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Effects of two nights partial sleep deprivation on an evening submaximal weightlifting performance; are 1 h powernaps useful on the day of competition?

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Abstract

We have investigated the effects that sleep restriction (3-h sleep during two consecutive nights) have on an evening (17:00 h) submaximal weightlifting session; and whether this performance improves following a 1-h post-lunch powernap. Fifteen resistance-trained males participated in this study. Before the experimental protocol commenced, 1RM bench press and inclined leg press and normative habitual sleep were recorded. Participants were familiarised with the testing protocol, then completed three experimental conditions with 2 nights of prescribed sleep: i) Normal (N): retire at 23:00 h and wake at 06:30 h, ii) partial sleep-deprivation (SD): retire at 03:30 h and wake at 06:30 h; and iii) partial sleep-deprivation with nap (SD_N): retire at 03:30 h and wake at 06:30 h with a 1-h nap at 13:00 h. Each condition was separated by at least 7 days and the order of administration was randomised and counterbalanced. Rectal (T_{rec}) and mean skin (T_s) temperatures, Profile of Mood Scores, subjective tiredness, alertness and sleepiness values were measured at 08:00, 11:00, 14:00 and 17:00 h on the day of the weightlifting session. Following the final temperature measurements at 17:00 h, participants completed a 5-min active warm-up before a ‘strength’ protocol. Participants performed three repetitions of right hand grip strength, then three repetitions at each incremental load (40, 60 and 80% of 1RM) for bench press and inclined leg press, with a 5-min recovery in between each repetition. A linear encoder was attached perpendicular to the movement, to the bar used for the exercises. Average power (AP), average force (AF), peak velocity (PV), distance (D) and time-to-peak velocity (tPV) were measured (MuscleLab software) during the concentric phase of the movements for each lift. Data were analysed using general linear models with repeated measures. The main findings were that SD reduced maximal grip (2.7%), bench press (11.2% AP, 3.3% AF and 9.4% PV), and leg press submaximal values (5.7% AP) with a trend for a reduction in AF (3.3% P=0.06). Furthermore, RPE increased for measures of grip strength, leg and bench press during SD. Following a 1-h powernap (SD_N), values of grip and bench press improved to values similar in N, as did tiredness, alertness and sleepiness. There was a main effect for ‘load’ on the bar for both bench and leg press where AP, AF tPV values increased with load (P<0.05) and PV decreased from the lightest to the heaviest load for both bench and leg press. An interaction of ‘load and condition’ was present in leg press only, where the rate of change of AP is greater in the N than SD and SD_N conditions. In addition, for PV and tPV the rate of change was greater for SD_N than N or SD condition values. In summary, SD had a negative effect on grip strength and some components of bench and inclined leg press. The use of a 1-h power nap that ended 3-h before the ‘strength’ assessment had a positive effect on weightlifting performance, subjective mood and ratings of tiredness.

Introduction

Partial sleep loss (a 2-3 h reduction of sleep per night compared to that habitually taken over a 24 h period) spread over a number of days is a common occurrence in athletic and non-athletic populations (Edwards and Waterhouse 2013; Thun et al. 2015). It might arise from the residual effects of disturbed circadian rhythms following a time-zone transition, but it might also occur when the event is taking place in the home time-zone (Reilly and Edwards 2007; Simpson et al. 2017). Sleep may be more disturbed than normal due to having to sleep in unfamiliar surroundings, apprehension the night before an important competition, or unfamiliar and distracting noise such as from sports fans. In addition, travel to a sports meeting or training session might involve getting up early in the morning or retiring late at night (Edwards and Waterhouse 2013). All these factors can have a detrimental effect on motivation which is essential for tasks requiring maximal or submaximal efforts (Blumert et al. 2007; Reilly and Edwards 2007), either at competition or during training (as seen in weightlifting, for example).

The negative effects of sleep loss on mood and performance of various mental tasks has been widely investigated and is unequivocal, with several mathematical simulations of mental performance reported (Åkerstedt and Folkard 1995; Krauchi et al. 2005; Neri 2004; Spencer 1987). These models incorporate separate effects due to circadian phase (of both a marker rhythm such as core temperature, and the daily rhythm in performance being investigated), time-since-waking (hence homeostatic drive to sleep) and sleep history (Edwards and Waterhouse 2013). These models are routinely utilised to provide a rationale for giving advice on ways to best combat negative symptoms associated with disturbed sleep, a period of extended wakefulness or an abnormal phasing of circadian rhythms (Reilly and Edwards 2007). Regarding physical exercise, there is evidence to support that complete sleep deprivation can have significant negative effects on athletic performance (see review by Fullagar et al. 2015). However, research investigating the effects of sleep restriction (partial disturbance of the sleep-wake-cycle) and potential interventions is sparse and conflicting; this a problem as athletes are more likely to experience this mode of sleep loss (see recent reviews Simpson et al. 2017; Thun et al. 2015). One of the reasons given for the discrepancies between findings in the literature is associated with the timing of the sleep restriction (normally amounting to 2.5-4 hours), where a ‘normal-hours-to-retire’ and ‘early-rising’ protocol appears more detrimental to gross muscular strength and power assessment than a late-bedtime and normal-rising (Bambaeichi et al. 2005; Souissi et al. 2013). This is somewhat predictable as with the mental performance model, the effects of sleep loss on muscular performance are subject to both i) the time-of-day and ii) the time awake (hours) when performing the measurement. Hence, the homeostatic or time-since-awake component may negatively modify the circadian component of a rhythm, such as motivation and mood that contributes to overall muscular performance. This sleep drive is further exacerbated if the competition or training session is scheduled not for the morning after the sleep restriction, but later that evening (Reilly and Piercy 1994; Edwards and Waterhouse 2013 In this case the cumulative fatigue due to partial sleep-deprivation may negatively affect the typical diurnal variations of short-term maximal performance, by a blunting in muscle strength and power in the late-afternoon and early evening (16:00 h, Souissi et al. 2003; Souissi et al. 2013). Further, these effects are generally compounded when the partial sleep restriction is extended from a 24 h period to 2-3 days**,** where no opportunity to 'nap' is given and this accumulated sleep loss results in an acute sleep-debt, which intensifies the time-since-awake component (Reilly and Piercy 1994). This sleep-debt is normally dissipated after a good night sleep, thereafter the effects of time-since-awake on mood and performance becomes as normal. However, if this does not occur and the sleep-debt persists over weeks, months or even years it has been linked with challenging system level and metabolic homeostasis. This can lead to disruption involving an increased secretion of cortisol, poor blood pressure control, higher C-reactive protein, triglycerides and low-density lipoprotein cholesterol levels (Arora et al. 2016). Resulting in an increase in the risks of heart disease, diabetes, depression and obesity (Irish et al. 2015).

When considering research that employs a late-to-bed and normal-rising sleep restriction protocol, wherein only one night's sleep is compromised, measures of maximal gross muscular performance (single all-out efforts) appear to be robust and unaffected under conditions of partial sleep deprivation - that is, the individual can shrug off fatigue, momentarily when maximal effort is needed and 'time on task' is short (<1 s; Edwards and Waterhouse 2013). When the task is repetitive or 'time on task' is extended such as in a 2-20 m sprints (>1 to 4 s respectively; Waterhouse et al. 2007), or Wingate and force-velocity testing (≥30 s; Souissi et al. 2003; Abedelmalek et al. 2012) detriments in performance are apparent. Regarding the effects of sleep loss on submaximal gross muscular tasks such as in weightlifting where there is a build-up phase in the intensity of the exercise (progressive increase of load on the bar) to achieve maximal effort/performance is less well established (Edwards and Waterhouse 2013; Leger et al. 2005; Reilly and Edwards 2007; Smith and Reilly 2005). One such study by Reilly and Piercy (1994) focused on weight-lifting tasks, using maximal and repeated submaximal lifts. They reported submaximal weight lifting efforts appear to be affected more by sleep loss than maximal efforts, particularly following the first two of three nights of successive sleep restriction.

