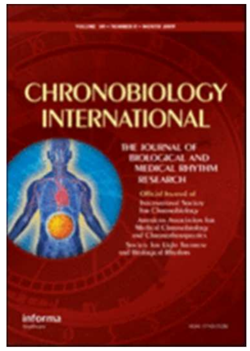

Is the diurnal variation in muscle force output detected/detectable when multi-joint movements are analysed using the MuscleLab force-velocity encoder?

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Is the diurnal variation in muscle force output detected/detectable when multi-joint movements are analysed using the MuscleLab force-velocity encoder?

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ABSTRACT

We have investigated the magnitude of diurnal variation in back squat and bench press performance using the MuscleLab force velocity transducer. Thirty resistance-trained males (mean ± SD: age 21.7 ± 1.4 years; body mass 80.5 ± 4.5 kg; height 1.79 ± 0.06 m) underwent two sessions at different times of day: morning (M, 07:30 h) and evening (E, 17:30 h). Each session included a period when rectal temperature (Trec) was measured at rest, a 5-min standardized 150 W warm-up on a cycle ergometer, then 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 Trec at rest were higher in the evening compared to morning values (0.48°C, $P < 0.0005$). Daily variations were apparent for both bench press and back squat performance for AF (1.9 and 2.5 %), PV (8.3 and 12.7 %) and tPV (-16.6 and -9.8 %; where a negative number indicates a decrease in the variable from morning to evening). There was a main effect for load where AF and tPV increased and PV decreased from the lightest load to the heaviest for both bench press and back squat (47.1 and 80.2 %; 31.7 and 57.7 %; -42.1 and -73.9 %; $P < 0.0005$ where a negative number indicates a decrease in the variable with increasing load). An interaction was found 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). In summary, diurnal variation in back squat and bench press was shown; and the time to peak velocity in complex multi-joint movements occurs earlier during the concentric phase of exercise when back squat or bench press is performed in the evening compared to the morning. This difference can be detected using a

low cost, portable and widely available commercial instrument and enables translation of past laboratory/tightly controlled experimental research in to main-stream coaching practice.

Introduction

A large body of laboratory-based research has shown that in male subjects in a temperate environment (around 17–20°C), muscle power output and force production consistently peak in the mid-afternoon or early evening. This is regardless of the muscle group measured (such as hand, elbow, leg, or back) or the speed of contraction (Drust et al. 2005; Reilly & Waterhouse, 2009). The observation of significant diurnal variation or circadian rhythms in muscle power and force production seems to be somewhat dependent on factors such as the time on task, the motivation of subjects to perform and familiarization of the subjects with the tasks to be performed (Bambaeichi et al. 2003; Giacomoni et al. 2005). Further, it is common in studies investigating time-of-day variation of muscle force output – for single-joint, isokinetic and isometric methods to be employed (Callard et al. 2000, Edwards et al. 2013 and Giacomoni et al. 2005). However, the physical demands of sport are such that athletes are required to move and function in multiple directions, at varying rates of speed and for varying periods of time. To train these athletes to meet this challenge is typically achieved *via* multi-directional exercises which are targeted towards enhancing multi-joint and gross muscular activation (Häkkinen & Komi, 1985). Because of this, strength and conditioning coaches routinely use multi-joint exercises (back squat 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 & Earle, 2015).

Whilst there is convincing evidence to support both time-of-day variation of muscle force output (Drust et al. 2005; Giacomoni et al. 2005) and the reliability of isokinetic and isometric maximum voluntary contraction (MVC) methods to measure these differences accurately (Drouin et al. 2004; Morton et al. 2005). It is yet to be established what tool to use and if there is a corresponding diurnal fluctuation in complex multi-joint movements that are more commonly used in applied practice. The ongoing development and validation of a number of accurate and reliable dynamometers which are able to evaluate dynamic muscle work have enabled research to be performed within a standardised laboratory environment with immediately accessible results (Bosco et al. 1995; Jennings et al. 2005; O'Donnell et al. 2017). Taken together with dynamometers being practical, cost-friendly and easy to transport, athletes, coaches and sport scientists have taken great interest in using these devices as means of determining and monitoring athlete performance (Chiu et al. 2003; García-Ramos et al. 2016; Harris et al. 2010). One such device/dynamometer is the MuscleLab linear encoder system, which measures average force (N), along with peak velocity ($m.s^{-1}$) and time to peak velocity (s), and can be attached to any moving limb or piece of exercise (resistance) equipment (Bosco et al. 1995). As such, it enables measurement across a broad range of human functions; as opposed to requiring – or stipulating – what movements are needed in order to measure such factors. However, to the knowledge of the authors this device has never been used in a chronobiological research design. Therefore, the aim of this study was to assess the sensitivity of the MuscleLab force-velocity linear encoder (Ergotest version 4010, Norway), to determine whether it was able to detect diurnal variation in multi-joint muscle force output at different masses (low and height) during a bench press (upper body) and back squat (lower body). We hypothesis that the MuscleLab force-velocity linear encoder is sensitive to measure diurnal variation in force output in bench press and back squat at difference masses on the bar.

