
E-mail: dovile.valanciene@lsu.lt

ABSTRACT: The current study assessed the impact of one night of sleep deprivation on cognitive, motor and psychomotor performance. Thirty healthy young adult male subjects completed a 24 h control or 24 h sleep deprived trial. For the control trial, participants (N = 15) were allowed normal night sleep (~8 h). For the sleep deprived trial, participants (N = 15) did not sleep for 24 h. Cognitive performance during go/no-go, Stroop and simple reaction tasks, psychomotor performance during speed-accuracy tasks with fixed and unfixed targets, and motor performance during countermovement jump, hand grip strength, and 30-s maximal voluntary contraction tasks were evaluated on day 1 at 8 am and 7 pm and on day 2 at 8 am. One night of sleep deprivation impaired psychological well-being and executive function but did not affect simple reaction time, the capacity for arm and leg muscle contraction, motor control performance during a speed–accuracy task with both fixed and unfixed targets, and central and peripheral motor fatigue in the 30 s maximal voluntary contraction task. The present study showed that one night of sleep deprivation resulted in executive function deterioration but did not modify motor control or maximal effort requiring performance of motor tasks.

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INTRODUCTION

Sleep loss affects motor and cognitive performance, the immune system, and emotional and physical well-being [1, 2]. From an epistemological point of view, sleep loss may play a role in the increased prevalence of diabetes and/or obesity [3]. Sleep deprivation increases homeostatic sleep drive and degrades waking neurobehavioral functions, as reflected in sleepiness (the condition of being in a drowsy state due to lack of sleep) and impaired attention, cognitive speed and memory [4]. However, other researchers have shown that performance of complex cognitive tasks may not be impacted by disrupted sleep as severely as that of simple cognitive tasks [5, 6]. Sleepiness differs from fatigue, which is characterized by a decline in performance capacity during physical work and depends on both central and peripheral mechanisms [7, 8]. Prolonged and/or intense stimulation of the central nervous system may produce conscious awareness of fatigue, which contributes to cognitive and emotional disturbances [9, 10] and a reduced ability to activate muscles [11].

A previous study concluded that the psychomotor vigilance test of simple reaction time (RT) is a reliable outcome metric for determining neurobehavioural deficits resulting from sleep deprivation [12]. It was demonstrated that sleep deprivation leads to a general slowing of response and increased variability in performance, particularly for simple measures of alertness, attention and vigilance [13]. However, there is much less agreement about the effects of sleep deprivation on many higher-level cognitive capacities and executive functions. Intra-individual variability in motor performance is a sensitive biomarker of the origin of fatigue [14, 15]. Therefore, we hypothesized that sleep deprivation should increase the variability of movement performance, especially during difficult speed–accuracy motor tasks when the target is not fixed.

Much of the previous research has reported that motor performance is negatively affected following sleep loss; however, the conflicting findings mean that the extent, influence, and mechanisms of sleep loss affecting motor performance remain uncertain [2, 16, 17]. Researchers concluded that sleep deprivation does not change those motor characteristics for which performance does not require motor control precision; that is, gross motor performance such as maximal

voluntary contraction (MVC) force does not change [2]. To our knowledge, no studies have analyzed the changes in central and peripheral motor fatigue during maximal-intensity exercise resulting from sleep deprivation. Only a limited number of studies have examined the effects of sleep deprivation on components of executive function and motor control variables (movement performance precision, speed, and intra-individual variability of motor performance) during speed–accuracy tasks and whether these effects depend on the task complexity [6]. Therefore, the objective of the present study was to assess the impact of one night of sleep deprivation on cognitive, motor and psychomotor performance. Because sleep deprivation diminishes waking neurobehavioral functioning, increases sleepiness and fatigue [18], and increases anxiety level [19, 20], we hypothesized that sleep deprivation should increase central motor fatigue during a maximal-intensity isometric task.