Regarding intervention strategies for sleep loss, an investigation into the effects of a 'nap' on athletic performance in the presence of smaller amounts of sleep loss would be useful to sports participants (Fullagar et al. 2015). Again, the advice for the duration (time) and timing during the day mainly comes from the mathematical models previously mentioned concerning sleep and mental performance (Åkerstedt and Folkard 1995; Krauchi et al. 2005; Neri 2004; Spencer 1987). In practice however, the timing of a nap is often determined by the individual's daily schedule. A short nap in the middle of the afternoon (~13:00 h) is not only often easier to incorporate into a daily lifestyle but also it is at a time when there is a transient fall in alertness, core temperature and increased tiredness (Brooks and Lack 2005; Hayashi et al. 2005; Waterhouse et al. 2007). Therefore, athletes are encouraged at the beginning of each afternoon to have a short nap (less than 0.5-h, to avoid sleep inertia) or if the nap is of longer duration (1 h) certainly allowing enough time >2 h to recover from this sleep inertia (Davenne 2009). The restorative effect of such naps (1 h) is less well investigated.

The physical demands of sport are such that athletes are required to move in multiple directions, at varying rates of speed, and for periods that depend upon the characteristics of each sport. As such, muscle force output in athletic terms is neither a singular non-linear movement performed at a steady velocity (Häkkinen and Komi 1985). Because of this, Strength and Conditioning coaches routinely use multi-joint exercises (Back squat, Leg press and Bench press) to monitor and evaluate muscle force output in a manner which better represents the sporting challenges for which they are preparing the athlete (Baechle and Earle 2005). Linear position technology (such as the Muscle Lab, FitroDyne and GymAware force-velocity linear encoders/transducers) can measure the displacement of an object and are increasingly used to measure power and force variables in research and in strength and conditioning practice as a means of determining and monitoring athletic performance (Harris et al. 2010). In a recent study (Robertson et al. 2018) the MuscleLab force-velocity linear encoder was reported to be sensitive to detect diurnal variation in multi-joint muscle force output at different masses (low and high) during a bench press and back squat. However, to date, no study has quantified the effects of partial sleep deprivation on varying intensities using linear position technology during submaximal weightlifting.

The purpose of the present study was to: **1)** determine both physical and psychological effects that partial sleep loss (3 h sleep per night, restricted by late retiring over 2 consecutive nights) had on measures for maximal grip-strength and muscle power, force, peak velocity, time-to-peak velocity and distance for varying submaximal intensities for both bench press and inclined leg press. As well as changes in profiles of tiredness, alertness, temperature and sleepiness caused by a limited amount of sleep during the previous two nights in participants otherwise living regular and conventional sleep–wake schedules. Lastly, **2)** investigate how effective the addition of a 1-h post-lunch nap is in improving both physical performance measures and subjective psychological profiles of mood, tiredness, alertness and sleepiness in a state of partial sleep deprivation.

Methods

Participants

Fifteen male participants with age (mean ± SD: 22.7 ± 2.5 years; body mass 89.0 ± 13.8 kg; height 182.4 ± 7.5 cm; normative retiring and rising times 23:33 ± 0:23 h:min and 07:21 ± 0:38 h:min respectively, volunteered for this study. Verbal explanation of the experimental procedure was provided to each individual; this included the aims of the study, the possible risks associated with participation and the experimental procedures to be utilized. Individuals then provided written, informed consent before participating in the study. The experimental procedures were approved by the Human Ethics Committee at Liverpool John Moores University and was conducted following the guidelines of the journal (Portaluppi et al. 2010). Participants were selected if they met all the inclusion requirements which were: habitual sleeping duration of ~8 h per day, no reported sleep problems, did not routinely nap, had at least 2 years' experience in strength and weight training (particularly proficient in bench press and inclined leg press exercises) and habitually trained at any time of the day during a typical week. Participants were also required to avoid all alcohol 48 hours (h) prior to each test. None of the participants presented with a history of bone fractures and/or a history of musculoskeletal abnormality; and none of the participants were receiving any pharmacological treatment during this study. Participants were excluded from participating if they had undergone recent shift work or rapid travel across time-zones or produced extreme scores from the Physical Activity Readiness Questionnaire (PARQ; Chisholm et al. 1975) and Composite Morningness questionnaire [CMQ] (Sleep Flexibility/Rigidity [F/R] and Languid/Vigour [L/V]; Smith et al. 1989). In regard to the CMQ rhythm stability is assessed via flexibility/rigidity (F/R) of sleeping habits. Rigid types are reported to be less able to; go to bed early, sleep or sleep at unusual hours. They also report a preference to sleep and eat at regular times. Languid/vigorous

(L/V) represents the rhythms amplitude. Languid types are reported to find it difficult to overcome drowsiness and feel lethargic following reduced sleep. Where vigorous and flexible types show better circadian adjustment on a number of psychological and physiological tasks. Mean chronotype score of the selected participants was intermediate (31.8 ± 4.5); F/R score 47.4 ± 4.2 hence more 'flexibility'; and L/V score 44.5 ± 6.3 hence more 'languidity'. All experimental tests were carried out between the months of March-May.

Research design

Each participant first completed one-repetition maximum (1RM) for bench press and inclined leg press. Familiarisation sessions were then undertaken (detailed below), followed by the completion of three experimental conditions, involving two nights of sleep taken at the participants home before coming into the laboratory. Either, **1)** Normal (N) retiring to sleep at 23:00 h and waking at 06:30 h, **2)** Partial sleep deprivation (SD) retiring to sleep at 03:30 h and waking at 06:30 h, and **3)** Partial sleep deprivation (SD_N) retiring to sleep at 03:30 h, rising at 06:30 h with 1-h nap at 13:00 h. Participants were randomly allocated into 3 groups, where group one did conditions N, SD and SD_N and group two, SD, SD_N then N and lastly group three did SD_N, N and SD. Hence, these experimental sessions were counterbalanced in order of administration in order to minimise any potential learning effects (Monk and Leng 1982), with a minimum of 1 week between conditions to ensure recovery between trials.

Protocol and measurements:

All sessions took place under standard laboratory conditions (lighting, room temperature, humidity and barometric pressure were 200-250 lux, 20.0 ± 1.5°C, 38.5 ± 4.0 %, and 750.2 ± 6.5 mmHg, respectively). Prior to the main experiment, participants completed sessions in which they determined their one-repetition maximum (1RM) for bench press and inclined leg press (bench press 1RM; 98.0 ± 24.8 kg, inclined leg press 1RM; 289.3 ± 30.6 kg). 1RM were tested to determine percentage loads for the experimental protocol and this was conducted from 17:00-19:00 h. Additionally, participants attended the laboratory on four more occasions for familiarisation sessions of the experimental protocol, each session separated by at least 2 days. Each participant was required to perform: i) three grip strength attempts from the dominant hand (right), with 2-min between each effort to limit the effects of fatigue. ii) one repetition of bench press at three incremental loads (40, 60 and 80 % of their 1RM), allowing a 5-min recovery in between each effort, iii) this protocol was repeated on the inclined leg press. The familiarisation sessions were also used to assess the physical capabilities of each subject during the lifting protocol, to minimise the risk of failed efforts during the experimental conditions that could have affected data collection. A schematic of the experimental protocol is given in Figure 1. Participants were free to live a "normal life" between sessions, sleeping at home at night and attending lectures and doing light office work in the day. They were restricted from napping, undertaking exercise involving heavy exertion out of the parameters of the experiment and refrained from caffeine or alcohol intake 48 h before the experimental conditions and during the experiment. Participants came into the morning session having fasted and were not allowed to consume food 4 h before the 17:00 h session. Participants verbally stated they had complied with these restrictions on entry to the laboratory and recorded their dietary habits throughout the day including amount, type and timing of food and fluid intake. Participants were asked to replicate their dietary habits as closely as possible for the three experimental conditions to promote consistency.