Methods

Subjects

Thirty healthy active males (mean ± SD: age 21.7 ± 1.4 years; body mass 80.5 ± 4.5 kg; height 1.79 ± 0.06 m) recruited from Liverpool John Moores University Sports Scholarship Scheme participated in 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. 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 of the participants used in this study had a minimum of two-year's experience of resistance training, 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 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 the course of 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 33.1 ± 5.5, hence all of the participants were 'intermediate types'. A circadian type inventory questionnaire of Folkard & Monk (1979) determining languidness/vigorous and flexibility/rigidity of participants was also utilized. The participants' mean scores were 39.8 ± 7.2 and 45.3 ± 6.4 for languidness/ vigour and flexibility/rigidity respectively. Only one of the participants was found to be flexible and two were found to be languid. All other participants were deemed rigid and vigorous according to the definitions of the questionnaire. 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), then the 2 experimental sessions at 07:30 and 17:30 h. These experimental sessions were counterbalanced in order of administration in order 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 in order to minimize learning effects. 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 minute (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 06:30 h; and be in the laboratory 30 min prior to measurements being taken so 07:00 and 17:00 h, respectively. Subjects came into the morning session having fasted and were not allowed to consume food 4 h before the evening session. On arrival compliance to the protocols sleeping, food intake and exercise restrictions were assessed verbally and this was high. Thereafter, rectal temperature (Trec) was measured using a soft flexible rectal probe (Mini-thermistor, Grant Instruments Ltd, Shepreth, UK) inserted ~10 cm beyond the external anal sphincter. While subjects remained in a standardised position (semi-supine and awake), Trec was recorded continuously for a 30 min period by means of a Squirrel 1000 data logger (Grant Instruments Ltd, Shepreth, UK), with the average value recorded over the last 5-min being retained for analysis. This standard body position was used since core body temperature is subject to other influences than that produced by the endogenous 24 h period oscillator, such as muscle activity, feeding and sleep (Bougard et al. 2009, Edwards et al. 2002). As with the familiarisation period, all procedures were conducted under standard laboratory conditions for lighting, humidity and temperature as previously described. 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 17.04.2018). Water and non-caffeinated/non-alcoholic, calorie-free beverages were allowed ad libitum up to a total volume of 3 L per day.

Participants were required to perform a standardized 5-min warm-up on a cycle ergometer (Monark 817E, Stockholm, Sweden) at 150 W. Following the warm-up procedure, the methods for assessing muscle force output were performed (See Figure 1).

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

Back Squat and Bench Press *(MuscleLab, Ergotest version 4010, Norway)*

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. Further, that low-load alternatives to traditional resistance training result in muscle hypertrophic changes similar to those resulting from traditional high-load resistance training, but with less robust changes observed with maximal strength as measured by the 1RM. For this present study, each of the participants performed the two exercises in a randomised order, performing either back squat or bench press (or vice versa), performing three lifts 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). There is evidence to suggest that the optimal training load for performance enhancement is one that emphasizes the athlete's maximum power output (Ammar et al. 2018, Comfort et al. 2011), in bench press and squat exercise, with moderate loads (from >30 to <70 % of 1RM) appearing to provide the ideal load for power production. However, 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 strength ability, and therefore prompting a 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. 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 lift. This process was repeated three times, with 5-min rest allowed between each individual lift, and against the progressive workloads as described above. 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 push. The highest of the three average force outputs (and associated peak velocity and time to peak velocity values) were used for analysis for each mass on the bar for both bench press and back squat respectively. 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 for the purpose of preparing the participant within the trial for the incremental increase in demand, to both reduce the potential for injury and to allow them to adjust more progressively to an increase external load. In order to reduce the likelihood of injury, two people were positioned either side of the participants as they performed their lifts, to 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).

Statistical analysis

The Statistical Package for the Social Sciences (SPSS), version 22, 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 'time of day' (2 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. Only the data obtained from the first and final lifts of the back squat and bench tests were analysed, as they represent the two extremities of the force-velocity relationship; lesser resistances typically allowing for greater peak velocities and greater resistances usually leading to larger average force values. 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 & 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 & 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.

Results

Resting rectal temperature

There was a significant time-of-day difference with higher resting Trec values in the E (mean difference = 0.49°C, $P < 0.0005$, 95 % CI: 0.34-0.64°C; ES=1.36) compared to the M condition (See Table 1).

******Insert Table 1 and Figure 2 near here******

Muscle Strength Measurements

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 = 10.8 N, $P < 0.0005$, 95 % CI: 6.4-15.3 N; ES=0.21), and PV values were higher in the evening than the morning (mean difference of two loads = 0.13 ms^{-1}, $P < 0.0005$, 95 % CI: 0.08-0.19 ms^{-1}; ES=0.52). And tPV values occurred earlier in the evening than the morning (mean difference of two loads = 0.12 s, $P = 0.001$, 95 % CI: 0.07-0.18 s; ES=0.45). There was a main effect for load ($P < 0.05$) such that for AF (mean difference = 363 N, $P = 0.001$, 95 % CI: 357-369 N), and tPV (mean difference = 0.62 s, $P < 0.0005$, 95 % CI: 0.45-0.78 s) values were higher at greater masses on the bar than lower ones. And PV (mean difference = 1.09 ms^{-1}, $P = 0.001$, 95 % CI: 0.95-1.22 ms^{-1}; See Table 1) values were lower with higher masses. There was a significant interaction for tPV such that the time to peak velocity occurred earlier in the evening than the morning for the highest load (mean difference of 0.62 s, $P = 0.006$; See Figure 2 and Table 1).