MATERIALS AND METHODS

Participants

Healthy male students (15 in the control group and 15 in the experimental group) volunteered to participate in this study after initially screening via interview for major medical disorders, physical activity and nocturnal sleep habits and giving written informed consent. Participants were invited through online posters at the Lithuanian Sports University. Slightly over 85% of the volunteers were eligible while others did not meet health and/or regular sleep criteria, or were physically too active. Participants were assigned to the groups randomly using a simple computer-generated random number list and were familiarized with procedures during their first visit to the laboratory. The control group's mean age (standard deviation (SD)) was 20.2 (1.4) years, and the mean height was 1.87 (0.10) m, weight 81.0 (15.5) kg, and body fat 14.5% (2.4%). The experimental group's mean age was 20.8 (1.3) years, height 1.85 (0.14) m, weight 77.4 (11.5) kg, and body fat 14.9% (3.7%). All volunteers participated two to three times per week in recreational activities and were considered physically active. None had participated in any controlled event of at least 24 h of sleep deprivation; nor, according to their recall, had they ever been fully without sleep for 24 h in the past. The experimental protocol was approved by the local Ethical Committee and was conducted in accordance with the Declaration of Helsinki.

Study design

All participants in the experimental group were instructed to sleep 8–9 h at night without consuming alcohol or caffeine for at least 24 h before the experiment. The participants came to the laboratory at 8 am and stayed until 9 am the next day. The participants were not allowed to drink coffee, tea, or any other caffeinated beverage from their arrival for the experiment session. The diet for each participant was based on their daily dietary routine, but they were asked to avoid high-fat food. Breakfast, lunch, and dinner were supplied at 9 am, 1 pm, and 9 pm, respectively, after the test session was finished. During the night, participants ate a light snack. During free time, the participants watched videos and interacted socially. The control group participants were given the same tests and instructions as the experimental group except that they were allowed to sleep at night.

The first test battery was performed when the participants arrived in the morning at 8-9 am (Morning-I), the second assessment was performed in the evening on the same day at 7-8 pm (Evening), and the last assessment was performed in the morning of the next day at 8-9 am (Morning-II). Sequence of measurements: subjective state of evaluation (Stanford Sleepiness Scale (SSS), visual analogue scale for motivation (VAS)); cognitive function evaluation (go/no go task, Stroop task); psychomotor function evaluation (speed–accuracy motor task); motor function evaluation (countermovement jump test (CMJ), hand grip strength, motor fatigue task). Participants were informed about the tasks and were taught to perform the cognitive and motor tasks 3–4 days before the experiment.

Measurements

Stanford Sleepiness Scale. Participants were asked to rate their personal level of sleepiness or alertness using the Stanford Sleepiness Scale [21]. The SSS consists of a seven-point scale of equal intervals varying from 1 ("feeling active and vital; alert; wide awake") to 7 ("almost in reverie; sleep onset soon, lost in struggle to remain awake").
Visual analogue scale. Based on scales used in a previous study [22], motivation was assessed using a VAS ranging from 1 (not motivated at all) to 10 (extremely motivated) on a 10-cm-long horizontal line. The participants marked on the line the point that they felt represented their perception of their current state.

Assessment of height of a countermovement jump. After a short warm-up (5 min of cycling with a 50 W load on an exercise bicycle), the subjects performed three CMJs with a 30 s interval between each jump. Each jump was performed from an upright standing position, then squatting to a position of 90° of flexion at the knee before jumping vertically up off the ground. The knee angle was controlled and recorded using a goniometer (Biometrics, UK). During the CMJs, the participant's hands were placed on the waist. The CMJs were performed on a contact mat (Powertimer Testing System, Newtest, Finland). The best result of three attempts was recorded for analysis.

Assessment of hand-grip strength. A dynamometer (Saehan Corporation, Korea) was used to measure isometric hand grip strength. Participants were standing, shoulders adducted and neutrally rotated, elbow flexed at 90°, forearm in a neutral position and wrist between 0 and 30° of dorsiflexion. The dominant hand was used for strength assessment; all participants were right handed. They were allowed three trials at 30 s intervals, and the best result was recorded.

Executive functions testing. The Automated Neuropsychological Assessment Metrics [23] was used to assess cognitive performance.

The participants were familiarized with the test battery before the experiments.

