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The Effects of Time of Day on Resistance Exercise Workout Responses

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The Effects of Time of Day on Resistance Exercise Workout Responses

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Chapter 1

Introduction

In today's day and age, Athletes and "weekend warriors" alike, with full and complex days and schedules, need to make the most of their workouts. With families, jobs, etc, finding the ideal time of day to get the best quality workout would be desirable. For athletes, strength training is a quintessential portion of their training. While the time of day that competitions are held may be out of their control, their time in the strength room could be chosen for peak results. Laymen in the gym want the "biggest bang for their buck"; they want to hit the gym when they believe they can get the most out of their strength routine. Finding a time to work out is part of the process for implementation of a resistance training program. Yet what time might best work to optimize the workout has been in question for some time. Whether at a gym or in the home finding, whether doing your own program or acting as a personal trainer, the time to work out and feeling as if you are ready to do so are problems that can arise in the real world of strength training.

The time of day at which one trains is a function of both physiological and psychological readiness. One's physiological responses to strength training can not be assumed to be the same at all points in the day simply because one has to or can train at a particular time of day. Whether or not there is an affect on the quality of one's resistance exercise workout could be of great importance for people who make time to insert a workout into their already busy and hectic life schedules and responsibilities. Typically, the choices for workout times are before work (0600 hours), at lunchtime (1200 hour), or after work (1800 hour). It is unclear as to whether or not the workout response to each of these time frames is similar.

Muscles respond to total work (sets x reps x Intensity); finding the ideal time of day leading to the greatest Total Work should lead to the greatest gains. An athlete and weekend warrior alike will attain more from their resistance exercise program when they are physiologically best prepared; this in turn should lead to the greatest work done.

Statement of the Problem

There is no research to date, which investigates whether there is an ideal time of day to strength train. Research on Circadian rhythms shows peaks and troughs in hormones and biological responses but no research has made the leap to practical application of strength training. The purpose of this investigation was to determine if the workout quality, as measured by number of repetitions, total work (sets x reps x resistance), power, fatigue level, perceived exertion, and physiological stress (heart rate and blood pressure), varies with the time of day of the resistance training workout.

Chapter 2

Review of Literature

Time is of the essence in the weight room due to schedules and available equipment. Optimizing the results of one's workout is always on the mind of the strength practitioner and athletes alike. How can the athlete benefit the greatest from each rep, set, or load? Optimal training where one is capable of performing a workout at the prescribed volume and intensity is vital to gain the most out of each training session. Is there a situation or a time at which a workout could provide a better training result or stimulate optimal adaptations? Choosing the time of day to train is also one of the many choices needed in developing a training program. Due to circadian changes throughout the day each individual the time of day may influence the quality of the workout. Perhaps there is an ideal time in order to attain an ideal result?

It has been long known, as far back as the mid-19th century, that the body's rhythms ebb and flow in observable patterns (5). These biorhythms are defined as a sequence of events, which under constant environmental conditions, repeat themselves in time in the same order and same interval (1,43) and which follow external zietgebers, or entrainment signals, such as the light-dark cycle (1,2,4,54). Those biorhythms, which occur in a period of 20 to 28 hours, are termed circadian (5,46,47,54) and have been observed in a multitude of biological functions ranging from cellular and tissue level to whole-body activities (24,47). With the recruitment of motor units during a workout, physiological systems supporting muscular activity may be influenced by these changes during a day.

Many biological functions and variables involved in physical performance display a circadian rhythm, mostly peaking in the late afternoon, could affect the circadian variations in muscular force & performance (12). Such fundamental biological functions as body temperature, heart rate, blood pressure, and hormone release all display a circadian pattern (47,54,58). Temperature, for example, peaks at about 1700 hours (46,49,54,59) and many human performance measures tend to follow the circadian rhythms in body temperature (47) so closely that temperature has been referred to as the “fundamental variable” (46). Some authors have suggested a causal link between core temperature and muscular force fluctuations (3,45), noting a reduced muscular torque in the early morning could be in part explained by the lower core temperature. They also propose higher temperatures in the PM may intensify metabolic reactions, increase connective tissue extensibility, reduce muscle viscosity, and increase action potential conduction velocity (13,56). However, artificial heating of muscle has not been shown to eliminate the diurnal variation in strength, suggesting that muscle strength is not completely governed by core temperature variations (41). Additionally, reports on circadian changes in short-term anaerobic performance have been linked to “both central (neural input to the muscles) and peripheral (contractile state of the muscle) mechanisms across the day (12,13). So while temperature may be considered a fundamental variable, there is certainly and clearly more involved in a potentially complex multivariate paradigm of influences.

