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Effects of an active warm-up on variation in Bench press and Back squat (upper and lower body measures).

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Running title: Offsetting time-of-day variations in power.

Key Words: Time of day, strength, upper body, lower body, core temperature.

Type of submission: Original investigations

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ABSTRACT

The present study investigated the magnitude of diurnal variation in back squat and bench press using the MuscleLab linear encoder over three different loads and assessed the benefit of an active warm-up to establish whether diurnal variation could be negated. Ten resistance-trained males underwent (mean ± SD: age 21.0 ± 1.3 yrs, height 1.77 ± 0.06 m and body mass 82.8 ± 14.9 kg) three sessions. These included control morning (M, 07:30 h) and evening (E, 17:30 h) sessions (5-min standardised warm-up at 150 W, on a cycle ergometer), and one further session consisting of an extended active warm-up morning trial (M_E, 07:30 h) until rectal temperature (T_{rec}) reached previously recorded resting evening levels (at 150 W, on a cycle ergometer). All sessions included handgrip, followed by a defined programme of bench press (at 20, 40 and 60 kg) and back squat (at 30, 50 and 70 kg) exercises. A linear encoder was attached to an Olympic bar used for the exercises and average force (AF), peak velocity (PV) and time to peak velocity (tPV) were measured (MuscleLab software; MuscleLab Technology, Langesund, Norway) during the concentric phase of the movements. Values for T_{rec} were higher in the E session compared to values in the M session (Δ 0.53°C, $P < 0.0005$). Following the extended active warm-up in the morning (M_E), T_{rec} and T_m values were no different to the E values ($P < 0.05$). Values for T_m were lower in the M compared to the E condition throughout ($P < 0.05$). There were time-of-day effects for hand grip with higher values of 6.49 % for left ($P = 0.05$) and 4.61 % for right hand ($P = 0.002$) in the E compared to the M. Daily variations were apparent for both bench press and back squat performance for AF (3.28 and 2.63 %), PV (13.64 and 11.50 %) and tPV (-16.97 and -14.12 %; where a negative number indicates a decrease in the variable from morning to evening). There was a main effect for load ($P < 0.0005$) such that AF and PV values were larger at higher masses on the bar than lower ones and tPV were smaller at lower masses on the bar than at higher masses for both bench press and back squat. We established that increasing T_{rec} in the M to E values did not result in an increase of any measures related to bench press and back squat performance ($P > 0.05$) to increase from M to E levels. Therefore, MuscleLab linear encoder could detect meaningful differences between the morning and evening for all variables. However, the diurnal variation in bench press and back squat (measures of lower and upper body force and power output) are not explained time-of-day oscillations in $T_{rec.}$

INTRODUCTION

In male participants in a temperate environment (around 17–22 °C), muscle force and power output values display diurnal variation, regardless of the muscle group measured (Drust et al. 2005; Reilly & Waterhouse, 2009). However, the magnitude of diurnal variation differs according to the muscle group tested (Coldwells et al. 1994). Time-of-day variations in grip strength (3–6.5 %, Edwards et al. 2013; Reilly et al. 1997), back strength (6 %, Coldwells et al. 1994), elbow flexion (7 %, Freivalds et al. 1983) adductor pollicis (8.9 %, Martin et al. 1999) quadriceps (6 %, Callard et al. 2000) and isometric strength of the knee extensors (12.7 %, Edwards et al. 2013) have been shown previously. Most of the research investigating time-of-day variation of muscle force output generally focuses on single-joint, isokinetic and isometric methods (Such as Callard et al. 2000, Giacomoni et al. 2005 and Edwards et al. 2013). Physical demands of sport require athletes to move and function in multi-direction, at varying speed rates and periods dependant on the characteristic of the sport (Häkkinen & Komi, 1985). Multi-directional exercises which target the enhancement of multi-joint and gross muscular activation are of more interest to strength and conditioning professionals (Baechle & Earle, 2015). Therefore, linear position technology is routinely used to measure displacement, power and force variables in practice to determine and monitor athletic performance (Harris et al. 2010; Robertson et al. 2018). Recently, Robertson et al. (2018) reported that the MuscleLab linear encoder (Ergotest, version 4010, Norway) could detect diurnal variation for both bench press and back squat performance for the three dimensions of muscle force output where average force (AF; 1.9 to 2.5 %) and peak velocity values (PV; 8.3 to 12.7 %) increased, whereas time to peak velocity (tPV; -16.6 to -9.8 %) decreased between morning and evening conditions. These findings represent far greater relevance to athletic performance as they deliver a greater insight into ecologically meaningful assessment of physical qualities that can be readily translated into coaching practice and ultimately impact training provision and performance.

At present, the exact mechanisms underpinning diurnal variation in human performance are still unknown but have been attributed to several factors (Edwards et al. 2013; Pullinger et al. 2018a, 2018b). It is believed that peripheral or muscle-related variables (contractibility, metabolism and morphology of muscle fibres and local muscle temperature), which are in turn influenced by hormonal and ionic muscle process variations (Reilly and Waterhouse, 2009; Tamm et al. 2009), and/or central/neurological factors (central nervous system command; alertness; motivation and mood: Castaingts et al. 2004; Giacomoni et al. 2005; Racinais et al. 2005; 2010) affect diurnal variation in muscle performance. Moreover, the most common hypothesis proposed is that the evening superiority in muscle force production and power output has been attributed to the causal link of the core temperature rhythm, which might be implicated directly or indirectly.

It has been proposed that the higher evening resting core temperature (~0.8°C in rectal and gut sites, Edwards et al. 2002) and local muscle temperature (≥ 0.35°C in vastus lateralis at depths of 3 cm, Edwards et al. 2013; Pullinger et al. 2018a,b) produce an increase in force-generating capacity of the muscle (Bernard et al. 1998; Giacomoni et al. 2005) and neural function such that there is a reduced twitch time-course or increase in speed of contraction (Martin et al. 1999). In order to determine whether or not core temperature and/or muscle temperature (T_m) plays a role in performance, manipulation of morning or evening temperatures – either by increasing morning temperatures to evening levels or decreasing evening temperatures to morning values has previously been studied assessing muscle force, power output and repeated sprint (RS) performance as performance outcomes (Edwards et al. 2013; Pullinger et al. 2018a, 2018b).