The go/no-go task measures response inhibition [24]. During this test, participants are required to respond to a "go" stimulus as quickly as possible but must withhold their response to a "no-go" stimulus. The go stimulus occurred in 80% of trials, and the no-go stimulus occurred in 20% of trials. Participants completed a practice session of 120 trials. The task took about 2 min to complete. The averages for the correct response RT and correct response number were calculated. The Stroop Color and Word Test measures cognitive flexibility, processing speed, and executive function [25]. The cognitive mechanism involved in this task is directed to attention, and the participants must manage their attention by inhibiting one response to say or do something else. The rationale of the task lies in visually presenting colour names to the participants while displayed in an incongruent ink colour (e.g., the word "red" is written in blue). Two hundred stimuli were presented, and the test took ~5 min. Participants had to press a red, green, blue, or yellow button for each stimulus. Different keys (buttons) were used to identify each stimulus response: A = red, S = green, D = blue, F = yellow. The ratio of congruent and incongruent stimuli was 50:50. The duration of each stimulus was 2 s. The averages for correct response RT and correct response number (in percent) were calculated.

Speed–accuracy movement task. For the movement tasks, the participant was seated in a special chair at a table with a Dynamic Parameter Analyzer (DPA–1, Kaunas, Lithuania) instrument fastened to it [26]. The participant's back was straight and leaned against the backrest, and both arms were bent 90 degrees at the elbow joint so that the upper arms rested against the sides, and the forearms rested on the DPA–1 support panel. The position of the DPA–1 chair was adjusted so that the participant could sit comfortably in a standard position. The distance between the computer screen and the participant's eyes was ~0.7 m. The participant's right hand was fixed to a joystick, from which the path and velocity of hand movements at the distal part of the hand were recorded. The sampling rate was 200 Hz. The handle at the end of the lever was adjusted to accommodate the participant's hand (the lever was allowed to move only in a horizontal plane). The target (a red circle, 0.007 m in diameter) appeared on the screen. The distance from the start zone to the target was 0.10 m.

The participant had to perform two different tasks with the right hand: 1) a simple reaction test with a 0.007 m target appearing on the screen and 2) a speed–accuracy task in which the subject had to react to the target on the computer screen as fast as possible and to push the handle of the device so that the circle of the handle symbol reached the target as fast as possible and followed the most accurate trajectory, and then stopped in it. The standard speed–accuracy instructions were, "Please give equal importance to speed and accuracy when completing this task. We would like you to respond as fast as possible while maintaining a high level of accuracy." The speed–accuracy task was implemented in two ways: 1) with the target always fixed at the same state (fixed target) and 2) with the target appearing every time in a different place but the distance to the target was the same (unfixed target). The program intermittently (every 1–3 s) generated a target on the computer screen. The endpoint of the movement was recorded when the centre of the handle symbol stopped in the circle and stayed there for at least 0.02 s. Each target appeared on the screen 20 times and the entire task took about 1 min to complete. The time interval between the tasks was 2 min.

During the speed–accuracy task, the participant was required to position the handle symbol 0.0035 m in diameter in the start zone (the centre of a 0.01 m green circle) on the computer screen. We calculated the average simple RT and the average velocity (Va), maximal velocity (Vmax), and path of movement (S, accuracy of movement) during the simple and complex speed–accuracy tasks. We also calculated the intra-individual variability (coefficient of variation) of these variables during the speed–accuracy tasks.

Motor fatigability testing. The isometric torque of knee extensor muscles was measured using an isokinetic dynamometer (System 3; Biodex Medical Systems, Shirley, NY). The subject sat upright in the dynamometer chair with the knee joint positioned at 110 degrees (180 = full knee extension). The equipment and procedure for electrical stimulation were essentially the same as previously described [27]. Direct muscle stimulation was applied using two carbonized rubber electrodes covered with a thin layer of electrode gel (ECG-EEG Gel; Medigel, Modi'in, Israel). A standard electrical stimulator (MG 440; Medicor, Budapest, Hungary) was used. The stimulus frequency was 100 Hz. Electrical stimulation was delivered in square-wave pulses of 0.5 ms in duration. MVC was reached and maintained for ~2 s before relaxation and was measured twice, and the larger value was used in the analysis. During the 30-s MVC task, the TT-100 Hz (250 ms test train of stimuli at 100 Hz.) was superimposed on the contraction at 3 s and 30 s. The TT-100 Hz stimulation was used to assess the central activation ratio (CAR) of the quadriceps muscle [28]. In later analysis, the fatigue index, which represents the percentage decline in MVC torque, was calculated as the difference between the MVC measured at 3 s and 30 s (MVC-3 and MVC-30, respectively). After the 30 s MVC, the quadriceps muscle was relaxed and the 100 Hz was delivered. The 100 Hz-induced torque fatigue index was calculated as the percentage torque decline from before to after MVC-30.