The light-dark cycle along with many different behavioral aspects might actually mask some of the common circadian patterns of change (2,34). A major factor thought to contribute to interindividual differences in the timing of circadian rhythms is the preference for morning vs. evening activity patterns (8,18,29,44). It was in the early 20th century that scientists considered morning types vs. evening types (47) and subsequent research in respect to circadian rhythm results demonstrate that some circadian rhythms, such as cortisol and body temperature, in morningness types show an earlier peak time (acrophase) of rhythms compared to eveningness types." (7,44). When corrected for by time of mid-sleep however, they were no longer significantly different, again reinforcing the suggested relationship between temperature and circadian rhythms (7). While a difference in timing of some circadian rhythms does appear to exist in morning types vs. evening types, there does not appear to be a difference in performance through out the day (6,47). This may be due in some part to factors such as Vo_2max, submaximal heart rate, and ratings of perceived exertion (RPE) not reflecting diurnal variation (47).

Reilly et al. (47) indicated that resting "heart rate varies with an amplitude of 5%-15% of the 24 hour mean" and the acrophase typically occurs between 1400 and 1500 hours (47,49,52). Likewise, rhythm characteristics exist for stroke volume, cardiac output, blood flow, and blood pressure (47). During submaximal (19,47,49,52) and maximal exercise, heart rate continues to be lowest in the AM and peaking in the late afternoon (47,49,52). While circadian HR rhythms seem to persist with exercise (19,47,52) some studies did not find a rhythm in maximal heart rate or found a reduced amplitude, suggesting there may be a reduction in the range of circadian variability with increasing levels of exercise intensity (19,52,62).

Many factors can impact blood pressure measurements that can change rapidly. For example, such influences as sleep, posture, activity, and ingestion of food can highly influence heart rate and blood pressure (52). Thus, the BP fluctuations over a 24-hour period can vary from the expected classic resting curves one might expect if the body was maintained in a homeostatic position for the 24hr period (47). It is generally accepted that resting blood pressure follows a circadian rhythm, lowest in the early hours of the morning (0300hr), rising before waking, peaking mid-morning and then falling gradually as the day goes on (42). The complex nature of blood pressure makes finding a rhythm or lack there of in exercise challenging. Cabri et al (10) examined performance of maximal muscular efforts of knee extensors and determined no significant rhythm was observed in either pre-exercise or post-exercise systolic pressure but found a rhythm of diastolic peaking between 0037 and 0205hr. Reilly et al (52) examined blood pressure rhythms before and after a cycle ergometer maximal test and also did not find statistically significant rhythms. With resistance exercise, typically blood pressure goes up regardless of time of day; this is dependent upon the load and the number of sets for a given exercise as well as the type of exercise and the experience of the participant (21). Fleck and Dean (21) showed that body builders as compared to novice weight lifters and sedentary controls, had a less significant response in blood pressure and heart rate to resistance exercise. However, studies are inconclusive as to whether exercise blood pressure varies with time of day (21,52). A phenomenon of post exercise reduction of blood pressure below pre-exercise levels is known as “post-exercise hypotension” (33) may however reflect a circadian rhythm. Jones et al (31,32) for example, have shown a reduction of the post-exercise hypotension effect in the early morning hours (0400-0800hr).

Reilly et al (47) suggests that circadian rhythms in the Rate of Perceived Exertion (RPE) may offer an alternate explanation for the rhythms that are seen in maximal exercise performance. While RPE was shown by Faria & Drummond (22) to be greater in the early AM than PM (47), this was due to work rates being set by heart rate, which, as previously noted, follows a circadian rhythm itself and is lower in the AM. Subsequent research has set work as a percentage of Vo2max, which does not vary with time of day (26,49) but still remains equivocal with studies finding every possible result. Ilmarinen et al (30) and others found an increase in PM RPE (30,58). Some studies suggest that whether RPE varies with TOD depends on the intensity of the workout. Hill et al (27) found that below ventilatory threshold (VT) there was no circadian rhythm for RPE but above VT RPE was greater in the PM Reilly et al (52) and Deschenes et al (17) tested both submaximal and maximal exercise on a cycle ergometer and found RPE did not vary with time of day. Atkinson et al (6) looked at RPE and TOD after a cycling time trial and again found no effects of time of day. The circadian rhythm of RPE, if any, remains unclear. Yet perceptual effort may be key to the quality of a workout since during resistance training, harder workouts yield high RPE values.