A warm-up is a widely accepted practice which precedes any form of exercise and considered essential to achieve optimal performance. It has been suggested that warming up affects performance through several mechanisms which are predominantly related to temperature, such as decreased stiffness, increased nerve-conduction rate and increased anaerobic energy provision (Bishop, 2003a, 2003b). The use of an active (by means of exercise) "warm-up" to increase rectal temperature (T_{rec}) in the morning, to approximately, or precisely, the temperature previously found at rest in the evening, and then examining whether this increases morning performance to evening levels could help establish whether or not manipulation of central temperature, which at rest has a high endogenous component, may provide some exogenous effect to the observed diurnal variation in bench press and back squat. Numerous studies have shown improvements in muscular performance (O'Brien et al. 1997; Sargeant, 1987; Souissi et al. 2010; Stewart & Sleivert, 1998) to take place following an active warm-up while others have reported no significant effects or a decrease in performance (Mitchell & Huston 1993; Pullinger et al. 2018a; Pyke, 1968; Sargeant, 1987; Stewart & Sleivert 1998). Further, research has found that the duration and type of warm-up affects short-term muscular performance (Souissi et al. 2010; Baklouti et al. 2015). It was established that increasing warm-up period in the morning resulted in an increase in performance, but their aim was not to increase "warm-up" to increase T_{rec} in the morning, to approximately, or precisely, the temperature previously found at rest in the evening. Given the conflicting results in the literature regarding the benefit of an active warm-up on muscular performance and considering only one study in the literature has shown diurnal variation using the MuscleLab linear encoder we aimed to establish whether an extended active warm-up negated diurnal variation in multi-joint muscle force output at different masses (low and high) during a bench press (upper body) and back squat (lower body). We hypothesised that the MuscleLab force–velocity linear encoder was able to detect diurnal variation in force output in bench press and back squat at difference masses on the bar, as previously established. We further hypothesise that an active warm-up will increase force output in bench press and back squat at difference masses on the bar to evening values and subsequently negate diurnal variation.

METHODS

Subjects

Ten highly trained, adolescent males (mean ± SD [range]: age 21.00 ± 1.26 [20.00 - 23.00] yrs, height 176.55 ± 5.59 [169.00 - 187.00] cm and body mass 82.8 ± 14.9 [72.6 - 115.2] kg), were recruited from Liverpool John Moores University and participated in this study. Verbal explanation of the experimental procedure was provided to everyone; this included the aims of the study, the possible risks associated with participation and the experimental procedures to be utilised. Any questions were answered. 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. All the participants used in this study had a minimum of two-years' experience of resistance training (specifically bench and back squat) and were competent in their use of such equipment and comfortable in this type of training environment. Recruiting participants with this specific type of exercise history meant that the known neuromuscular facilitative responses, which are typically associated with acute increases in muscular strength amongst untrained individuals due to neural adaptations and responses were reduced (Häkkinen, 1989). Participants were asked to avoid any strength training during the entire experimental condition and to avoid taking part in any physical training or hard activity sessions of an aerobic or anaerobic nature. Participants were also required to avoid all alcohol 24 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. The circadian chronotype of the participants was assessed using a composite “morningness questionnaire” by Smith et al. (1989). The participants’ mean “chronotype” score on a 13–52 scale was 29.00 ± 2.00; hence, all of the participants were “intermediate types”. A circadian-type inventory questionnaire of Folkard and Monk (1979) determining languidness/vigorous and flexibility/rigidity of participants was also utilised. The participants’ mean scores were 47.00 ± 4.00 and 42.00 ± 6.00 for languidness/vigour and flexibility/rigidity respectively. All participants gave their written informed consent. The study was conducted in accordance with the ethical standards of the journal and complied with the Declaration of Helsinki.

Research design

Each participant first completed familiarisation sessions (detailed below), and thereafter each participant completed three experimental sessions three days apart: a morning and an evening trial (07:30 and 17:30 h; M and E) followed by an extended active warm-up morning trial (M_E). These experimental sessions were counterbalanced in order of administration to minimise any potential learning effects (Monk & Leng, 1982), with a minimum of 72 h to ensure recovery between trials.

Protocol: Familiarisation Session

Each participant performed a minimum of four familiarisation sessions under standard laboratory conditions (lighting = 200-250 lux, temperature = 20-22 °C, mean humidity = 50±5 %), conducted over a two-week period and finishing one week before the study commenced to minimize learning effects. The overall coefficient of variation and 95 % ratio limits of agreement were both lower than 10 %. The initial familiarisation sessions were used to determine working loads (mass/resistance) that would be appropriate for the cohort. Each participant was asked to perform the back squat with incrementing loads (30, 50, 70 and 90 kg) with one repetition at each load, and 5-min rest was allowed between each effort. For bench press, each participant performed one repetition against each incrementing load (20, 40, 60 and 80 kg) and, again, 5-min rest was given between each load. This was done so that the upper loads required for the experimental trials (back squat, 70 kg; bench press, 60 kg) were known to be comfortably within each of the participant's physical capabilities, and so there was minimal likelihood of their failing to perform the required efforts for data collection especially as this trial was not a measure or test of maximal strength but rather an investigation regarding the components which produce muscle force output. The familiarisation sessions were allocated in a counterbalanced fashion, with half of the participants taking part in the morning (at 07:30 h) and the remaining half during the evening (at 17:30 h), and were separated by at least 3 days, and each participant did this twice.