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 = 27.6 N, $P < 0.0005$, 95 % CI: 17.7-37.5 N; ES=0.18), and PV values were higher in the evening than the morning (mean difference of two loads = 0.13 ms^{-1}, $P < 0.0005$, 95 % CI: 0.08-0.17 ms^{-1}; ES=0.51). And tPV values occurred earlier in the evening than the morning (mean difference of two loads = 0.07 s, $P = 0.001$, 95 % CI:

0.04-0.10 s; ES=0.31). There was a main effect for load (P < 0.05) such that for AF (mean difference = 330 N, P = 0.001, 95 % CI: 320-340 N), and tPV (mean difference = 0.32 s, P < 0.0005, 95 % CI: 0.25-0.39 s) values were higher at greater masses on the bar than lower ones. And PV (mean difference = 0.48 ms^{-1}, P < 0.0005, 95 % CI: 0.37-0.59 ms^{-1}) See Table 1) values were lower with heavier masses. There was a significant interaction for tPV such that the time to peak velocity occurred earlier in the evening than the morning for the highest load (mean difference of 0.32 s, P = 0.001 See Figure 2 and Table 1).

Discussion

We report the MuscleLab linear encoder (Ergotest, version 4010, Norway) is capable of detecting a diurnal variation in muscle force output when used with back squat and bench press (multi-joint) exercises. More importantly, this piece of apparatus is able to detect this fluctuation for the three dimensions of muscle force output: average force, peak velocity and time to peak velocity. Where average force and peak velocity increased from morning to evening by 2.5, 12.7 % and time to peak velocity decreased by 16.6 %, for bench press (for 20 and 60 kg). And, similarly average force and peak velocity increased from morning to evening by 1.9, 8.3 % and time to peak velocity decreased by 9.8 %, for back squat (for 30 and 70 kg). Further, a diurnal variation in resting rectal temperature of 0.49°C was found, a difference previously reported. Taken together these finding are in agreement with existing literature regarding time-of-day variation in rectal temperature and muscle force output (See Edwards et al. 2013), which has consistently demonstrated that the highest values of muscle force output coincide with the daily peak of the rhythm for core temperature (15:00–18:00 h; Reilly & Waterhouse, 2009) and the least values with the lowest core temperatures (03:00–06:00 h).

A main effect for 'load' was also found as expected, for both bench press and back squat, where average force and time to peak velocity increased and peak velocity decreased, from lower to higher loads on the bar (47.1 and 80.2 %; 31.7 and 57.7 %; -42.1 and -73.9 %; P < 0.0005 where a negative number indicates a decrease in the variable with increasing load). That force production increases with increasing load, agrees with other authors who have used different methodology's such as equipment (force platforms and motion capture systems) and strength techniques (power clean, hang clean and hang power clean; Ammar et al. 2018). This is a typical relationship in terms of the production of overall power; as the external load increases, the rate (ms^{-1}) at which the movement is achieved is inhibited by the greater mass. As such, the strength (force output/power) component of the power equation (power = force x speed) is the primary influence of the increase 'load' we have observed during the evening. In the present study, only the data obtained from the first and final lifts of the back squat and bench tests were analysed. The lower resistance (mass on bar) creates an opportunity for the participant to perform at greater velocities, whilst the greater resistance will ascertain a difference in overall muscle force output when the ability to move quickly has been reduced. 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 average force values.

A main finding of the current study was that an interaction was found for time of day and load on the bar. Such that participants could achieve maximal rates of velocity in less time during the heavier lifts, in both lower and upper body exercise in the evening. Although, the mechanisms regarding development of RFD remain largely unknown (Rodriguez-Rossell et al. 2017), this evening superiority in rate of force development (RFD) provides an insight as to how greater peak velocities and power outputs in the evening are achieved. This time of day effect on RFD may be linked with a selective effect on fast twitch protein isoforms (e.g. IIa or x myosin heavy chain profile) or on the processes of excitation contraction coupling.

At present, the exact mechanisms for the observed diurnal variation in muscle performance are unknown. We have covered this previously (Edwards et al. 2013) but in brief it has been attributed to **i)** input from the body clock and proteins and peripheral clocks - that is, an endogenous component to the daily variation in muscle force production - has been suggested to be important (Zhang et al. 2009). The evidence relating to this is limited. **ii)** The causal link between core temperature and performance has been investigated, although this has been shown to be complex, due to a multiplicity of components and mechanisms which require further research (Edwards et al. 2013). Further, **iii)** peripheral or muscle-related variables (contractility – time to peak velocity in agreement with the current study's findings, metabolism, morphology of muscle fibres, accrued damage during exercise and local muscle temperature), which can be influenced by hormonal and ionic muscle process variations (Reilly & Waterhouse, 2009; Tamm et al. 2009), and/or **iv)** central/ neurological factors (central nervous system command, alertness, motivation, and mood; Castaingts et al. 2004; Giacomoni et al. 2005; Racinais et al. 2005a, 2010) have been suggested.

To the best of our knowledge, this is the first study using linear encoder technology in a chronobiological research design. We have duplicated time of day and muscle force and power findings previously reported in only laboratory based strength assessment (such as isokinetic and isometric methods); but used complex exercises that better replicate the movements associated with athletic performance (Chapman et al. 1998, LeSuer et al. 1997). In the case of the lower limbs the back squat and in the case of the upper limbs/torso the bench press. Power output is arguably the primary determinant of sport success; however RFD is also important on its own and can be considered an underpinning mechanism of power output (Bevan et al. 2010; Hawley et al. 1992; Stone et al. 2002, Taber et al. 2016). The findings presented in this study are, therefore, of far greater relevance to athletic performance that previously research in this area and provide an ecologically meaningful assessment of the vital physical qualities (particularly rate of force development) that contribute towards sport performance allowing previously published laboratory based and tightly controlled experimental research to be readily translated into main-stream coaching practice. In the case of the current study's findings have implications for training RFD in evening and impact on sporting performance.