Reilly et al (47) suggested in a review on chronobiology and physical performance that while there is no overall pattern to the endocrine rhythms that could explain the circadian rhythm of exercise performance, the rhythms in catecholamines, epinephrine & norepinephrine, are the most closely related to the performance curve.

Additionally in several studies much has been reported that the testosterone to cortisol ratio's circadian rhythm is important to understanding anabolic to catabolic effects. Testosterone is a signal for muscle tissue synthesis, which overtime leads to hypertrophy and increased strength (25,35,36,39,53). While cortisol is primarily catabolic and will lead to the degradation of proteins from skeletal muscle (25,53), the testosterone to cortisol ratio (T/C) is thought to "represent an approximation of the anabolic/catabolic status of an individual" (8,25) and considered to be of high importance to strength training adaptations (53). T/C naturally peaks at 2000h (16). During acute bouts of resistance training, immediately after and during recovery, testosterone has been shown to increase above base circadian concentrations (8,35,36) and may have implications for muscle anabolism (35). In acute bouts of resistance training in the *evening*, testosterone increases, as it does in AM, but since the T/C is already elevated in the PM, the increase is even greater than the already expected elevation in circadian levels. Some results show that post-resistance exercise testosterone elevations are even greater in the afternoon than the morning (38). While research in this area may still be inconclusive (60), it has been suggested that optimal time for resistance training may be evening, as opposed to the morning, in order to enhance the anabolic/catabolic ratio and in theory affect recovery by decreasing muscle breakdown (8). Yet the circadian pattern for testosterone has repeatedly shown that higher values exist in the morning when compared to the afternoon. In contrast to this some sport scientists have stated that training in the evening might be optimal (35). However, training time based on testosterone remains unclear and still under investigation. While the T/C research does not suggest an improvement in a single bout of exercise in the afternoon, the physiological impacts along with the PM peak in catecholamines may set the stage for optimizing performance.

Not only does it appear that the circadian rhythms in biological functions which affect exercise *should* influence performance, there is mounting evidence that biorhythms *do* influence human performance (54). Due to peak of circadian rhythms of many physiological factors (HR, hormones, etc.) in the late afternoon, it appears that performance and strength should also peak in the afternoon/evening. And in fact, most authors find competitive performance is best in the late afternoon as has been documented in several reviews (46,47,54,60,62). Although some types of performance such as maximum aerobic performance are equivocal as to whether they exhibit a circadian rhythm (16) most sports & athletic performance, for example Wingate anaerobic power, badminton serve accuracy, and cycling time trials, appears to peak in the late afternoon/evening (6,13,15,20,28,54,55,56,57,62) with performance curves closely associated with the rhythm of core body temperature (23,46,48).

“Circadian rhythms have been identified in laboratory measures of anaerobic power and conventional tests of short-term dynamic activity” according to Reilly et al (47). Hill and

Smith's study (28) suggests a circadian rhythm to power with Wingate tests' peak power, defined as the highest power output during a 5-second period in the test, varying throughout the day with an 8% greater mean at 2100h than at 0300h. Souissi et al's (55,57) also confirm the conclusion that Wingate peak power and mean power are greatest in the afternoon (18:00hr). Reilly and Down (51) tested the circadian rhythm of peak power with anaerobic stair-run test and again found a similar acrophase at 1726hr. This time measuring power in the form of the standing broad jump, Reilly and Down (50) discovered the peak of performance occurred at 1745hr. Chtourou et al (13) tested short term maximal performances in with the Wingate test, squat jump, & counter movement jumps, and all were significantly higher in the pm., 1700-1800, than in the AM, 0700-0800. Study upon study supports the conclusion that power is greatest around 1800hrs.