Statistical Analyses

Two-way analysis of variance for repeated measures was used to determine the effect of time (Morning-I vs. Evening vs. Morning-II) and the effect of sleep deprivation (control vs. experimental group) on different variables. If significant effects were found, post hoc testing was performed using paired *t* tests with a Bonferroni correction for multiple comparisons. Descriptive data are presented as mean scores ± SD. The level of significance was set at $p < .05$. Together

with this, calculations for statistical power (observed power, OP) were performed and the partial eta squared ($\eta_p 2$) was estimated as a measure of the experimental trial effect size.

RESULTS

Motor performance. One night sleep deprivation did not change significantly ($p = 0.752$; $\eta 2 = 0.02$; OP = 0.16) hand grip strength (Table 1). Sleep deprivation did not change significantly ($p = 0.69$; $\eta 2 = 0.01$; OP = 0.12) height of CMJ (Table 1).

Cognitive function (executive function). The effect of sleep deprivation on response inhibition control (correct response) was significant during both go/no-go and Stroop tests ($p = 0.023$; $\eta 2 = 0.28$; OP = 0.81) (Table 2).

Motor control variables. Simple RT did not change significantly after sleep deprivation ($p = 0.352$; $\eta 2 = 0.09$; OP = 0.23) (Tables 1, 3 and 4).

TABLE 1. Hand grip strength, height of vertical counter-movement jump and simple reaction time (RT) in control (C) and experimental (E) groups (mean ± SD).

		Morning-I	Evening	Morning-II
Hand grip strength, kg		41.1 ± 9.1	42.1 ± 7.8	43.4 ± 10.2
Height of vertical counter-movement jump, m	**C**	0.49 ± 0.05	0.48 ± 0.05	0.48 ± 0.04
Simple reaction time, s		0.22 ± 0.03	0.208 ± 0.02	0.205 ± 0.03
Hand grip strength, kg		44.8 ± 9.7	46.2 ± 11.2	46.5 ± 11.5
Height of vertical counter-movement jump, m	**E**	0.47 ± 0.07	0.46 ± 0.06	0.46 ± 0.07
Simple reaction time, s		0.232 ± 0.02	0.222 ± 0.01	0.218 ± 0.02

TABLE 2. Go/no-go and Stroop Color and Word (Stroop) task variables in the control (C) and experimental (E) groups (mean ± SD).

	Morning-I	Evening	Morning-II
C: Go/no-go, RT, ms	321.3 ± 18.5	309.5* ± 15.1	327.4 ± 34.7
C: Go/no-go, correct amount, %	94.2 ± 3.4	95.4 ± 3.4	92.9 ± 5.7
E: Go/no-go, RT, ms	314.3 ± 20.5	301.5* ± 16.1	347.4* ± 54.7
E: Go/no-go, correct amount, %	95.0 ± 2.4	93.7 ± 3.0	88.7* ± 5.7
C: Stroop, RT, ms	537.2 ± 45.1	505.3* ± 44.3	542.1 ± 60.5
C: Stroop, correct amount, %	93.4 ± 5.1	94.9 ± 4.1	95.8 ± 4.8
E: Stroop, RT, ms	542.2 ± 65.1	500.3* ± 46.3	572.9* ± 70.5
E: Stroop, correct amount, %	93.4 ± 6.1	93.3 ± 4.7	90.8* ± 5.8

* $p < .05$ compared with Morning-I; RT – reaction time.

TABLE 3. Reaction time (RT), average velocity (Va), maximal velocity (Vmax), and path of moment (S) in the control (C) and experimental (E) groups during the speed–accuracy task (mean ± SD).