Testing Procedure

Participants were required to retire at 22:30 h and rise at 06:00 h; and be in the laboratory 30-min prior to measurements being taken at 07:00 (M, M_E) and 17:00 h (E). Subjects arrived in a post-absorptive state having undertaken an overnight fast in the morning and were asked not to eat in the 4-h prior to the evening session. On arrival compliance to the protocols sleeping, food intake and exercise restrictions were assessed verbally, and this was high. The protocol is shown in Figure 1. Participants arrived 1h before the start of the test, inserted a soft flexible rectal probe (Mini-thermistor; Grant instruments Ltd, Shepreth, UK) ~10 cm beyond the external anal sphincter and lay down and relaxed in the laboratory. T_{rec} was then recorded continuously over 30-min by means of a Squirrel 1000 data logger (Grant Instruments Ltd, Shepreth, UK) while subjects remained semi-supine but awake. The average value of the last 5-min recording was defined as resting T_{rec} and used for subsequent analysis. The subjects then undertook a standardised 5-min warm-up run at 150 W on a cycle ergometer or the extended active warm-up procedure (M_E) at 150 W on a cycle ergometer to increase resting T_{rec} in the morning to T_{rec} values observed in the evening. Following the warm-up T_{rec} and T_m which was assessed using a needle thermistor inserted into the right leg vastus lateralis (13050, ELLAB, Hilleroed, Denmark) was recorded. The area was marked with a permanent marker to minimize site variation between testing sessions. Thigh skinfold thickness was measured using Harpenden skinfold callipers (HSK BI, West Sussex, UK) and halved to determine the thickness of the thigh subcutaneous fat layer of the participant's vastus lateralis (Emwemeka et al. 2002). The needle thermistor was then inserted a depth of 3 cm plus one-half the skinfold measurement for determination of deep T_m (in compliance with procedures set out by Saltin et al. 1968; Gregson et al. 2011). T_m was recorded using an ELLAB electronic measuring system (CTF 9004, ELLAB, Denmark). T_{rec} and T_m were also recorded prior to the bench press and back squat exercises. Thermal comfort (TC; Bakkevig & Nielsen, 1994), rated on a scale from hot to cold; and effort, rated on a scale from 0 (no effort) to 10 (maximal effort) were measured after the warm-up, and during measures of strength.

Muscle Strength Measurements

Subjects performed handgrip, bench press and back squat during the muscle strength exercise procedure. The initial strength measure assessed was that of left and right-hand grip strength using a hand-held grip dynamometer (Takei Kiki Kogyo, Tokyo, Japan). Left and right grip strengths were recorded three times on each hand after the equipment was adjusted until correctly positioned for the individuals' hand and measured alternatively to limit the effects of fatigue (Edwards et al., 2000). The highest value attained for each hand was utilised for further analysis (See Figure 1).

Following this, each of the participants performed the two multi-joint exercises in a randomised order, performing either the back squat or bench press first. Three lifts were performed at each exercise against progressively increasing loads (bench press: 20, 40 and 60 kg; back squat 30, 50 and 70 kg), with 5-min rest allowed between each lift (See Figure 1). The individual's own body mass was factored into the back-squat exercise, as this is a whole-body movement, but not into the bench press. The MuscleLab force-velocity linear encoder was attached to an Eleiko Olympic bar (20 kg) which was set upon rests within a standard squat rack so that the participant had a 90° knee flexion position (settings measured and recorded during the familiarisation process). From this position, the participant was instructed to drive the bar upwards as forcefully as possible; the value recorded during the test was for the concentric phase of the action only. The MuscleLab system measured both the average force produced, the peak velocity and time-to-peak velocity for each individual repetition. This process was repeated three times, with 5-min rest allowed between each individual lift, and against the progressive workloads (See Figure 1). For the bench press, the bar was set so that it rested just above (~2.5 cm) the participant's chest and, again, the instruction given was to push against the bar as forcefully as possible. Again, this was repeated three times against the workloads described above, with 5-min rest between each repetition. The highest of the three average force outputs (and associated peak velocity and time to peak velocity values) were used for each 2 loads on the bar for both bench press and back squat respectively. Like our previous study (Robertson et al. 2018) only the lower and highest loads of the back squat and bench tests were analysed. This was to allow the participant to perform at greater velocities (lowest load) and challenging overall muscle force output when the ability to move quickly has been reduced (at the highest loads). The middle load was used purely to prepare the participant within the trial for the incremental increase in demand, to both reduce the potential risk for injury and to allow them to adjust more progressively to an increase external load. To further reduce the likelihood of injury, two people, either side of the participants as they performed their lifts, could intervene if there was a problem. In addition, there were safety supports in place on every occasion (so that, if any participant had to release the weight for any reason, it would not fall upon them). We have explained this before but in brief the decision not to employ one-repetition-maximum (1RM) testing in this present study was largely due to the varying nature of the elite athletic disciplines the participants came from, and that as Buckner et al. (2017) report the 1RM is a specific skill which warrants specific training, and therefore favours those with experience of using it in training. Whilst muscle strength is commonly measured via the performance of a one-repartition maximum (1RM) protocol, Buckner et al. (2017) state that a true measurement of strength remains tenuous with this approach. In line with recommendations provided by Buckner et al. (2017), and the findings of Pareja-Blanco et al. (2016), the present study utilised loads above 80 % of those measured as a better indication of maximal strength, and therefore maximal effort. The upper values here (bench press: 60 kg, and back squat: 70 kg) equate to 85 % (bench press) and 80 % (back squat) of the upper load achieved during the familiarisation phase. As such, the participants were performing outside of the loading realms of a routine training stimulus, and confidently within a maximal loading/effort range.

During all sessions, participants undertook a task-specific warm-up procedure. The task-specific bursts of activity were brief enough not to cause significant fatigue. Standardized strong verbal encouragement was given during all sessions.

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

Statistical Analyses

Using statistical power software (G*Power v3.1.10, Germany), the sample size required for this study was estimated to be a minimum of six to find a meaningful difference in muscle strength. This estimation was based on detecting a meaningful difference of 5 % in average power, a statistical power of 0.80 and an alpha level of 0.05 (Morris et al. 2009) between morning and evening conditions. All data were analysed using Statistical Package for the Social Sciences version 22 for Windows (SPSS, Chicago, IL, USA). 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 'time of day' (3 levels) and within subject factor 'load on bar' (2 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. 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 (≤ 0.20), small (> 0.20 - 0.60), moderate (> 0.60 - 1.20), large (> 1.20-2.00) and very large (> 2.00) based on guidelines from Batterham & 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 and where corrected for between subject differences such as in figures this was done using the method suggested by Atkinson 2001. The approach involves the conceptualization of the trends over time for the `average person' by normalizing subject means and expressing all changes relative to the same mean.

The alpha level of significance was set at 5 % and values of '0.000' given by the statistics package are shown here as $P < 0.0005$ (Kinear & Gray, 1995).

Results

Resting T_{rec}

A main effect for condition was observed for T_{rec} with higher resting values in the E (mean difference = 0.53 ± 0.23°C, $P < 0.0005$, 95 % CI: 0.31-0.75°C; ES = 2.23) compared to the M condition (Table 1 and Figure 2). This variation was consistent and in the expected direction with resting values of T_{rec} also higher in the evening E conditions compared to the M_E condition (mean difference = 0.53 ± 0.24°C, $P < 0.0005$, 95 % CI: 0.33-0.73°C; ES = 2.18). There was no statistical difference between resting T_{rec} levels in the morning (07:30 h) for M and M_E conditions ($P = 1.000$).