Research in force production has also consistently shown that force peaks in the evening. Callard et al (11) found that knee extension torque peaked at 1930 and Guette et al (24) found peak torque of the quadriceps/knee extensors was observed at 1800hr for both the dominant and non-dominant leg. Looking at maximal voluntary contraction (MVC), Chtourou et all (13) found that results were higher in the evening (1700-1800) than in the AM (0700-0800). Martin et al (41) tested the MVC of the adductor pollicis muscle and also confirmed that "the MVC was significantly higher in the evening (1800hr) than in the morning (0700hr)". Martin et al (41) used EMG to clarify that the "subject's capacity to activate the muscle is not affected by the time of day" but rather that the circadian rhythm is at the level of the muscle. Nicolas et al (45) studied MVC as well and found maximal torque values to be significantly higher at 1800hr as compared to 0600hr. Coldwells et al (14) observed back strength peaked at 1653hr and leg strength peaked at 1820hr after testing 6 times during the day; peak to trough variations for back and leg strength were 21.1% and 17.9% of the means respectively. Similarly Lundeen et al (40) found the acrophase of quadriceps maximal strength to occur at 1536hr. Souissi et al's (57) pretreatment results also confirm the findings that peak knee extension torque naturally occurs in the evening, 1800hr, as compared to morning, 0700. Gauthier et al (23) found elbow flexor torque has "an acrophase at 1800 and a bathypase at 6:00" which keeps in phase with temperature. Wyse et al (63) looked at isokinetic leg strength indices at three times, 0800-0900, 1300-1400, and 1800-1930, and discovered significantly higher scored in during the 1800-1930 session. This multitude of research points toward the ideal time for force production to be in the early evening.

Investigations have indicated that any apparent circadian rhythm of performance or strength favoring PM might be attenuated by training thus diminishing any possible PM advantage. As mentioned above Soussi et al's (57) pretreatment results are consistent with the findings that peak torque occurs in the evening. However, they demonstrated in this study that a 6-week resistance-training program between 0700 and 0800 attenuated the PM peak. The participant's typical pretest afternoon peaks for torque and anaerobic power were no longer statistically significant suggesting a temporal specificity to strength training. The PM exercisers (between 1700 and 1800) continued to see a peak torque in the evening and there was no significant difference in torque between the AM and PM exercisers (57). These findings seem to suggest that if one trains in the AM, any disadvantage can be trained away. Chtourou et al (13) found similar results with even a potential greater gain in AM training vs. the typical PM. benefits when the participant trained in the AM However Souissi et al (57) , seems to suggest that with PM training, the already improved PM results would be amplified making PM training ideal.

The aforementioned research on the circadian rhythms of force production used laboratory force production tests but little to no research exists in which the individual's high intensity local muscular endurance is tested throughout the day in the form of a typical strength-training program as opposed to a laboratory test. While many physiological functions as well as force and performance appear to peak in the afternoon, does performance in an individual strength training workout have a circadian rhythm? Does the local muscular endurance volume (sets x repetitions x resistance), or total work, vary throughout the day? Such questions remain to be answered.

It appears that PM peaks in performance, strength and power, heart rate and physiological factors suggest a PM workout advantage. That greater success on the field and in the laboratory should translate to greater performance in the weight room. The PM peaks should mean in increase in work and volume but little or no research exists to elucidate this projection. There is a gap in literature is in the arena of local muscular endurance in resistance training and circadian rhythms.

In this study the following hypotheses will be tested:

Hypothesis 1: The fatigue ratings and ratings of perceived exertion will be greater at 1800hrs as compared to other time points.

Hypothesis 2: The total volume of work will be greater at 1800hrs.

Hypothesis 3: Both pre-exercise and post exercise heart rates will be greater at 1800hrs as compared to other time points. Heart rate will be higher after exercise than before exercise.

Hypothesis 4: Blood Pressure will be greater post exercise, will not vary with time of day, and will reflect post-exercise hypotension.

Chapter 3

Methods

Experimental Approach to the Problem

The design of this study was structured to examine the workout responses to a strength-training workout at different times of the day. We utilized a within subject experimental day so that comparisons could be made while removing the underlying individual variations in responses. The experimental protocol consisted of a total of 6 study days for each subject: a familiarization day, 2 preliminary testing days, three resistance training days. The workout days were performed at 0600, 1200, or 1800hrs in a randomized, balanced, crossover design. While this was a free-living experiment and many variables were not controlled, participants were instructed to maintain similar activities throughout their workday and for the three days prior to each testing day.