******Insert Figure 1 near here******

Following the 2 nights prescribed sleep prior to the testing day; participants entered the laboratory at 08:00, 11:00 and 14:00 h. For the SD_N experimental condition, participants were required to sleep/rest on bed provided in a dark, quiet room for 1 h in the sleep laboratory of the University. During this period in other conditions, the participants sat in the laboratory quietly, but remained awake for the same duration at the same time of day. At each measurement time point (see Figure 1); participants inserted a rectal probe approximately 10 cm past their external anal sphincter (Grant, Squirrel, Cambridge). Skin thermistors (Grant, Cambridge) were attached to four points of the body: sternum, upper arm (bicep mid-point), thigh (quadriceps mid-point) and calf (mid-point; Ramanathan 1964). Recordings of skin temperature and rectal temperature values (T_{rec} and T_{skin}) were measured every minute for 30 min, whilst participants remained awake in a semi-supine position. Mean body temperature (T_{MB}) was derived from the values of T_{rec} and T_{skin} (Reilly and Cable 2001). The values obtained during the last 5 min of the recording sessions were defined as resting values, averaged, and subsequently used for data analysis (Edwards et al. 2002). During each laboratory visit alongside temperature measurements, participants completed subjective questionnaires: Profile of Mood States (POMS; McNair and Lorr 1971), tiredness and alertness (0-10 cm Visual Analogue Scale) and sleepiness scales using the Stanford Sleepiness Scale

(Hoddes et al. 1973). Participants returned to the laboratory at 17:00 h for temperature measurements and questionnaires followed by a standardised 5-min active warm up (10 km·h^{-1} run on a motorised treadmill; Pulsar, H/P cosmos, Nussdorf-Traunstein, Germany). Final skin and rectal temperature values were taken immediately after the active warm-up and the skin thermistors and rectal probe were removed for the remainder of the experimental protocol. The daily energy intake on test days was controlled and limited to 2500 kcal, which complies with the British Nutrition Foundation's recommended daily calorific intake for a mature man (www.nutrition.org.uk/home.asp, accessed on 19.06.2018). Water and non-caffeinated/non-alcoholic, calorie free beverages were allowed ad libitum up to a total volume of 3 L per day.

Grip strength (Takei Kiki Kogyo, Tokyo, Japan) testing comprised of 3 attempts from the dominant hand (right), with 2-min between each effort to limit the effects of fatigue – with the highest value being recorded and used for analysis (Edwards et al. 2000). After this, participants completed the following: three attempts per load (40, 60 and 80 % of 1RM) of bench press, with 5-min rest between each repetition. This protocol for bench press was then repeated for inclined leg press. A force-velocity linear encoder (Muscle Lab, Ergotest version 4010, Norway) was attached to a 20 kg Olympic barbell for bench press, and to the loading bar of the inclined leg press, respectively. In both cases the linear encoder was mounted perpendicular to the line of movement of the lift. Participants were told to push against the bar as forcefully as possible and given verbal encouragement. A rating of perceived exertion (RPE; Birk and Birk 1987) was taken following each grip strength effort and each lift. The liner encoder recorded AP (W), AF (N), PV (ms^{-1}) and tPV (ms^{-1}) for each lift. The distance (D, cm) that the encoder moved during each attempt was also recorded to assess consistency of the lifts, allowing bar to remain within 3 cm for each bench lift and individualised for each leg press dependent on the participant. The highest of the three AF outputs (and associated AP, AF, PV, D and tPV values) were used for analysis for each mass on the bar for both bench press and back squat respectively.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS IBM), version 24, for Windows were used. All data were checked for normality using the Shapiro-Wilk test. Differences between conditions were evaluated using a general linear model with repeated measures, within subject factor 'condition (3 levels) and within subject factor 'load on bar' (3 levels) and interaction. To correct violations of sphericity, the degrees of freedom were corrected in a normal way, using Huynh-Feldt ($\varepsilon > 0.75$) or Greenhouse-Geisser ($\varepsilon < 0.75$) values for ε, as appropriate. Graphical comparisons between means and Bonferroni pairwise comparisons were made where main effects were present. The α-level of statistical significance was set at $P < 0.05$, and values of '0.000' given by the statistics package are shown here as $P < 0.0005$ (Kinear and Gray 1995). Effect sizes (ES) were calculated from the ratio of the mean difference to the pooled standard deviation. The magnitude of the ES was classified as trivial (≤ 0.2), small (> 0.2-0.6), moderate (> 0.6-1.2), large (> 1.2-2.0) and very large (> 2.0) based on guidelines from Batterham and Hopkins (2006). The results are presented as the mean ± the standard deviation throughout the text unless otherwise stated. Ninety-five percent confidence intervals are presented where appropriate as well as the mean difference between pairwise comparisons.

Results

Performance variables (measured at 17:00 h only)

Mean ± SD values and the results from the ANOVA statistical analysis are displayed in Tables 1 and 2. Statistical significance of the results can be seen in Figures 2 and 3.

******Insert Tables 1 and 2 and Figures 2 and 3 near here******

Muscle Strength Measurements

Grip strength (dominant hand)

There was a significant effect of sleep condition on peak grip strength values ($P = 0.019$). Pairwise comparisons showed that grip strength was higher in the N condition than in the SD condition (mean difference = 1.2 Nm^{-1}, $P = 0.041$, 95% CI: 0.1-2.4 Nm^{-1}; ES = 0.35). Grip strength was also significantly higher in the SD_N condition compared to the SD condition (0.7 Nm^{-1}, $P = 0.002$, 95% CI: 0.3-1.1 Nm^{-1}; ES = 0.21). There was no significant difference in grip strength values between the N and SD_N condition ($P = 0.53$), indicating that grip strength returned to values similar to N with the addition of a powernap in a partial sleep deprived condition.

Bench press

There was a significant main effect of sleep condition for AP, AF, PV, RPE and a trend for tPV values ($P < 0.05$ and $P = 0.062$ respectively). Pairwise comparisons showed that participants produced significantly more AP, AF, PV values in the N condition than in the SD condition (AP: 47.2 W, $P < 0.0005$, 95% CI: 28.1-66.4 W; ES = 0.90. AF: 18.9 N, $P = 0.007$, 95% CI: 5.1-32.6 N; ES = 0.26. PV 0.07 ms^{-1}, $P < 0.0005$, 95% CI: 0.05-0.10 ms^{-1}; ES = 0.65 see Figure 2); and perceived the exertion during lifts as harder in SD than N condition (RPE: 0.9, $P = 0.004$, 95% CI: 0.3-1.5 N; ES = 1.31). Both tPV and D showed no effect between the N conditions than in the SD condition ($P > 0.05$). There was significantly higher AP and PV values obtained in the SD_N condition compared to the SD condition (AP: 33.8 W, $P = 0.002$, 95% CI: 12.7-54.8 W; ES = 0.73. PV: 0.05 ms^{-1}, $P < 0.005$, 95% CI: 0.02-0.07 ms^{-1}; ES = 0.48); and a trend for tPV (with lower tPV data indicating a shorter time-taken, and hence greater speed of execution) and RPE values be lower in the SD_N vs SD condition ($P = 0.088$ and $P = 0.081$). *In summary, these findings indicate that the sleep loss produced changes in Bench press that were required to test the basic research question (the role of a nap) and there was no difference between N and SD_N values for the performance variables.* There was a significant main effect of 'load' on all bench press variables measured apart from D (see Table 1). As anticipated, AP, AF, tPV and RPE were significantly lower at 40 % 1RM and highest at 80 % 1RM ($P < 0.0005$). Conversely, PV was highest at 40 % 1RM and lowest at 80 % 1RM ($P < 0.0005$). For PP alone was there no difference between 60 and 80 % 1RM ($P > 0.05$). There was a significant main effect of load on subjective RPE values, 40 % 1RM load eliciting the lowest values whereas 80 % 1RM produced the highest ($P < 0.05$). There were no significant interaction of 'load and condition' for any variable, such that the profiles values for the three loads for the three conditions rose or fell in the same manner (see Figure 2).