******Insert Table 1 here******

Pre-post warm-up for T_{rec}

A main effect for condition was observed for T_{rec} with higher values in the E (mean difference = 0.53 ± 0.08 °C, $P < 0.0005$, 95 % CI: 0.31 - 0.80 °C; ES = ?) and M_E condition (mean difference = 0.25 ± 0.07 °C, $P = 0.015$, 95 % CI: 0.05 - 0.45 °C; ES = ?) respectively compared to the M condition. Further, T_{rec} values were higher in the E condition than M_E (mean difference = 0.28 ± 0.05 °C, $P = 0.001$, 95 % CI: 0.14 - 0.42 °C; ES = ?). Main effect for warm-up was present where values increased from resting levels (mean difference = 0.20 ± 0.03 °C, $P < 0.0005$, 95 % CI: 0.13 - 0.26 °C; ES = ?). A significant interaction was found where ME pre-values increased due to the extended warm-up by 0.53°C to that of resting Evening levels. The mean difference between the ME pre-values and E resting values was 0°C and a paired *t*-test showed this not to be significant ($P = 1.000$, See Figure 2). *In summary, the protocol produced the changes in T_{rec} (to resting values previously observed in the morning) that were required to test the basic research questions.*

Post warm-up T_{rec} and T_m values for immediately after (pre-grip strength), pre bench press and pre back squat

A main effect for condition was observed for T_{rec} with higher values post warm-up in the E (mean difference = 0.51 ± 0.12 °C, P = 0.006, 95 % CI: 0.16 - 0.87 °C; ES = ?) and M_E (mean difference = 0.44 ± 0.11 °C, P = 0.011, 95 % CI: 0.11 - 0.77 °C; ES = ?) respectively compared to the M condition. Further, T_{rec} values were no different in the E condition than M_E (mean difference = 0.08 ± 0.05 °C, P = 0.482, 95 % CI: -0.07 - 0.23 °C; ES = ?). Main effect for 'time' was present where T_{rec} values increased from pre-grip to pre bench press only (mean difference = 0.10 ± 0.02 °C, P = 0.006, 95 % CI: 0.03 - 0.17 °C; ES = ?). No significant interaction was found where the profiles of all three conditions rose and fell in parallel over the three time points (P = 0.493, See Table ?).

A main effect for condition was observed for T_m with higher values post warm-up in the E (mean difference = 0.61 ± 0.13 °C, P = 0.003, 95 % CI: 0.23 - 0.99 °C; ES = ?) and a trend for M_E (mean difference = 0.53 ± 0.20 °C, P = 0.084, 95 % CI: -1.12 - 0.06 °C; ES = ?) respectively compared to the M condition. Further, T_m values were no different in the E condition than M_E (mean difference = 0.08 ± 0.14 °C, P = 0.1.00, 95 % CI: -0.34 - 0.49 °C; ES = ?). Main effect for 'time' was present where T_m values increased from pre-grip to pre bench press (mean difference = 0.21 ± 0.04 °C, P = 0.001, 95 % CI: 0.01 - 0.32 °C; ES = ?) and pre-bench press to pre-back squat (mean difference = 0.24 ± 0.03 °C, P = 0.001, 95 % CI: 0.14 - 0.33 °C; ES = ?). No significant interaction was found where the profiles of all three conditions rose and fell in parallel over the three time points (P = 0.206, See Table ?). The mean difference between the ME and E immediately post warm-up values was 0.04°C and a paired *t*-test showed this not to be significant (P = 0.830).

******Insert Figure 2 here******

Muscle Strength Measurements

Handgrip

A main effect for condition was observed for handgrip in left and right hand (Table 1 and Figure 3). There were time-of-day effects for hand grip which showed values to be higher in the E condition compared to the morning condition. Left hand values were 6.5 % greater in the E (mean difference = 3.10 ± 1.04 N·m, P = 0.47, 95 % CI: 0.05 - 6.16 N·m; ES = 0.42), while right hand values were 4.6 % higher in the E condition (mean difference = 2.24 ± 0.77 N·m, P = 0.050, 95 % CI: 0.01 - 4.50 N·m; ES = 0.30) compared to the M condition. The active warm-up strategy (M_E) did not significantly increase any handgrip values when compared to M levels (P > 0.05).

Bench Press

Daily variations were apparent for the bench press for AF, PV and tPV (See Table 1), where AF (mean difference of two loads = 24.02 N, P = 0.013, 95 % CI: 5.38 - 42.66 N; ES = 0.57), and PV values were higher in the evening than the morning (mean difference of two loads = 0.21 ms^{-1}, P < 0.0005, 95 % CI: 0.13 - 0.30 ms^{-1}; ES = 0.81). tPV values were larger in the evening than the morning (mean difference of two loads = 0.08 s, P = 0.005, 95 % CI: 0.03 - 0.13 s; ES = 1.31). The active warm-up strategy (M_E) in the morning did not significantly increase any bench press values to E levels with values no different to those found in the M (P > 0.05). There was a main effect for load (P < 0.0005) such that for AF (mean difference = 294.81 N, P < 0.0005, 95 % CI: 255.74 - 333.87 N) and PV (mean difference = 1.39 ms^{-1}, P < 0.0005, 95 % CI: 1.25 - 1.52 ms^{-1})

were larger at higher masses on the bar than lower ones. And tPV values (mean difference = 0.58 s, P < 0.0005, 95 % CI: 0.35 - 0.80 s; see Table 1) values were lower at higher masses. The active warm-up strategy (M_E) in the morning did not significantly increase any bench performance values to E levels with bench values no different to those found in the morning (P > 0.05). There was no difference between any values for any other conditions (P > 0.05).