Lastly, effective managing, planning, periodization and phase potentiation of the specific component parts of muscle force output is essential for optimal training (DeWeese et al. 2015). The linear encoder equipment lends itself for this use, as well as measurement of adaption during micro- and mesocycles and providing real time information to submaximal and one-repetition maximum tests (1 RM). The Linear encoder system can fit to any traditional gym based equipment for specificity assessment, hence giving the researcher or practitioner freedom of choice to choose exercises that employ the required sports-specific technical abilities and important skills being developed an investigated; whilst also providing insights and relationships of average force, peak velocity and time to peak velocity of specific muscle force output. Unlike the traditional approaches of muscle assessment such as Wingate anaerobic power test, force plate (for RFD) and/ or isokinetic or isometric dynometry which limit the range and type of movements being assessed and measurement of single muscles might (as in the instance of isokinetic dynamometry) mask the force output of a group of muscles (Chtourou et al. 2011, Souissi et al. 2010).

Limitations

We have shown clear diurnal variation for muscle performance using the linear encoder but further work should extend this to a 24 h period allowing circadian characteristics to be determined (such as mesor, acrophase and amplitude), but also using protocols where in the endogenous component to performance can be elicited (either using a constant routine or ultra-short wake-cycle experimental design). In the current study we measured only resting rectal temperature, future work should measure pre and post exercise rectal and muscle temperature to better explore the core and muscle temperature causal link with gross muscular performance (See Edwards et al. 2013 and Pullinger et al. 2018). In our study, we recruited intermediate chronotypes, future work could investigate the sensitivity of linear encoders to find a diurnal variation for muscle performance using outright morning or evening types.

Summary

The MuscleLab linear encoder provides a suitable tool for measuring diurnal variations in muscle force output on multi-joint movements which more closely resemble athletic performance. The advantages of this approach allow the time-of-day variation in muscle force output to be measured in complex multi-joint human movements, over an array of submaximal to maximal loads rather than isolated single joint maximal efforts.

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.

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.

Practical implications

The present study supports the established notion of an evening preference (or optimal time of day) for strength training, but due to the diurnal nature of the current investigation it is not possible to quantify how much of this is due to the endogenous component of circadian rhythmicity. That said, as the majority of athletes will live and train in typical diurnal conditions such that they sleep at night and wake and are active in the day time, the findings of this study support the idea strength training should be undertaken in the early to late evening (17:00 to 19:00 h). Specifically where maximal or near-maximal external loads are involved or a requirement for producing peak velocity outputs (explosive power work, sprinting, or plyometric training for example).

Participants could achieve maximal rates of velocity in less time during the heavier lifts in both lower and upper body exercise in the evening. Although the mechanisms regarding development of RFD remain largely unknown (Rodriguez-Rossell et al. 2017), this evening superiority in rate of force development (RFD) provides an insight as to how greater peak velocities and power outputs in the evening are achieved. Research investigating the potential time of day specificity to training as previously attempted by other authors (such as Sedliak et al. 2008), but now employing linear encoders (measuring muscle force output, RFD and peak velocity) and conducting upper and lower body tasks such as in this study are warranted.

Past laboratory based and tightly controlled experimental research can now be translated into main-stream coaching practice. New and emerging intervention and methods that look to use either chronobiotics such as bright light or exercise, to directly shift the body clock or dawn simulators to improve mood (Thompson et al. 2014) or investigate the causal relationship between performance and Trec or muscle temperature – to ultimately increase morning gross muscular performance and aid athletes that have to compete or undergo training in the morning could be tested in a real world context using MuscleLab (linear encoder).

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List of Figures and Tables

Figure 1: Schematic of the protocol for the morning (M 07:30 h) and evening (E, 17:30 h) conditions. Rectal (Trec) temperature was measured after the subjects had reclined for 30 min at the start of the protocol (solid black box). Average force, peak velocity and time to peak velocity were measured three times for each weight (black lines), for bench press and back squat respectively. There was 5-min recovery time for each lift.

Figure 2: Mean and 95 % confidence intervals (corrected for between-subject variability) for average force, peak velocity and time to peak velocity for Bench Press (for 20 and 60 kg) and Back Squat (for 30 and 70 kg) respectively at 07:30 and 17:30 h. # indicates a time of day effect; + indicates a load effect; * indicates interaction between 'load' and 'time of day'.

Table 1: Mean (± SD) values for rectal temperature, bench press and back squat for morning (07:30 h) and evening (17:30 h) conditions. Where only a P-value for time of day is given this indicates a paired t-test has been undertaken to remove load and interaction effects. Statistical significance ($P < 0.05$) is indicated in bold.

References

Ammar, A., Riemann, B.L., Masmoudi, L., Blaumann, M., Abdelkarim, O. & Hökelmann, A. 2018. Kinetic and kinematic patterns during high intensity clean movement: searching for optimal load. Journal of Sport Sciences. 36(12):1319-1330. doi: 10.1080/02640414.2017.1376521. PMID: 28895467.

Baechle, TR, Earle, RW. Essentials of strength training and conditioning (4th edition), 2015; Champaign, IL: Human Kinetics.

Batterham AM, Hopkins WG. 2006. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 1(1):50–57. doi:10.1123/ijspp.1.1.50. PMID: 19114737.