Leg press

There was a significant main effect of sleep condition for AP, RPE and D (*P* < 0.005) and a trend for tPV and AF for leg press values (*P* = 0.09 and *P* = 0.062 respectively). PV showed no significant main effect of sleep condition (see Table 1). Pairwise comparisons show that participants produced significantly more AP values and perceived the effort as harder during lifts (RPE) in the N condition than in the SD condition (AP: 54.7 W, *P* = 0.002, 95% CI: 20.0-89.5 W; ES = 0.55. RPE: 0.9, *P* < 0.0005, 95% CI: 0.5-1.3 N; ES = 0.97). AP was significantly higher in the SD_N condition compared to the SD condition (mean difference = 43.6 W, CI = 3.48-83.64 W; *P* = 0.031). No significant difference in AP was found between N and SD_N conditions (*P* = 0.65). There was no significant difference in leg press RPE observed between SD_N and the two other condition variables. There was a significant main effect of 'load' on all leg press variables measured (see Table 1). As anticipated, AP, AF, tPV and RPE were significantly lower at 40 % 1RM and highest at 80 % 1RM (*P* < 0.0005). Conversely, PV and D values were highest at 40 % 1RM and lowest at 80 % 1RM (*P* < 0.0005). There was a significant main effect of load on subjective RPE values, 40 % 1RM load eliciting the lowest values whereas 80 % 1RM produced the highest (*P* < 0.05). An interaction of 'load and condition' was present in inclined leg press, where rate of change of AP from low to high loads was greater in the N than SD and SD_N conditions. Further, there were modifications tPV and PV values in the SD_N condition such that it took longer to peak velocity at the heaver load and peak velocities were highest at the lowest loads respectively. *In summary, these findings indicate that the sleep loss produced changes in leg press that were required to test the basic research question (the role of a nap) and there was no difference between N and* SD_N *values for AP values.*

Physiological and psychological variables (measured at 08:00, 11:00, 14:00 and 17:00 h)

There was no significant main effect of sleep condition on T_{rec}, T_{skin} and T_{MB} (*P* > 0.05 see Table 2). There was a significant main effect of condition on subjective tiredness and alertness, with tiredness being the reciprocal of alertness. N produced highest alertness values compared to both SD (3.5, *P* < 0.0005, 95% CI: 2.9-4.1; ES = 5.6) and SD_N (2.5, *P* < 0.0005, 95% CI: 2.1-2.9; ES = 5.4). Alertness was higher in the SD_N condition than the SD condition (3.5, *P* < 0.0005, 95% CI = 0.52-1.52; ES = 1.6). N produced highest tiredness values compared to both SD (3.5, *P* < 0.0005, 95% CI: 2.9-4.1; ES = 5.6) and SD_N (2.5, *P* < 0.0005, 95% CI: 2.1-2.9;

ES = 5.4). Tiredness was higher in the SD_N condition than the SD condition (3.5, $P < 0.0005$, 95% CI = 0.52-1.52; ES = 1.6). There was a significant main effect of condition on subjective sleepiness rating. N sleepiness was significantly lower than SD (2.3, $P < 0.001$, 95 % CI = 1.8-2.7; ES = 4.0) and SD_N (1.7, $P < 0.0005$, 95 % CI = 1.2-2.1; ES = 3.4). In addition, SD_N sleepiness rating was significantly less than SD (0.6, $P = 0.01$, 95 % CI = 0.3-0.9; ES = 1.6), indicating that a powernap decreased the subjective feeling of sleepiness when in a partially sleep-deprived state. Concerning mood, apart from tension there was a significant main effect of condition on all mood profiles where all variables were rated more positively in N vs SD condition such as higher (vigour, calm, happiness) or lower (anger, tension, confusion, depression and fatigue, $P < 0.05$, see Table 2). There was no difference between anger ratings ($P > 0.05$) and a trend for ratings of happiness and depression to be similar for N and SD_N conditions respectively ($0.05 > P < 0.01$). There was a significant main effect of time-of-day on T_{rec}, T_{skin} and T_{MB} ($P < 0.05$, see Table 2 and Figure 3), where morning values significantly lower than evening (T_{rec} 0.41°C, 95% CI = 0.07-1.05°C; $P = 0.019$, ES = 2.61; T_{skin} 0.52°C, $P = 0.02$, 95% CI = 0.07-0.97°C; ES = 0.66; T_{MB} 1.02°C, $P < 0.0005$, 95% CI = 0.12-0.36°C; ES = 1.6). Sleepiness and alertness levels were significantly affected by time-of-day ($P < 0.005$), highest levels were reported in the morning upon waking and lowest levels at 17:00 h pre-warm up (see Table 2). There were significant effects of time-of-day on all mood profiles. Vigour, calmness, confusion and happiness were all significantly lower in the morning compared to the evening, whereas tiredness, anger, tension, depression and fatigue were all significantly higher in the morning than the evening (see Table 2). Interactions were evident for T_{rec}, and T_{MB} temperature profiles, where over the four times of day for the N condition the temperature rose from morning to evening. However, in both the SD and SD_N condition values rose from 08:00-12:00 h, then from 12:00 and 14:00 h the values levelled and rose thereafter to 17:00 h ($P < 0.05$, see Table 2 and Figure 3). Subsequently after the nap in the SD_N condition, there was a decrease in tiredness, fatigue, confusion, sleepiness, and an increase in calm, vigour, happiness and alertness in the evening, similar to values produced in the N condition. These altered mood profiles account for the significant interactions observed ($P < 0.05$; See Figure 2 and Table 2). No other variable showed a significant interaction ($P > 0.05$; see Table 2). *In summary, in relation to aims of the study, time-of-day profiles were evident from 08:00 h to 17:00 h, and the partial sleep-deprivation condition produced increases in tiredness, sleepiness and decreases in alertness. However, after the nap in the* SD_N *condition, values of tiredness, sleepiness and alertness were similar to those in the N condition.*

Correlations between ratings of tiredness, T_{rec} Chronotype, Flexibility/rigidity and Languidness/ and measured variables.

Correlations between the measured variables are shown in Table 3. Important findings were: there were significant positive correlations between ratings of Tiredness and Sleepiness, between Tiredness and PV (at 40 and 80 % 1RM) for bench press; and tPV (at 40 and 80 % 1RM) and RPE (80 % 1RM) for bench press and Leg press. In addition, negative correlations were present between ratings of Tiredness and, **i)** grip strength, and **ii)** AP (at 40 and 80 % 1RM). Negative correlations were also present for tiredness and AF for bench press and Leg press at 80 % 1RM, but only Leg press at 40 % of 1RM. However, there were no significant correlations between $T_{rec,}$ Chronotype, Flexibility/Rigidity and Languidness/Vigorousness and any other variable.

******Insert Table 3 near here******

Discussion

We report that 3 h of partial sleep deprivation from 03:30-06:30 h accumulated during two nights resulted in a decrease in maximal grip strength (2.7 %), submaximal values for bench press (AP 11.2 %, AF 3.3 % and PV 9.4 %) and inclined leg press variables (AP 5.7 %) using the MuscleLab linear encoder (Ergotest, version 4010, Norway) in the SD compared to the N condition. There was also a trend for a reduction in AF and increase in D (P = 0.062, P = 0.067) in inclined leg press and a decrease in tPV for both bench press and inclined leg press respectively (P = 0.062, P = 0.09). Furthermore, subjective RPE values were higher for both grip, leg and bench press in the SD compared to the N condition. Following a 1-h powernap (SD_N), grip and bench press values improved to values similar in N, as did subjective values of tiredness, alertness and sleepiness. Only PV during bench press was unaffected by the 1-h nap and values were still lower than N condition ($P < 0.05$). The 2.7 % drop in isometric maximal grip strength is in agreement with others who used a sleep restriction protocol for 2 nights (3 h per night, Soussi et al. 2013) and taken strength measurements in the evening, but in disagreement with others who used a 3 night sleep restriction protocol (2.5 h per night; Reilly and Deykin 1983) and measured in the morning and found no significant difference after the sleep loss. The proposed mathematical models of ‘sleep regulation’ have been successful in predicting alertness and sleepiness for experimental manipulations mainly to do with mental and cognitive performance tasks, but have been applied sparingly for more sporting type tasks such as in the current study (weight lifting). These models consist of 1) a homeostatic process mediating the rise of sleep propensity during waking and its dissipation during sleep; 2) a circadian process independent of prior sleep/wake controls the alternation of periods with high and low sleep propensity; and 3) an ultradian process which occurs within the sleep episode, representing the alternation of the two basic sleep states (nonREM sleep and REM sleep; Achermann and Borbély 2003; Klerman and Hilaire 2007). The differences between our main findings and others could be readily explained by the framework of these models, where the homeostatic component increases due to the weight lifting being in the evening rather than morning; as a result of a greater time-awake. This drive-to sleep negatively modifies the circadian component of a rhythm, such as motivation and mood that contributes to overall muscular performance (Souissi et al. 2003; Souissi et al. 2013).