Back-Squat

Daily variations were apparent for the back-squat for AF, PV and tPV (See Table 1), where AF (mean difference of two loads = 39.51 N, P < 0.0005, 95 % CI: 22.70 - 56.31 N; ES = 0.19), and PV values were higher in the evening than the morning (mean difference of two loads = 0.18 ms^{-1}, P < 0.0005, 95 % CI: 0.10 - 0.27 ms^{-1}; ES = 0.59). tPV values were larger in the evening than the morning (mean difference of two loads = 0.05 s, P < 0.0005, 95 % CI: 0.03 - 0.08 s; ES = 0.57). The active warm-up strategy (M_E) in the morning did not significantly increase any back-squat values to E levels with values no different to those found in the M (P > 0.05). There was a main effect for load (P < 0.0005) such that for AF (mean difference = 327.06 N, P < 0.0005, 95 % CI: 302.25 - 351.61 N), and PV (mean difference = 0.62 ms^{-1}, P < 0.0005, 95 % CI: 0.40 - 0.84 ms^{-1}) were larger at higher masses on the bar than lower ones. tPV values (mean difference = 0.16 s, P < 0.0005, 95 % CI: 0.10 - 0.21 s) values were lower with heavier masses (See Table 1). There was no difference between any values for any other conditions (P > 0.05).

Thermal comfort (TC) and effort levels

There was a main effect for condition (P = 0.005) and time (P < 0.0005) for thermal comfort. TC was significantly higher in the M_E compared to the M and E conditions. TC increased following the warm-up, when compared to resting values (P < 0.0005) and then dropped throughout back to resting levels (P = 0.166). In addition, effort levels were rated as maximal, 10 out of 10 throughout all muscle strength measurements.

DISCUSSION

We report that the MuscleLab linear encoder (Ergotest, version 4010, Norway) can detect diurnal variation in muscle force output when used with back squat and bench press (multi-joint) exercises. An extended active warm-up to resting evening T_{rec} levels, a rise of 0.53°C, did not result in bench press or back squat performance to become equal to evening values (Figure 4).

In line with the findings of Robertson et al. (2018), we agree that this apparatus can detect diurnal fluctuation for the three dimensions of muscle force output: AF, PV and tPV, yielding similar results in two studies using a different set of participants. Our values for AF and PV increased from morning to evening by 3.3 % (vs. 2.5 %), 16.2 % (vs. 12.7 %) while tPV decreased by 16.0 % (vs. 16.2 %), for bench press. Values for AF and PV increased from morning to evening by 2.7 % (vs. 1.9 %), 12.2 % (vs. 8.3 %) while tPV decreased by 14.6 % (vs. 9.8 %), for back squat. A main effect for "load" was also found, for both bench press and back squat, where AF and tPV increased and PV decreased, from the lowest to the highest load on the bar (42.1 % and 80.1 %; 28.6 % and 68.2 %; and -35.6 % and -65.4 %, respectively). An increase in force production with an increase in load agrees with the study performed by Robertson et al. (2018) and Ammar et al. (2018) and is a typical relationship in terms of overall power production. Further, as similarly observed by Robertson et al. (2018), tPV and PV exhibit something of an inverse relationship; whilst the participants moved faster overall, under the demand of increased external resistance they take longer to become quicker. As expected, the rhythm of isometric grip strength showed significant diurnal variation (Reilly, 1990; Reilly et al. 1997; Reilly et al. 2007). In the current study left and right isometric grip strength followed the previously reported daily fluctuation with highest values in the evening than the morning and a variation of 4.6 % and 6.5 % of the 24-h mean, - similar to 6 % values reported by Reilly et al. (2007). Furthermore, a diurnal variation in resting T_{rec} values of 0.53°C was found, similar to values previously reported (Edwards et al. 2013; Pullinger et al. 2014, 2018a, 2018b; Robertson et al. 2018). Our findings agree with current literature regarding time-of-day variation in T_{rec} and muscle force output (Edwards et al. 2013). It has been established that values of muscle force output coincide with the daily peak of the rhythm for core temperature (15:00–18:00 h; Reilly & Waterhouse, 2009), regardless of the muscle group measured (Drust et al. 2005; Reilly & Waterhouse, 2009).

To the best of our knowledge, this is only the second study to demonstrate diurnal variation in bench press and back squat, but the first to assess the effect of an active warm-up on multi-joint exercises. Relatively few studies have looked at precise modelling of pre-exercise temperature (by removing individuals from the active warming stimulus when the required T_{rec} was reached) through an active warm-up (Edwards et al. 2013; Pullinger et al. 2018a). It has previously been established that the use of an active warm-up of standard duration (Sim et al. 2009; Taylor et al. 2013; Yaicharoen et al. 2012), results in producing large variations in core and/or T_m within individuals. Consequently, the required core and/or T_m result in being under- or overshot. The morning inferiority in the production of muscle force and power output has been attributed to a causal link between resting core temperatures and performance. It has been highlighted that higher evening core temperatures produce an increase in neural function to the muscle (reduced twitch time-course or increase in speed of contraction) and an increase in the force-generating capacity of the muscle (Bernard et al. 1998; Coldwells et al. 1994; Giacomoni et al. 2005; Melhim, 1993).

However, we found that increasing morning T_{rec} by 0.53°C through an active warm-up to values previously measured at rest in the evening although resulting in similar post warm-up of T_m between E and MWP conditions (0.04°C difference) did not result in grip strength, performance variables of bench press or back squat to become equal to evening values. Previous studies which have precisely modelled pre-exercise temperature by removing individuals from the active warming stimulus when the required T_{rec} was reached also found no significant effect of an active warm-up on performance measures in muscle strength and repeated sprint performance (Edwards et al. 2013; Pullinger et al. 2018a). This further suggests that the lack of a beneficial increase in the three dimensions of muscle force output in back squat and bench press indicates that the daily variation of muscular function is also not wholly explained by local or central temperature.