Bambaeichi E, Reilly T, Cable N, Giacomoni M. 2005. The influence of time of day and partial sleep loss on muscle strength in eumenorrheic females. Ergonomics. 48(11-14):1499–511. doi:10.1080/00140130500101437. PMID: 16338716.

Bevan HR, Bunce PJ, Owen NJ, Bennett MA, Cook CJ, Cunningham DJ, Kilduff LP. 2010. Optimal loading for the development of peak power output in professional rugby players. Journal of strength and conditioning research / National Strength & Conditioning Association, 24(1), 43-47. doi:10.1519/JSC.0b013e3181c63c64.

Bosco C, Belli A, Astrua M, Tihanyi J, Pozzo R, Kellis S, Tsarpela O, Foti C, Manno R, Tranquilli C. 1995. A dynamometer for evaluation of dynamic muscle work. Eur J Appl Physiol Occup Physiol. 70(5):379-86. PMID: 7671871.

Bougard C, Bessot N, Moussay S, Sesboüé B, Gauthier A. 2009. Effects of waking time and breakfast intake prior to evaluation of physical performance in the early morning. Chronobiol Int. 26(2):307-323. doi:10.1080/07420520902774532. PMID: 19212843.

Buckner SL, Jessee MB, Mattocks KT, Mouser JG, Counts BR, Dankel SJ, Loenneke JP. 2017. Determining Strength: A Case for Multiple Methods of Measurement. Sports Medicine. 47(2):193-195. doi: 10.1007/s40279-016-0580-3. PMID: 27380100.

Callard D, Davenne D, Gauthier A, Lagarde D, Van Hoecke J. 2000. Circadian Rhythms in Human Muscular Efficiency: Continuous Physical Exercise Versus Continuous Rest. A Crossover Study. Chronobiol. Int. 17(5):693-704. doi:10.1081/CBI-100101075. PMID:11023216.

Castaingts V, Martin A, VanHoecke J, Perot C. 2004. Neuromuscular efficiency of the triceps surae in induced and voluntary contractions: morning and evening evaluations. Chronobiol. Int. 21(4-5):631–643. doi: 10.1081/CBI-120039207. PMID:15470959.

Chapman PP, Whitehead JR, Binkert RH. 1998. The 225-lb Reps-to-Fatigue Test as a Submaximal Estimate of 1-RM Bench Press Performance in College Football Players. J Strength Cond Res. 12(4):258-261. doi:10.1519/00124278-199811000-00010

Chiu LZ, Fry AC, Weiss LW, Schilling BK, Brown LE, Smith SL. 2003. Postactivation potentiation response in athletic and recreationally trained individuals. Strength Cond Res. 17(4):671-677. PMID:14636093.

Chtourou H, Zarrouk N, Chaouachi A, Dogui M, Behm DG, Chamari K, Hug F, Souissi, N. 2011. Diurnal variation in wingate-test performance and associated electromyographic parameters. Chronobiol Int. 28(8):706–713. doi:10.3109/07420528.2011.596295. PMID:21793694.

Comfort P, Allen M, & Graham-Smith P. (2011). Comparisons of Peak Ground Reaction Force and Rate of Force Development During Variations of the Power Clean. The Journal of Strength and Conditioning Research. 25(5):1235-1239. PMID: 21522071 doi: 10.1519/JSC.0b013e3181d6dc0d.

DeWeese BH, Sams ML, Williams JH, Bellon CR. 2015. The nature of speed: Enhancing sprint abilities through a short to long training approach, in: Techniques in Track & Field and Cross Country. pp 8-24.

Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T. 2005. Circadian rhythms in sports performance: an update. Chronobiol Int. 22(1):21-40. doi:10.1081/CBI-200041039. PMID:15865319.

Edwards BJ, Pullinger SA, Kerry JW, Robinson WR, Reilly TP, Robertson CM, Waterhouse JM. 2013. Does raising morning rectal temperature to evening levels offset the diurnal variation in muscle force production? Chronobiol Int. 30(4):486-501. doi:10.3109/07420528.2012.741174. PMID: 23281719.

Edwards B, Waterhouse J, Reilly T, Atkinson G. 2002. A comparison of the suitabilities of rectal, gut, and insulated axilla temperatures for measurement of the circadian rhythm of core temperature in field studies. Chronobiol Int. 19(3):579-597. doi:10.1081/CBI-120004227. PMID:12069039.

Folkard S, Monk TH. 1979. Towards a predictive test of adjustment to shiftwork. Ergonomics, 22(1):79-91. doi:10.1080/00140137908924591. PMID: 436816.

García-Ramos A, Stirn I, Strojnik V, Padial P, De la Fuente B, Argüelles-Cienfuegos J, Feriche B. 2016. Comparison of the force-, velocity-, and power-time curves recorded with a force plate and a linear velocity transducer. Sports Biomech. 15(3):329-41. doi:10.1080/14763141.2016.1161821. PMID: 27239893.

Giacomoni M, Edwards B, Bambaeichi E, Waterhouse J, Reilly T. 2005. Gender differences in the circadian variations in muscle strength assessed with and without superimposed electrical twitches. Ergonomics. 48(11-14):1473-1487. doi:10.1080/00140130500101452. PMID:16338714.

Häkkinen K, Komi. PV. 1985. Changes in electrical and mechanical behaviour of leg extensor muscles during heavy resistance strength training. Scand J Sports Sci. 7(2):55-64.

Hakkinen K. 1989. Neuromuscular and hormonal adaptations during strength and power training. J Sports Med Phys Fitness. 29(1):9-26. PMID: 2671501.