	Morning-I		Evening		Morning-II	
	Fixed vs unfixed target		Fixed vs unfixed target		Fixed vs unfixed target	
C: RT, s	0.261 ± 0.05	0.322 ± 0.046	0.248 ± 0.03	0.302 ± 0.04	0.261 ± 0.04	0.311 ± 0.05
E: RT, s	0.256 ± 0.03	0.310 ± 0.05	0.246 ± 0.04	0.293 ± 0.05	0.250 ± 0.04	0.310 ± 0.04
C: Va, m/s	0.136 ± 0.018	0.128 ± 0.031	0.157* ± 0.022	0.133 ± 0.014	0.163* ± 0.023	0.128 ± 0.018
E: Va, m/s	0.143 ± 0.016	0.134 ± 0.012	0.166* ± 0.015	0.135 ± 0.011	0.169* ± 0.03	0.126 ± 0.011
C: Vmax, m/s	0.410 ± 0.066	0.349 ± 0.06	0.479* ± 0.07	0.399* ± 0.112	0.472* ± 0.05	0.388* ± 0.120
E: Vmax, m/s	0.429 ± 0.08	0.361 ± 0.07	0.463* ± 0.112	0.359 ± 0.075	0.447 ± 0.114	0.349 ± 0.078
C: S, m	0.110 ± 0.004	0.112 ± 0.006	0.111 ± 0.004	0.112 ± 0.046	0.108 ± 0.042	0.112 ± 0.007
E: S, m	0.109 ± 0.006	0.109 ± 0.004	0.110 ± 0.007	0.108 ± 0.004	0.108 ± 0.006	0.107 ± 0.004

* $p < .05$ compared with Morning-I.

TABLE 4. Coefficient of variation (intra-individual variability) for reaction time (RT), average velocity (Va), maximal velocity (Vmax), and path of moment (S) in the control (C) and experimental (E) groups during the speed–accuracy task (mean ± SD).

	Morning-I		Evening		Morning-II	
	Fixed vs unfixed target		Fixed vs unfixed target		Fixed vs unfixed target	
C: RT, %	13.7 ± 3.5	14.1 ± 3.3	13.5 ± 3.4	12.4 ± 3.1	13.6 ± 3.7	14.5 ± 3.9
E: RT, %	13.2 ± 3.4	12.7 ± 3.1	13.6 ± 3.1	10.6 ± 3.1	11.6 ± 2.8	11.1 ± 3.8
C: Va, %	33.2 ± 5.5	29.5 ± 5.9	36.5 ± 5.9	30.3# ± 5.1	30.6 ± 6.6	29.3 ± 4.1
E: Va, %	30.4 ± 5.6	33.5 ± 5.1	28.5 ± 5.8	30.1 ± 5.7	30.5 ± 6.8	28.6 ± 4.7
C: Vmax, %	15.3 ± 5.2	17.7 ± 4.2	14.3 ± 4.5	15.2 ± 3.1	10.7* ± 3.2	17.4# ± 3.3
E: Vmax, %	11.4 ± 3.5	16.1# ± 3.9	11.4 ± 3.9	15.1# ± 3.2	10.9 ± 3.1	16.6# ± 4.3
C: S, %	7.6 ± 2.5	10.8 ± 2.2	8.1 ± 3.1	11.2 ± 4.3	5.6* ± 2.2	10.5 ± 2.3
E: S, %	7.1 ± 2.1	8.9 ± 2.8	7.1 ± 2.8	7.8 ± 2.9	7.1 ± 3.1	6.8 ± 1.9

* $p < .05$ compared with Morning-I; # $p < .05$ compared with variables with a fixed target.

TABLE 5. Peak torque, fatigue index (FI) and central activation ratio (CAR) during the 30 s maximal voluntary contraction (MVC) task in the control (C) and experimental (E) groups (mean ± SD).