At present and in line with views of others and previous findings, the exact mechanisms for the observed diurnal variation in bench press and back squat are unknown. The results of this study further support the view that morning-evening differences in bench press and back squat, do not depend only on core and T_m (Guette et al. 2005; Martin et al. 1999; Edwards et al. 2013; Pullinger et al. 2018a, 2018b), but are a result of other factors such as the environment (exogenous) and the body clock and peripheral clocks (endogenous factors) that we have covered previously in the introduction. Currently the strength of the input from exogenous and endogenous components related to the daily variation in muscle force production it is presently unknown (Sargent et al. 2010; Zhang et al. 2009). Even though direct evidence has been established regarding a large endogenous component related to the daily variation in muscle force production (from the body clock and peripheral clocks: Zhang et al. 2009), it is presently still unproven (Sargent et al. 2010). To fully explore this internal component, complex, time consuming and challenging chronobiological protocols (for both researchers and participants) are required. Protocols which attempt to reduce or standardise the exogenous component of the rhythm using constant routines, forced desynchronisation or ultra-short sleep-wake-cycle protocols remain to be performed (Kline et al. 2007; Reilly & Waterhouse, 2009), adding to our understanding regarding which diurnal variation factors might play a major role. Nevertheless, findings relating to greater muscle force production in back squat and bench press in the evening still have practical implications. The effectiveness of the warm-up is a common consideration for athletes, coaches and sport scientists. Considering a warm-up is made up of two major components: 1) the increase in metabolism, oxygen consumption core and T_m (the warm- up component), etc., in preparation for the upcoming task; and 2) the pre-practice of the motor skill component of the task that the athlete will undertake, our results did not show any direct evidence that increasing morning T_{rec} (by an active warm-up) to evening resting values leads to a positive change in bench press and back squat performance. Nevertheless, our findings help us to unpick the contribution of core (and T_m to the diurnal variation in bench press and back squat performance. It also provides us with some guidance to athletes, sports practitioners and coaches alike.

Limitations

In the current study we only assessed the causal link between core temperature and performance (bench press and back squat) using an active warm-up. The effects of a passive warm-up condition on this link may help to unpick the active vs. passive differences where we have previously shown an active warm-up (using cycle ergometry) increases both T_{rec} and T_m values but a passive one (using a water bath) only increases T_{rec} values (Edwards et al. 2013). Although we removed the subjects from the cycle ergometer when they reached the required T_{rec} values and we kept the period as short as possible before they completed both the bench press and back squat performance protocol, both T_{rec} and T_m decreased over time in the M_E protocol. In the current study, the population were all intermediate chronotypes and as such, the effect of modulating T_{rec} values on outright morning or evening types, and corresponding effect on performance is beyond the scope of this study. Lastly, there might be times of day when an individual is less inclined to produce a maximal effort; although we did collect subjective measures of motivation, effort and arousal, we can only assume that our reflection of diurnal variation of performance was not heavily influenced by other central mechanisms.

Summary

In this highly motivated population, raising morning T_{rec} to evening values by active warm-up did not increase performance in bench press or back squat to evening values. Therefore, evidence from this study suggests that the diurnal variation in bench press and back squat does not seem to be attributed to diurnal changes in core and T_m.

Acknowledgements

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.

Practical implications

The present study shows muscle force production is higher in the evening than the morning thus supporting the recognised view of an optimal time of day or evening preference for strength training. The findings of the study further support the notion that strength training should be undertaken in the early to late evening (17:00 to 19:00 h), when athletes live and train in accordance to a typical training environment (sleeping at night and active during the day). Our results showed no evidence that increasing morning T_{rec} (by an active warm-up) to evening resting values leads to a positive change in bench press or back squat. These findings help us to further un-pick the contribution of core temperature to the diurnal variation in bench press and back squat using a linear encoder. To further investigate the causal relationship T_{rec} or T_m on muscular performance can be done by increasing or decreasing temperatures to specific values.

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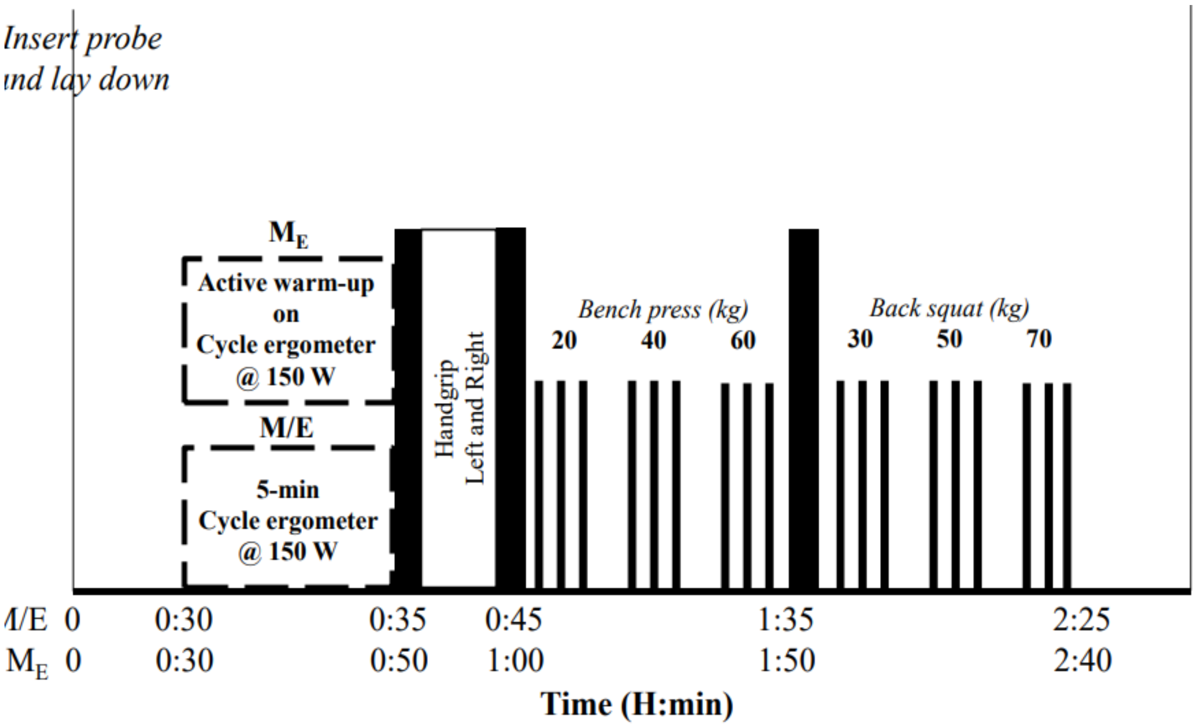
Table 1. Mean (± SD) values for rectal temperature, bench press and back squat for morning (M, M_E; 07:30 h) and evening (E; 17:30 h) conditions. Statistical significance ($P < 0.05$) is indicated in bold. (**a**) values significantly higher than in the morning condition