Harris NK, Cronin J, Taylor K-L, Jidovsteff B, Sheppard, JM. 2010. Understanding Position Transducer Technology for Strength and Conditioning Practitioners. Strength Cond J. 32(4):66-79. doi:10.1519/SSC.0b013e3181eb341b.

Hawley JA, Williams, MM, Vickovic MM, Handcock, P. J. 1992. Muscle power predicts freestyle swimming performance. Br J Sports Med. 26(3):151-155. doi:10.1136/bjsm.26.3.151. PMID:1422650.

Jennings CL, Viljoen W, Durandt J, Lambert MI. 2005; The reliability of the FitroDyne as a measure of muscle power. J Strength Cond Res. 19(4):859-63. doi:10.1519/R-15984.1. PMID:16287353.

Kinear PR, Gray LD. (1995). SPSS for windows made simple. London:Lawrence Ehbaum. pp. 228.

LeSuer DA, McCormick JH, Mayhew JL, Wasserstein RL, Arnold MD. 1997. The Accuracy of Prediction Equations for Estimating 1-RM Performance in the Bench Press, Squat and Deadlift. J Strength Cond Res, 11(4):211-213. doi:10.1519/00124278-199711000-00001.

Monk TH, Leng VC. 1982. Time of day effects in simple repetitive tasks: some possible mechanisms. Acta Psychol. 51:207-221. doi:10.1016/0001-6918(82)90035-X

Morton JP, Atkinson G, MacLaren DPM, Cable NT, Gilbert G, Broome C, McArdle A, Drust B. 2005. Reliability of maximal muscle force and voluntary activation as markers of exercise-induced muscle damage. Eur. J. Appl. Physiol. 94:541-548. doi 10.1007/s00421-005-1373-9.

O'Donnell S, Tavares F, McMaster D, Chambers S, Driller M. 2017. The validity and reliability of the GymAware linear position transducer for measuring counter-movement jump performance in female athletes. Measurement in Physical Education and Exercise Science. 22:101-107. doi:10.1080/1091367X.2017.1399892.

Pareja-Blanco F, Rodríguez-Rosell D, Sánchez-Medina L, Sanchis-Moysi J, Dorado C, Mora-Custodio R, Yáñez-García JM, Morales-Alamo D, Pérez-Suárez I, Calbet, JAL, González-Badillo JJ. 2016. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. Scandinavian Journal of Medicine and Science in Sports. 27(7):724-735. PMID: 27038416. doi: 10.1111/sms.12678.

Pullinger SA, Oksa J, Brocklehurst EL, Iveson RP, Newlove A, Burniston JG, Doran DA, Waterhouse JM, Edwards BJ. 2018. Controlling rectal and muscle temperatures: Can we offset diurnal variation in repeated sprint performance? Chronobiol Int. 1-10. doi: 10.1080/07420528.2018.1444626. PMID: 29557676. [Epub ahead of print].

Racinais S, Connes P, Bishop D, Blonc S, Hue O. 2005. Morning versus evening power output and repeated-sprint ability. Chronobiol Int 22(6):1029–39. doi:10.1080/07420520500397918. PMID: 16393706.

Racinais S, Oksa J. 2010. Temperature and neuromuscular function. Scan J Med Sci Sports 20(3):1–18. doi:10.1111/j.1600-0838.2010.01204.x. PMID: 21029186.

Reilly T, Waterhouse J. 2009. Sports performance: is there evidence that the body clock plays a role? Eur J Appl Physiol. 106(3):321-332. doi:10.1007/s00421-009-1066-x. PMID: 19418063.

Rodríguez-Rosell D, Pareja-Blanco F, Aagaard P, González-Badillo JJ. 2017.Physiological and methodological aspects of rate of force development assessment in human skeletal muscle. Clin Physiol Funct Imaging. doi: 10.1111/cpf.12495. [Epub ahead of print]

Sedliak M, Finni T, Peltonen J, Häkkinen, JK. 2008. Effect of time-of-day-specific strength training on maximum strength and EMG activity of the leg extensors in men. J Sports Sci. 26(10):1005-1014. doi:10.1080/02640410801930150. PMID: 18608836.

Smith C, Reilly C, Midkiff K. 1989. Evaluation of three circadian rhythm questionnaires with suggestions for an improved measure of morningness. J Appl Psych. 74(5):728-738. doi:10.1037/0021-9010.74.5.728. PMID: 2793773.

Souissi N, Driss T, Chamari K, Vandewalle H, Davenne D, Gam A, Fillard J-R, Jousselin E. 2010. Diurnal variation in wingate test performances: influences of active warm-up. Chronobiol Int. 27(3):640-652. doi:10.3109/07420528.2010.483157. PMID: 20524806.

Stone MH, Moir G., Glaister, M, Sanders R. 2002. How much strength is necessary? Phys Ther Sport. 3(2): 88-96. doi:10.1054/ptsp.2001.0102.

Taber C, Bellon CR, Abbott H, Bingham GE. 2016. Roles of maximal strength and rate of force development in maximizing muscular power. Strength & conditioning Journal 38(1):71-78. doi:10.1519/SSC.0000000000000193.

Tamm AS, Largerquist O, Ley AL, Collins DF. 2009. Chronotype influences diurnal variations in the excitability of the human motor cortex and the ability to generate torque during a maximum voluntary contraction. J. Biol. Rhythms. 24(3):211–224. doi:10.1177/0748730409334135. PMID:19465698 .