Our control condition shows daily rhythms for rectal temperature, tiredness/sleepiness and alertness similar to values in the scientific literature (Edwards et al. 2008; Drust et al. 2005). Where from morning to evening, tiredness and sleepiness values fall and subjective rating of alertness increase in parallel to the diurnal variation of rectal temperature (see Figure 3). The general parallel between alertness and core temperature is normally interpreted to indicate some sort of causal link, and the earlier phasing of alertness has been interpreted to indicate that ratings of alertness declines and tiredness increases (reciprocal of alertness) due to effects of time-awake (Carrier and Monk 2000; Folkard 1990; Johnson et al. 1992; Reilly and Edwards 2007; Waterhouse et al. 2001). However, in the SD condition, subjective tiredness and alertness did not parallel the diurnal variation of rectal temperature. This dissociation from core temperature of alertness and tiredness has been observed previously and is attributed to the increase in homeostatic pressure during prolonged wakefulness and reduced sleep (Saper et al. 2005; Sinnerton and Reilly, 1992; Waterhouse et al. 2007). Indeed, it is thought that the homeostatic and circadian facets of sleep regulation are controlled by separate mechanisms, although the cellular and molecular pathways are yet to be charted (Achermann and Borbély 2003; Cirelli 2002). The time-since awake component rather than T_{rec} values appears to be the predominant factor modifying mood and strength parameters. The evidence for this statement comes from firstly, there was no significant differences (from general linear modelling) between T_{rec} values at 17:00 h post warm-up for any conditions yet strength and mood measures did change. Secondly, there was no significant correlation for T_{rec} and any measure of strength (Grip, back or leg), or subjective rating of tiredness and sleepiness values. It would follow that if T_{rec} were related to muscle power output directly, or indirectly through subjective mood measures of tiredness or sleepiness that in turn may effect muscle power output this would be evident and this was shown not to be so. Lastly, in support of a time-since awake component, significant correlations for an increase in tiredness being negatively associated with bench press variables (PP, AF, PV, tPV), grip strength and some components of leg press (PP and AF); this observation regarding tPV should be interpreted as a reduction in time-taken to achieve a slower peak-velocity, essentially faster at being slower. Following the 1-h powernap (SD_N), subjective values of tiredness, alertness and sleepiness improved to values similar in N as did grip and bench press values. This is thought to be due to the dissipation of homeostatic pressure, with an optimal time-of-day element as we timed the nap to occur (13:00 h) when there is a transient fall in alertness, core temperature and increased tiredness (Waterhouse et al. 2007). Currently a short nap less than 0.5-h is commonly recommended to avoid sleep inertia, although a recent review highlights this recommendation is by no means absolute and should consider time-of-day the nap is to be taken and prior sleep/wake history of the individual (Hilditch et al. 2017). Comparison of our findings surrounding the effectiveness of a nap to others is complicated as we used a nap that is of longer duration (1 h) than normally recommended, but then allowed >2 h to recover from this sleep inertia (Davenne, 2009). In view of the results, the nap was deemed successful as a short-term countermeasure to sleep restriction effects on mood and performance.

Despite the alterations in tiredness, alertness and sleepiness in SD, variables for leg press were generally less affected than bench press. It has previously been suggested that lifts that are more 'skill-orientated' and with a high cognitive component (e.g. bench press) may be more affected by sleep loss compared to those that are less skill-orientated (e.g. bicep curl; Drust et al. 2005; Reilly and Piercy 1994). This deterioration in cognitive tasks has been attributed to circulation of catecholamines in the blood (increasing arousal, Reilly and Edwards 2007) and homeostatic drive due to time awake and/or mental fatigue (Carrier and Monk 2000). As leg press requires subjects to push in one direction against a tilted platform, it is possible that this is not largely skill-orientated. However, for bench press, subjects are required to stabilize the bar during the downwards (eccentric) and upwards (concentric) contractions (Hori et al., 2007). In a similar study, Reilly and Piercy (1994) observed deterioration in performance in leg and bench press (denoted by increased RPE), even though bicep curl was unaffected. Further, Takeuhchi et al. (1985) observed that performance of vertical jump and strength of isokinetic knee extension deteriorated because of 64 h total sleep deprivation, but isometric strength and performance at a 40-yard dash were unaffected. These results demonstrate that the execution of some gross muscular tasks may less affected by sleep loss (for example, Leg press) compared to others (for example, Bench press).

A main finding was a main effect for "load" was present as expected, the load on the bar had a significant effect on AF, PV and tPV for both bench press and inclined leg press exercises. Movements against the high-load condition produced greater AF but PV was lower, and the time-to-PV longer compared to movements against the low-load conditions. This is consistent with the fundamental force-velocity properties of skeletal muscle and has previously been demonstrated during complex movements such as power clean, hang clean etc., analysed using force platforms or motion capture systems (Ammar et al. 2018). As well as by similar work using the Muscle Lab linear encoder looking at diurnal variations in submaximal loads in bench press and squat (Robertson et al. 2018). To explore the effect of time-since awake on performance we analysed the data using correlations (Bland and Altman 1995) from the first and final lifts (40 and 80 % 1RM) for bench and leg press. Essentially, they represent the two extremities of the force–velocity relationship, lesser resistances typically allowing for greater peak velocities and greater resistances commonly leading to larger AF values (Robertson et al. 2018). Higher negative correlations where found for some parameters than others at 40 % rather than 80 % 1RM suggesting that the negative of effects of tiredness could be dependent on the load on the bar hence effort required to move it (see Table 3). Further, for inclined leg press the displacement value showed a main effect for load with higher displacements or lack of control at the lower rather than at the higher loads. The reason for this finding is unclear but may relate to concentration and motivation being lower at the lowest submaximal load, hence 'form' dropped.

Interactions of 'load and condition' was only present for the inclined leg press, where at 80 % 1RM AP values are higher in the N than both SD and SD_N conditions suggesting only at the highest load did sleep deprivation reduce AP produced. Further, tPV values for all conditions were similar up to 60 % 1RM and only at 80 % did tPV values increase (occur later) in SD_N condition compared to the other two. In addition, at 40 % 1RM PV values were higher for SD_N than N or SD conditions. In essence, modifications to tPV and PV values in the SD_N condition occurred such that it took longer to reach PV at the heavier load and PV were highest at the lowest loads respectively. These observations are quite typical, as the external load increases the time taken to overcome inertia and complete the movement increases, whilst the addition of the greater resistance magnifies the overall power or force which is measured. Comparison of our data with other studies is limited, as only a few studies have used the linear encoder. However, we have previously shown the MuscleLab force-velocity linear encoder to be sensitive to detect diurnal variation in multi-joint muscle force output at different masses (low and high) during a bench press and back squat. With an interaction only for tPV, such that the tPV occurs earlier in the evening than the morning at the highest loads (60 and 70 kg) for both bench press and back squat, respectively (mean difference of 0.32 and 0.62 s).