Measure	Variable	Morning (M)	Evening (E)	Active Warm-up (M_E)	*P*-value		
					Condition	Load	Interaction
Resting Temperature	Trec (°C)	36.91 ± 0.31	37.44 ± 0.26 **a**	36.91 ± 0.32	**<0.0005**		
Pre-Post Warm-up T...	Trec (°C)	36.92 ± 0.35	37.46 ± 0.22 **a**	37.18 ± 0.37	**<0.0005**	**<0.0005**	**<0.0005**
Post Warm-up Temperature	Trec (°C)	37.03 ± 0.45	37.55 ± 0.25 **a**	37.47 ± 0.22**a**	**= 0.001**	**= 0.011**	= 0.493
	Tm	37.07 ± 0.61	37.67 ± 0.46 **a**	37.60 ± 0.55 **a**	**= 0.007**	**< 0.0005**	= 0.206
Handgrip	Right	46.40 ± 8.14	48.64 ± 7.00 **a**	46.61 ± 6.42	**= 0.034**		
	Left	44.69 ± 7.56	47.79 ± 7.06 **a**	46.09 ± 6.62	**= 0.034**		
Bench press							
Combined 20 and 60 kg	AF (N)	432.38 ± 13.1	447.02 ± 16.0 **a**	439.41 ± 11.9	**= 0.002**	**< 0.0005**	**= 0.005**
	PV (ms^{-1})	1.36 ± 0.23	1.58 ± 0.23 **a**	1.44 ± 0.24	**< 0.0005**	**< 0.0005**	= 0.697
	tPV (s)	0.55 ± 0.19	0.47 ± 0.16 **a**	0.54 ± 0.19	**= 0.014**	**< 0.0005**	= 0.120
20 kg	AF (N)	251.04 ± 13.46	270.65 ± 16.41 **a**	260.11 ± 11.53	**< 0.0005**		
	PV (ms^{-1})	2.04 ± 0.31	2.28 ± 0.26 **a**	2.13 ± 0.28	**= 0.002**		
	tPV (s)	0.24 ± 0.05	0.21 ± 0.05 **a**	0.24 ± 0.03	**= 0.009**		
60 kg	AF (N)	613.71 ± 16.69	623.39 ± 19.17 **a**	618.71 ± 16.80	**= 0.024**		
	PV (ms^{-1})	0.68 ± 0.24	0.86 ± 0.24 **a**	0.75 ± 0.26	**< 0.0005**		
	tPV (s)	0.85 ± 0.36	0.73 ± 0.31 **a**	0.84 ± 0.38	**= 0.021**		
Back Squat							
Combined 30 and 70 kg	AF (N)	1464.92 ± 196.41	1504.43 ± 194.53 **a**	1460.20 ± 211.02	**< 0.0005**	**< 0.0005**	= 0.840
	PV (ms^{-1})	1.41 ± 0.27	1.60 ± 0.26 **a**	1.43 ± 0.28	**< 0.0005**	**< 0.0005**	= 0.764
	tPV (s)	0.44 ± 0.09	0.38 ± 0.08 **a**	0.42 ± 0.08	**= 0.002**	**< 0.0005**	= 0.896
30 kg	AF (N)	1298.84 ± 206.52	1343.94 ± 215.22 **a**	1296.17 ± 240.7	**= 0.036**		
	PV (ms^{-1})	1.74 ± 0.31	1.90 ± 0.28 **a**	1.74 ± 0.40	**= 0.020**		
	tPV (s)	0.36 ± 0.08	0.30 ± 0.07 **a**	0.35 ± 0.07	**= 0.006**		
70 kg	AF (N)	1631.00 ± 208.72	1664.91 ± 197.96 **a**	1624.23 ± 206.49	**= 0.002**		
	PV (ms^{-1})	1.10 ± 0.32	1.30 ± 0.34 **a**	1.11 ± 0.29	**< 0.0005**		
	tPV (s)	0.52 ± 0.13	0.46 ± 0.11 **a**	0.50 ± 0.12	**=0.049**		



Insert probe
ınd lay down
ME
Active warm-up
on
Cycle ergometer
@ 150 W
M/E
5-min
Cycle ergometer
@ 150 W
Handgrip
Left and Right
Bench press (kg)
20
40
60
Back squat (kg)
30
50
70
ı/E 0 0:30 0:35 0:45 1:35 2:25
ME 0 0:30 0:50 1:00 1:50 2:40
Time (H:min)

'igure 1.

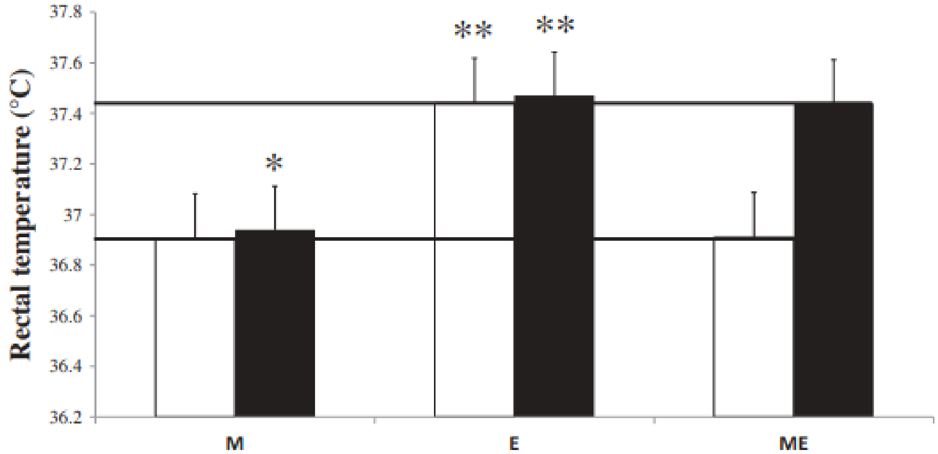


Figure 2. Means and 95% confidence intervals (corrected for between-subjects variability) at rest (□) and after a warm-up (■). *T_{rec} significantly lower (P = 0.001) in the M condition after the warm-up compared to the E and ME condition. **Significant diurnal variation in rectal temperature as deduced from the morning value (07:30 h) being significantly less than the evening value (17:30 h; $P < 0.05$) both pre and post-warm-up. Horizontal lines indicate that M resting versus ME resting T_{rec} and E resting versus ME post-warm-up T_{rec} are no different.