Thompson A, Jones H, Gregson W, Atkinson G. 2014. Effects of dawn simulation on markers of sleep inertia and postwaking performance in humans. Eur J Appl Physiol. 114(5):1049–56. doi: 10.1007/s00421-014-2831-z. PMID: 2450 9892.

Drouin JM, Valovich TC, Shultz SJ, Gansneder BM, Perrin DH. 2004. Reliability and validity of the Biodex System 3 Pro Isokinetic Dynamometer velocity, torque and position measurements. European Journal of Applied Physiology. 91(1):22-29. doi: 10.1007/s00421-003-0933-0.

Zhang X, Dube TJ, Esser KA. 2009. The role of clock genes in 685 cardiometabolic disease: Working around the clock: Circadian rhythms and skeletal muscle. J Appl Physiol 107(5):1647–54. doi:10.1152/japplphysiol.00725.2009. PMID: 19696362.

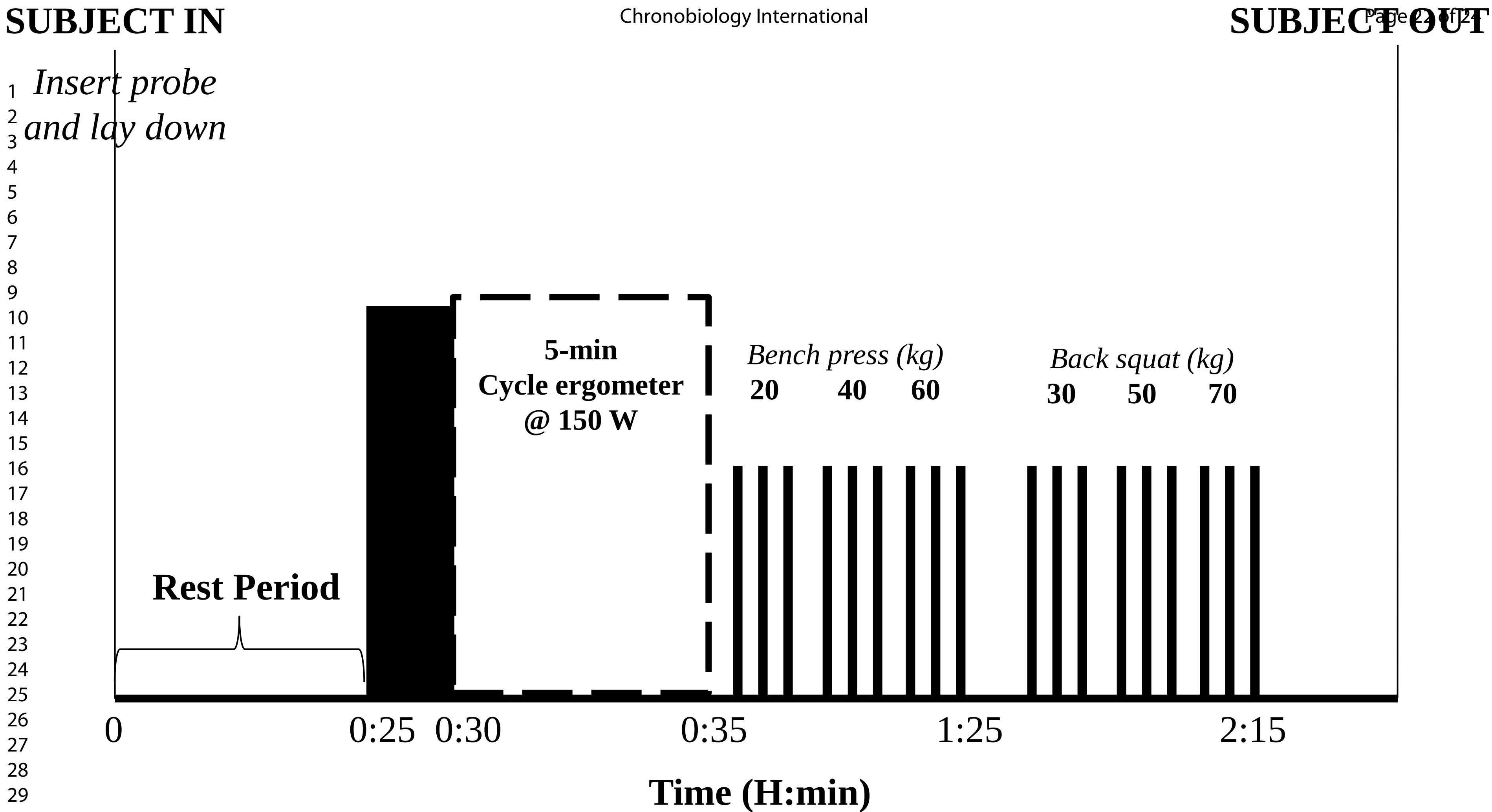
SUBJECT IN
SUBJECT OUT
Insert probe
and lay down
5-min
Cycle ergometer
@ 150 W
Bench press (kg)
20
40
60
Back squat (kg)
30
50
70
Rest Period
0
0:25
0:30
0:35
1:25
2:15
Time (H:min)

Figure 1.