	Morning-I		Evening		Morning-II	
	C	E	C	E	C	E
MVC, Nm	325.5 ± 48.2	336.5 ± 51.2	321.9 ± 62.1	297.8 ± 82.2	301.2 ± 61.5	291.2 ± 74.4
MVC FI, %	27.9 ± 12.7	30.5 ± 11.2	24.1 ± 6.3	31.1 ± 12.9	26.7 ± 10.3	34.9 ± 13.4
100 Hz, Nm	158.9 ± 20.4	160.7 ± 18.2	157.5 ± 15.4	161.4 ± 17.7	159.9 ± 19.1	157.2 ± 14.3
100 Hz FI, %	40.7 ± 8.7	43.8 ± 13.2	44.7 ± 8.7	48.2 ± 12.2	43.3 ± 11.2	47.2 ± 14.4
CAR-0 s, %	96.6 ± 2.4	95.9 ± 4.1	98.8 ± 5.5	94.3 ± 5.1	96.3 ± 5.8	96.5 ± 6.1
CAR- 30 s, %	86.3 ± 12.1	85.3 ± 14.1	90.3 ± 8.2	86.3 ± 16.5	87.5 ± 8.5	88.5 ± 11.2

TABLE 6. Sleepiness and motivation in the control (C) and experimental (E) groups (mean ± SD).

	Morning-I	Evening	Morning-II
C: Sleepiness	1.9 ± 0.6	1.6 ± 0.5	2.0 ± 0.6
E: Sleepiness	1.9 ± 0.5	1.7 ± 0.5	4.2* ± 1.1
C: Motivation	7.6 ± 1.1	7.7 ± 1.2	7.7 ± 1.3
E: Motivation	7.6 ± 1.3	7.8 ± 1.2	6.4* ± 1.4

* $p < .05$ compared with Morning-I.

Central and peripheral fatigue during the 30 s MVC. Sleep deprivation did not significantly change the measures of central fatigue (change in the central activation ratio) ($p = 0.112$; $\eta 2 = 0.09$; OP = 0.27) and peripheral fatigue (change in 100 Hz torque) ($p = 0.442$; $\eta 2 = 0.01$; OP = 0.11) during the 30 s MVC (Table 5).

Sleepiness and motivation. Sleep deprivation significantly increased sleepiness ($p = 0.001$; η 2= 0.28; OP = 0.99) and decreased motivation ($p = 0.01$; $\eta 2 = 0.22$; OP = 0.89) (Table 6).

DISCUSSION

The main findings suggest that one night of sleep deprivation impaired psychological well-being and executive function but did not affect simple RT, the capacity for arm and leg muscle contraction, motor control performance during a speed–accuracy task with both fixed and unfixed targets, or central and peripheral motor fatigue in the MVC-30 s task. To our knowledge, ours is the first study to examine the effects of one night of sleep deprivation on executive function and motor control during speed–accuracy tasks of varying difficulty and on fatigability of the motor system (central vs. peripheral fatigue).

Executive function. In contrast to another study [29] we found that sleep deprivation impaired executive control (longer RT and more errors both during both the Stroop and go/no-go tests). Our data are consistent with a recent meta-analysis that reported that sleep restriction significantly impairs waking neurocognitive functions such as executive function, sustained attention, and long-term memory [30]. Our findings are also consistent with those of another study showing that sleep deprivation impairs executive function [1]. Unlike other studies [4, 13] our study showed that sleep deprivation did not change simple RT (Table 1). The mechanisms by which sleep disruption alters executive function are unknown but likely involve functional impairment of the prefrontal cortex and/or its afferents [31]. For example, self-reported increased anxiety has been observed in humans after sleep deprivation.

There is less agreement about the effects of sleep deprivation on many higher-level cognitive capacities, including attention and executive functions. Therefore, interpreting measures of overall performance without consideration of the specific task requirements can lead to misleading conclusions [32]. Specifically, one night of sleep deprivation markedly impairs hippocampal function and imposes a deficit in the ability to commit new experiences to memory [33]. Deterioration of executive function after sleep deprivation may be related to the vulnerability of the prefrontal cortex to sleep deprivation [34].

Motor performance and motor control. In our study, MVC force of the arms and CMJ height did not change after sleep deprivation. These findings are consistent with those of another study showing that sleep deprivation does not change maximal force or gross motor performance when motor control precision is not necessary [2].