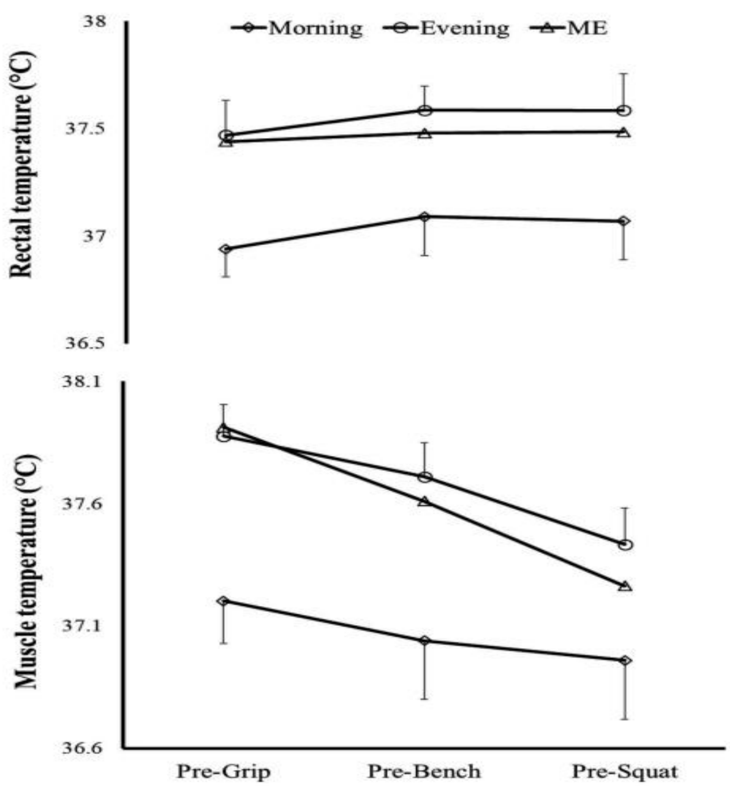


Figure 3. Means and 95% confidence intervals (corrected for between-subjects' variability) for rectal and muscle temperatures before grip strength and bench and back squat exercises.

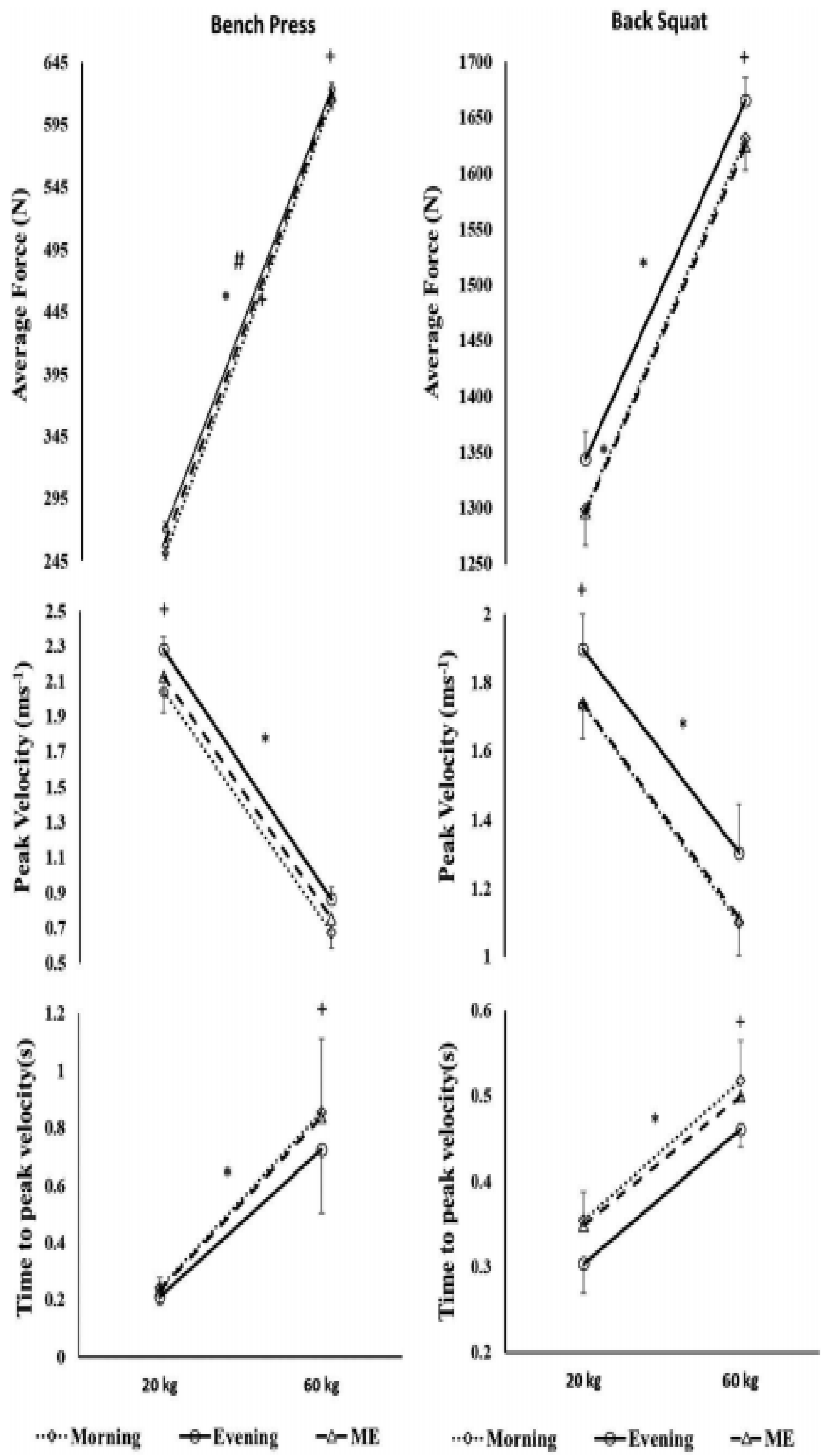


Figure 4. Means and 95% confidence intervals (corrected for between-subjects' variability) for average force, peak velocity, and tin to peak velocity for bench press (for 20 and 60 kg) and back squat (for 30 and 70 kg), respectively, at 07:30 h (M), 17:30 h (E), ar 07:30 h extended active warm-up conditions (M_E).

*Indicates a time-of-day effect between E and both M conditions. +Indicates a load effect. #Indicates interaction between "load" ar "time of day."