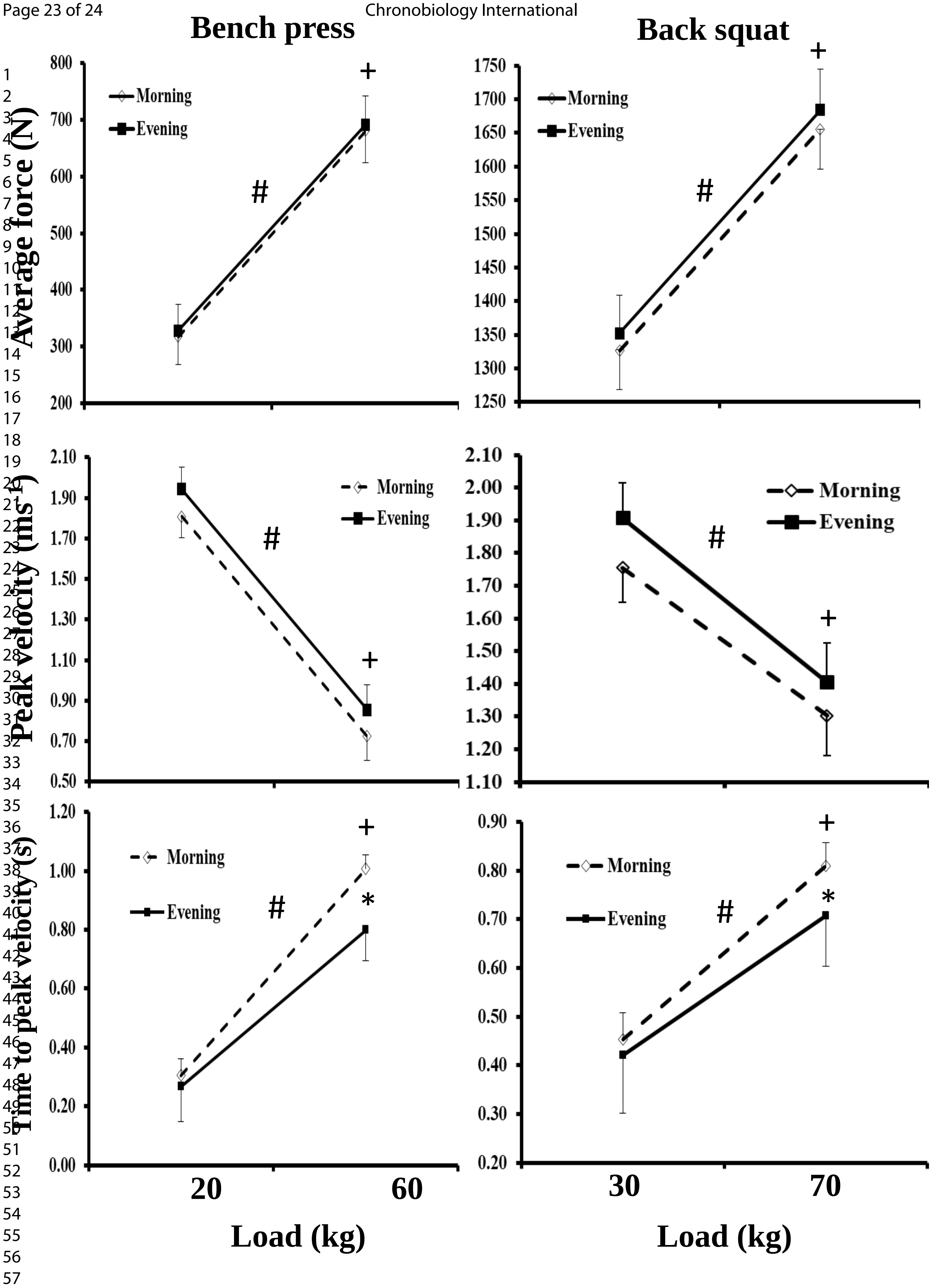
Bench press
Back squat
Average force (N)
800
700
600
500
400
300
200
Morning
Evening
#
+
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
Peak velocity (ms-1)
2.10
1.90
1.70
1.50
1.30
1.10
0.90
0.70
0.50
2.00
1.80
1.60
1.40
1.20
Time to peak velocity (s)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
*
0.90
0.70
0.50
0.30
20
60
30
70
Load (kg)
Load (kg)

Table 1

Measure	**Variable**	**Morning (M)**	**Evening (E)**	***P*-value Time of day**
Resting Rectal temperature	Trec (°C)	36.5 ± 0.3	37.0 ± 0.4	**<0.0005**
Bench Press				
20 kg	AF (N)	317.3 ± 46.5	328.3 ± 48.6	**= 0.0004**
	PV (ms^{-1})	1.81 ± 0.34	1.94 ± 0.35	**= 0.002**
	TpV (s)	0.31 ± 0.07	0.27 ± 0.07	**< 0.0005**
60 kg	AF (N)	680.5 ± 51.1	691.1 ± 56.5	**< 0.0005**
	PV (ms^{-1})	0.73 ± 0.26	0.86 ± 0.34	**< 0.0005**
	TpV (s)	1.01 ± 0.58	0.80 ± 0.43	**< 0.0005**
Back Squat				
30 kg	AF (N)	1326.3 ± 150.4	1352.4 ± 162.0	**= 0.0002**
	PV (ms^{-1})	1.76 ± 0.28	1.91 ± 0.32	**= 0.0002**
	TpV (s)	0.45 ± 0.15	0.42 ± 0.13	**= 0.011**
70 kg	AF (N)	1654.9 ± 156.2	1683.9 ± 155.7	**< 0.0005**
	PV (ms^{-1})	1.30 ± 0.29	1.41 ± 0.30	**< 0.0005**
	TpV (s)	0.81 ± 0.32	0.71 ± 0.28	**< 0.0005**