To the authors' knowledge, this is the first study using linear-position technology to quantify effects of partial sleep deprivation on submaximal weight lifting efforts (Bench and inclined Leg Press). Force-velocity linear encoders such as the one we used in this study allow measurement of power output, arguably the primary determinant of sport success; as well as rate of force development, also an important and an underpinning mechanism of power output to be measured (Bevan et al. 2010; Hawley et al. 1992; Stone et al. 2002; Taber et al. 2016).We have found similar muscle force and power findings in our control condition to those previously reported at 17:00 h in bench press using a different cohort (Robertson et al. 2018). We have used complex exercises that replicate the movements associated with athletic performance (Chapman et al. 1998; LeSuer et al. 1997). In the case of the lower limbs the inclined leg press and in the case of the upper limbs/ torso the bench press. Further, it has been suggested that the optimal training load for performance enhancement is one that emphasizes the athlete's maximum power output (Comfort et al. 2011; Ammar et al. 2018), in bench press and squat exercise moderate loads (from >30 to <70 % of 1RM) appear to provide the optimal load for power production (Soriano et al. 2017; Soriano et al. 2015). Hence the choice of the upper and lower loads employed in the current study compliments optimal loads for training.

Limitations

Participants were allowed 1-h to nap during the SD_N. Upon waking from the nap at 14:00 h, they had 3 h until the weightlifting protocol began at 17:00 h, to allow for the effects of any sleep inertia to dissipate (which usually takes approximately 1-h). However, many factors are involved in the characteristics of sleep inertia and the severity and decay time course is related to i) the duration of prior sleep and accumulated sleep-debt (Jewett et al. 1999; Stampi et al. 1990), but also ii) the sleep stage prior to awakening - such that an abrupt awakening during a slow wave sleep (SWS) episode produces greater sleep inertia than awakening in stage 1 or 2; with REM sleep being intermediate (Tassi and Gilles 2000). That said, there is a small possibility that participants were still experiencing sleep inertia especially during the bench press, but not before the completion of the leg press repetitions (4 and 5 h after the nap respectively). Lastly, the quality of the sleep during the nap in the current study was only verbally reported by the participants, hence the sleep or sleep stage was not measured or quantified. This was a limitation to the study and this measurement would be beneficial to include in future work, as the length of time allotted to the nap may not have been optimal.

Even though the subjects were thoroughly familiarised with the loads and lifts another limitation of the study was the increase in distance of movement for the leg press at 40 % 1RM which we interpreted as a loss of 'form', this may have affected the results. Lastly, we acknowledge we did not select individuals of extreme chronotype (morning-eveningness), or rhythm stability and sleep flexibility (flexibility/rigidity/languidity/ vigour). Future research investigating an individuals' circadian preference or ability to 'momentarily' shrug off fatigue and their response to sleep restriction and performance, and use of naps may yield different results than ours. We did however, run regression analysis on these factors with our participants who as a group where rated as higher 'flexibility' and 'languidity' but found no significant relationships.

Although participants verbally stated on entry to the laboratory they had replicate their dietary habits as closely as possible for the three experimental conditions to promote consistency. This was not formally assessed and hence is a limitation of the study, sleep deprivation alters impulse control and interferes with the leptin/grehlin balance and may have altered what and how much was eaten, which in turn, may have some impact on 'performance' and mood.

Summary

The results obtained from this study indicate that partial sleep loss (3-h for 2 consecutive nights) causes a significant reduction in maximal and submaximal muscular performance, in agreement with mathematical models of sleep regulation. A 1-h post-lunch nap alleviated deterioration in performance experienced in SD conditions, raising performance values up to or around levels found during N sleep condition. The exact mechanisms are yet to be defined, however, it is thought that the reduced performance in SD conditions is a product of psychological factors (increased subjective sleepiness and tiredness, deterioration in mood and decreased alertness) all having an impact on levels of motivation and ratings of perceived exertion. Additionally, as Leg Press variables were relatively unaffected, it might be that there is a substantial cognitive component (skill) for Bench Press in recreationally athletic subjects.

Practical implications

As far as the authors are aware, this is the first study to use linear-position technology that measures the three dimensions of muscle force output (average force, peak velocity and time-to-peak velocity) that are important for sports such as Olympic weightlifting (Hori et al. 2007); to determine quantifiable effects of partial sleep deprivation on varying intensities during sub-maximal weightlifting performance. The findings of this current investigation may hold important suggestions for athletes faced with demanding training schedules or those preparing for competition. Further work in this area should analyse and quantify the physical effects of partial sleep deprivation with more complex weightlifting or sport-specific movements with a higher cognitive requirement.

A 1-h power nap (13:00 h) was shown to alleviate deterioration in performance experienced after sleep restriction; raising some performance values up to levels found during N sleep condition, these findings have implications for athletes with restricted sleep during training or before competition. Work into the use of naps is worth pursuing rather than prescribing medications (Baird and Asif 2018). Future work should investigate the most effective nap duration, time-of-day in relation to prior sleep restriction (Hilditch et al. 2017); incorporating relaxation techniques to further seek to 'improve' the effectiveness of sleep 'naps' (Debellemaniere et al. 2018).

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We would like to thank the participants who participated in the study. We would also like to acknowledge the intellectual input of Professor James M. Waterhouse who sadly passed away in October 2016.

Declaration of interest:

The authors report no conflicts of interest, the linear encoder was bought from internal funds and there is no link between our laboratory and chronobiology group and the MuscleLab Company. The authors are responsible for the content and writing of this article.

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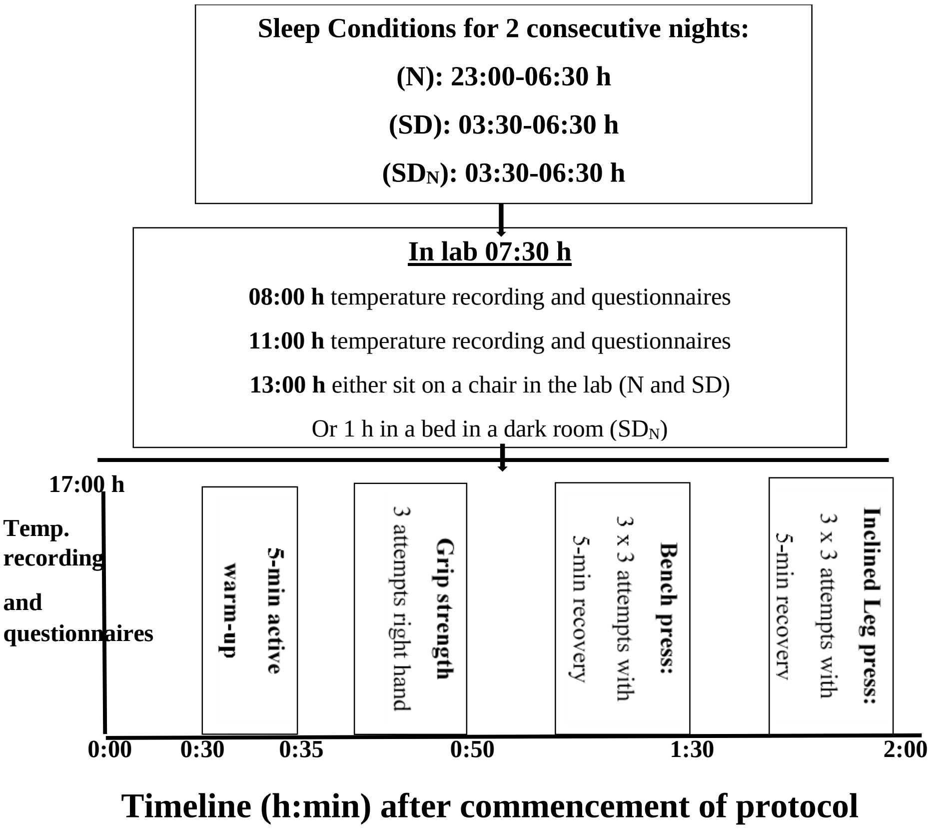

Figure 1

Figure 1. Schematic of experimental protocol. Participants followed the same procedure for each condition (N=7.5 h, SD=3 h and SD_N=3 h sleep) but with the addition of a nap at 13:00 h in the SD_N condition. At 17:00 h participants entered the laboratory and undertook the performance measures.