It was surprising that sleep deprivation did not impair arm motor control during the speed–accuracy test in both the simple (fixed target) and complex (unfixed target) tasks. We found no deterioration in RT, precision of movement performance, speed, or intra-individual variability for these tasks (Tables 3 and 4). Other studies have reported that sleep deprivation worsens the effectiveness of motor control during postural control [35] and driving performance [14]. Motor control requiring decision-making [36] may deteriorate because of increased anxiety [37]. Because other studies have reported increased intra-individual variability of motor or cognitive performance as a result of fatigue [15], we expected that sleep deprivation would increase variability of movements during the speed–accuracy task.

Central vs. peripheral fatigue. Another unexpected finding was the lack of effect of sleep deprivation on central and peripheral fatigue during the 30 s MVC. This is inconsistent with the findings of authors who reported that sleep deprivation impaired neuromuscular performance during submaximal isometric knee extensor exercises performed until task failure [38, 16].

In our study, MVC torque decreased, and central and peripheral fatigue increased with exercise, which agrees with the findings of previous studies of sustained isometric MVC [39]. However, contrary to our expectations, neuromuscular performance was not affected by one night of sleep deprivation. It has been suggested that a decrease in inhibition is associated with decreased motor function, although recent studies have observed that mental fatigue induced by tasks requiring inhibitory control does not affect neuromuscular function [40]. We note that some studies have reported performance decrements during prolonged endurance exercise under conditions of sleep deprivation [38]. However, they did not find an association between decreased exercise performance and increased peripheral or central fatigue.

It is possible that increased anxiety may have increased central fatigue during our maximal-intensity isometric task and that, during this type of task, group III/IV muscle afferents may disfacilitate or inhibit the motor cortex and promote central fatigue [41]. It is clear that group III/IV afferents were activated during the MVC-30 s, although we found that peripheral and central fatigue were not changed by sleep deprivation (Table 5). It is known that acute total sleep deprivation decreases brain activation in the frontoparietal attention network (prefrontal cortex and intraparietal sulcus) and in the salience network (insula and medial frontal cortex). Increased thalamic activation after sleep deprivation may reflect a complex interaction between the de-arousing effects of sleep loss and the arousing effects of task performance on thalamic activity [42].

In spite of some contradictory observations, the results of our study can be explained by the two popular hypotheses described as wake-state instability [43] and lapse [44], according to which performance during sleep deprivation deteriorates in long, simple, and monotonous tasks requiring reaction speed or vigilance. Therefore, compared to cognitive tasks, a much shorter duration and more intense nature of motor control tasks could have been one reason why motor control performance was detected to deteriorate less compared to cognition. The present data support the previous notion that appropriate disposition, e.g., the proper focus and motivation, can compensate for the cognitive fatigue during short-term high-intensity exercises [45].

It can be speculated that if longer-duration motor performance and motor control tasks had been used, motor function deterioration might have been evident. However, we did not investigate this possibility and thus it could be viewed as a limitation. Another limitation is the rather specific population in the current study, and its results should be considered with caution within people different in age, sex and physical activity. One more limitation was absence of power calculation prior to data collection, but rather typical sample sizes were used and the effect sizes were sufficient. The order of testing was not randomized and it is possible that the tasks at the end became relatively more discouraging for the sleep-deprived participants compared to controls. However, such risk was minimized by selecting the test order from presumably high to low sensitivity to fatigue; indeed, the results showed the largest differences between groups for the tasks in the middle but not at the end. We also were not able

to properly control for the task expectation effects. Sleep-deprived participants might expect greater fatigue from the exercise, but it did not prove to be the case for motor control or maximal effort requiring performance of motor tasks.

CONCLUSIONS

MVC, CMJ height, motor control performance during speed–accuracy tasks, and central and peripheral fatigue during the isometric 30 s MVC did not change after one night of sleep restriction. However, executive function in the Stroop and go/no-go tasks deteriorated after sleep deprivation. These data suggest that motor functions, especially those requiring maximal effort, and motor control are more resistant to one night of sleep restriction than is executive function. These findings may be important for goal maintenance, mental flexibility, problem solving, and novel thinking.

List of Abbreviations:
CAR – central activation ratio
CMJ – countermovement jump
MVC – maximal voluntary contraction
RT – reaction time
S – path of movement (accuracy of movement)
SD – standard deviation
SSS – Stanford Sleepiness Scale
Va – velocity
Vmax – maximal velocity
VAS – visual analogue scale

Conflicts of interest: The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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