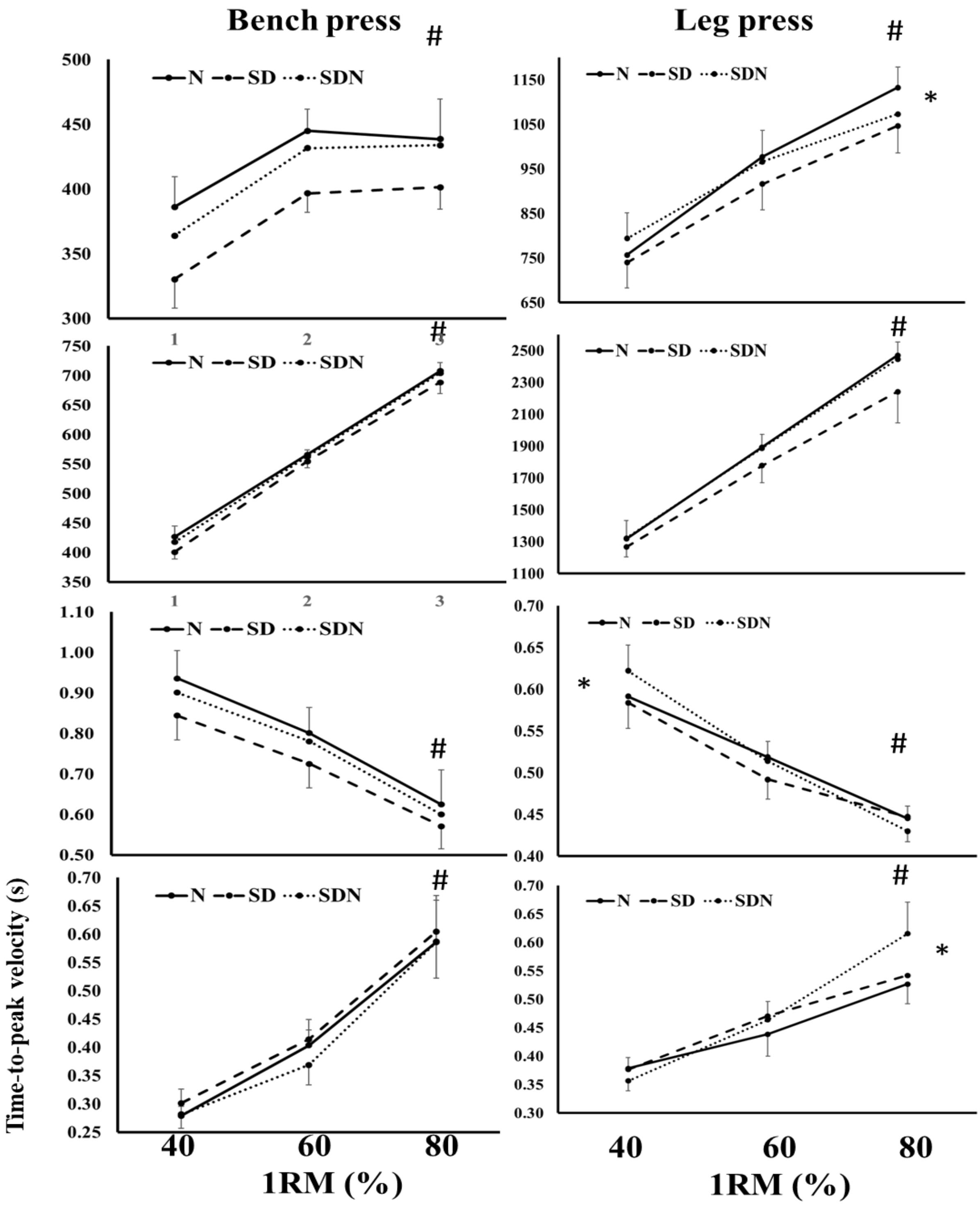

Figure 2

Figure 2. Mean and 95 % confidence intervals values and of each performance variable for both bench press and leg press at 40, 60 and 80 % 1RM loads for the 3 experimental conditions. # Load effect, * Interaction (Load by Condition) effect, as shown by Bonferonni pairwise comparisons ($P < 0.05$).

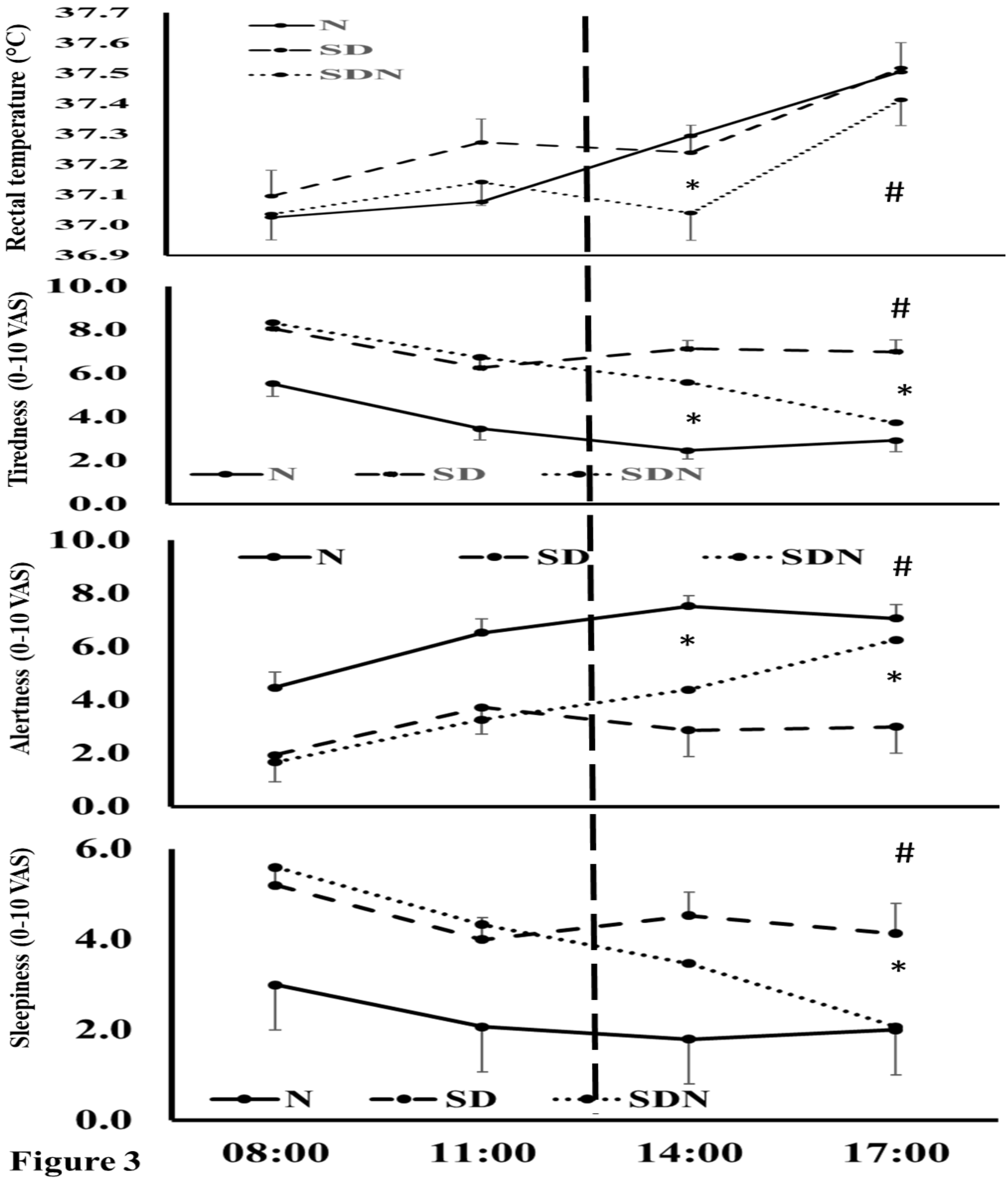

Figure 3. Mean and 95 % confidence intervals values for rectal temperature, subjective tiredness, alertness and sleepiness at 08:00, 11:00 14:00 and 17:00 h under N, SD and SD_N conditions. # time-of-day effect, * Interaction (time-of-day by Condition) effect, as shown by Bonferonni pairwise comparisons ($P < 0.05$).

Table 1. Mean ± SD, F-values and *P*-values for all performance variables measured in this study (‘average power’, ‘average force’, ‘peak velocity’, ‘time-to-peak power’, ‘distance’) and RPE for both bench press and inclined leg press. **Bold** indicates significant ($P < 0.005$); *Italic* indicates a trend ($0.1 < P > 0.05$). a – Significantly different from values of SD condition ($P < 0.05$). b – Significantly different than values of N condition ($P < 0.05$).

Variable	N	SD	SD_N	Significance (*P*-value) Condition	Significance (*P*-value) Load	Significance (*P*-value) Interaction
Grip strength (N)	43.9 ± 3.8a	42.47 ± 3.1	43.4 ± 3.4a	**$F_{1.2, 16.8}$ = 6.29 (*P* = 0.019)**		
Bench Press						
Average power (W)	423 ± 78 a	376 ± 59	410 ± 70 a	**$F_{2, 28}$= 23.28 (*P* <0.0005)**	**$F_{1.2, 17.1}$ = 11.60 (*P* = 0.002)**	$F_{4.0, 55.6}$= 1.21 (*P* = 0.318)
Average force (N)	567 ± 140 a	548 ± 138	561 ± 142 a, b	**$F_{1.1, 15.3}$= 11.99 (*P* = 0.003)**	**$F_{1.9, 20.9}$= 347.91 (*P* < 0.0005)**	$F_{1.8, 24.6}$= 2.25 (*P* = 0.132)
Peak velocity (ms^{-1})	0.79 ± 0.19 a	0.71 ± 0.16	0.76 ± 0.17 a, b	**$F_{2, 28}$= 27.57 (*P* <0.0005)**	**$F_{1.1, 16.3}$ = 69.67 (*P* < 0.0005)**	$F_{4, 56}$ = 1.54 (*P* = 0.202)
Time-to-peak velocity (s)	0.42 ± 0.15	0.44 ± 0.15	0.41 ± 0.15 *a*	*$F_{1.3, 17.8}$= 3.72 (P = 0.062)*	**$F_{1.3, 17.7}$ = 96.00 (*P* < 0.0005)**	$F_{2.2, 30.4}$= 1.02 (*P* = 0.379)
Distance (cm)	45.5 ± 11.4	46.1 ± 5.9	46.6 ± 5.8	$F_{1.1, 15.9}$ = 0.211 (*P* = 0.684)	$F_{1.4, 18.0}$ = 1.20 (*P* = 0.302)	$F_{1.5, 20.6}$ = 0.62 (*P* = 0.500)
RPE General (6–20 VAS)	11.4 ± 2.1 a	12.3 ± 2.3	11.8 ± 2.0 a	**$F_{2, 28}$ = 8.89 (*P* = 0.001)**	**$F_{2.0, 27.4}$ = 332.11 (*P* < 0.0005)**	$F_{2.3, 32.5}$ = 2.40 (*P* = 0.100)
Leg Press						

Table 2. Mean ± SD, F-values and *P*-values for all physiological and psychological variables measured in this study (temperature, sleepiness, tiredness/alertness, POMS. **Bold** indicates significant; $P < 0.005$). a – Significantly different from values of SD condition ($P < 0.05$). b – Significantly different than values of N condition ($P < 0.05$).

Table 2.

Variable	N	SD	SD_N	Significance (P-value) Condition	Significance (P-value) Time of Day	Significance (P-value) Interaction
Rectal temperature (ºC)	37.23 ± 0.36	37.28 ± 0.21	37.16 ± 0.22	$F_{1.4, 18.9}$ = 2.15 (*P* = 0.16)	**$F_{3, 42}$ = 44.82 (*P* < 0.0005)**	**$F_{3.1, 42.8}$ = 4.19 (*P* = 0.011)**
Mean skin temperature (ºC)	31.15 ± 1.51	31.49 ± 0.99	31.52 ± 1.00	$F_{2.0, 27.7}$ = 1.77 (*P* = 0.19)	**$F_{1.8, 25.4}$ = 4.30 (*P* = 0.028)**	$F_{3.6, 49.7}$ = 1.12 (*P* = 0.36)
Mean body temperature (ºC)	36.03 ± 0.42	36.14 ± 0.22	36.06 ± 0.27	$F_{1.7, 24.3}$ = 2.11 (*P* = 0.15)	**$F_{1.9, 26.2}$ = 8.52 (*P* = 0.002)**	**$F_{3.5, 49.5}$ = 3.97 (*P* = 0.009)**
Tiredness (0-10 VAS)	3.6 ± 1.5 a	7.1 ± 1.4	6.1 ± 1.9 a, b	**$F_{1.7, 24.1}$= 184.50 (*P* < 0.0005)**	**$F_{1.9, 26.7}$ = 43.23 (*P* < 0.0005)**	**$F_{4.1, 57.7}$ = 18.73 (*P* < 0.0005)**
Alertness (0-10 VAS)	6.4 ± 1.5 a	2.9 ± 1.4	3.9 ± 1.9 a, b	**$F_{1.9, 27.1}$= 184.63 (*P* < 0.0005)**	**$F_{2.0, 27.96}$ = 30.79 (*P* < 0.0005)**	**$F_{4.2, 58.86}$ = 6.90 (*P* < 0.0005)**
Sleepiness (0-10 VAS)	2.2 ± 0.8 a	4.5 ± 1.1	3.9 ± 1.6 a, b	**$F_{2, 28}$= 114.41 (*P* < 0.0005)**	**$F_{1.75, 24.6}$ = 38.18 (*P* < 0.0005)**	**$F_{4.0, 56.5}$ = 13.35 (*P* < 0.0005)**
Mood State – Vigour	9.0 ± 3.0 a	4.5 ± 2.5	5.6 ± 3.4 a, b	**$F_{1.1, 15.3}$= 24.66 (*P* < 0.0005)**	**$F_{1.5, 20.7}$ = 36.52 (*P* < 0.0005)**	**$F_{2.9, 40.0}$ = 6.60 (*P* = 0.001)**
Mood State – Anger	0.6 ± 1.3 a	1.5 ± 1.8	0.8 ± 1.6 a	**$F_{1.8, 24.9}$= 5.50 (*P* = 0.013)**	**$F_{2.1, 29.9}$= 13.52 (*P* < 0.0005)**	$F_{3.8, 52.5}$ = 1.00 (*P* = 0.41)

Table 3. Correlations between T_{rec}, Tiredness, Chronotype, Flexibility/Rigidity, Languidity/Vigour and performance for grip strength, bench press and leg press (at 40, 60 and 80 % 1RM) and RPE. Method of Bland and Altman (1995) used. Correlations either negative or positive are denoted by the sign + or – and the correlation is given in parenthesis. Bold values represent $P > 0.05$, and correlation coefficient given; italicised values represent a statistical trend and correlation coefficient given ($0.10 > P > 0.05$). If $P > 0.05$, values are not bold and no correlation coefficient given, rather a ‘‘0’’ is given in the text.

Table 3.

	T_{rec}	T_{MB}	Sleep	Grip	PP (40%)	PP (80%)	AF (40%)	AF (80%)	PV (40%)	PV (80%)	tPV (40%)	tPV (80%)	RPE (40%)	RPE (80%)
Bench press														
Tiredness	0	0	+ (0.64)	N/A	- (0.60)	- (0.27)	0	- (0.31)	+ (0.49)	+ (0.27)	+ (0.36)	+ (0.01)	0	+ (0.35)
T_{rec}	0	0	0	N/A	0	0	0	0	0	0	0	0	0	0
Chronotype	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flex/Rigid	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lang/Vig	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grip strength														
Tiredness	0	0	+ (0.64)	- (0.39)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T_{rec}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chronotype	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flex/Rigid	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lang/Vig	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leg press														
Tiredness	0	0	+ (0.64)	N/A	- (0.23)	- (0.15)	- (0.16)	- (0.18)	0	0	0	0	0	+ (0.35)
T_{rec}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chronotype	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flex/Rigid	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lang/Vig	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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