Subjects

With the approval from the Institutional Review Board of the University of Connecticut, 12 healthy, non-smoking men between the ages of 18 to 40 who work 1st shift (9am-5pm), and who had been taking part in a regular resistance training program for at least 3 months were recruited and volunteered to participate in the study. Each subject had the experiment explained to them as to the benefits and risks and signed an intuitionally approved informed consent document (see Appendix A). The characteristics of the group were (N = 12; age: 30.17 ± 4.75 yrs; body mass: 86.68± 11.71 kgs; height: 176.13± 6.36 cm). Subjects were employees of ESPN and were members of the ESPN Wellness Center, a corporate fitness center located at ESPN's headquarters in Bristol, Connecticut where the study was run. Subjects had been exercising at different times of the day as to their own routine prior to the study at either 0600, 1200, 1800, or at no regular time; three subjects from each group were recruited. Subjects were free of injury: no previous bone or muscle problems or previous injuries that would prevent free movement about the shoulder, hip knee or ankle, or that would increases the risk of injury during running, walking, or lifting weights. No ongoing back problems, pain, or sensitivity such as herniated spinal discs or sciatica were reported for any subject.

Familiarization Day

The subjects had the protocol explained to them and they were familiarized with the apparatus and tests. While diet was not controlled, subjects were given diet and activity recording instruction as well as instructed to maintain consistent patterns of sleep, activity, and eating for 3 days prior to each experimental day. Anthropometric measurements (height, weight, body composition as measured by skin fold calipers) were recorded.

Repetition Maximum Testing

Two days were allotted for one repetition maximum testing (1 RM) and were spaced a minimum of 72 hours apart. The 1RM tests were performed, as previously described by (25) for the Smith Squat, Bench Press, and Upright Row. 5RM were performed for the remaining exercises (Seated Row, Leg Curl, Lat Pull Down, Knee Extension, Arm Curls, & Calf Raises). At every exercise session, the exercises were performed in the same order.

Test Sessions

All testing sessions were performed identically on the same equipment in a corporate fitness facility's gym. For each test session, the subject was lead through the workout by the primary investigator. Prior to each training session, blood pressure, resting heart rate, and fatigue rating was obtained. Fatigue ratings were obtained after the workout and heart rate was obtained 5 minutes after exercise and blood pressure was obtained using standard blood pressure cuff and auscultation techniques.

The experimental workout consisted of the exercises listed in Table 3.1 and were performed at the corresponding percentage of 1RM or 5 RM exercise intensity. At every exercise session, the session began with a 5 minute treadmill walking warm up on and the exercises were performed in the same order, each set to failure with 2-minute rest periods between sets.

Table 3.1 describes the strength training protocol.

Smith Machine Squat	3 sets	85% of 1RM
Bench Press	3 sets	80% of 1RM
Seated Rows	3 sets	80% of 1RM
Leg Curls	3 sets	80% of 1RM
Lat Pull Down	3 sets	80% of 1RM
Knee Extensions	3 sets	80% of 1RM
Arm Curls	3 sets	75% of 1RM
Calf Raises	3 sets	85% of 1 RM

Upright Rows	3 sets	80% of 1RM

Immediately post-workout and 30-minutes post workout, blood pressure, resting heart rate, and fatigue ratings were again obtained. Ratings of perceived exertion (CR-10 scale with magnitude estimation (25) and heart rate (Polar Heart Rate Monitor) were obtained immediately after each set. Table 3.2 shows the dependent measures that were used to evaluate the hypotheses.

Table 3.2. Dependent variables measured in the study.

Fatigue Ratings	Pre-workout, immediately post-workout, 30 minutes post workout
Blood Pressure, Heart Rate	Pre-workout, immediately post-workout, 30 minutes post workout
Heart Rate	After each set of exercise
Repetitions	For each exercise set
Average Power	For each of the exercise sets; average of the reps and per rep
Ratings of Perceived Exertion	For each of the exercise sets
Total Work	Sets x Reps x Intensity

Statistical Analyses

A 4 x 3 x 3 (regular exercise time x trial x time point) ANOVA with repeated measures for “trial” and “time point” was used to determine statistically significant differences. If there was no main effect or interaction involving “regular exercise time”, then pooled values were reported. If a significant F score was obtained, then a Fisher LSD post-hoc test was used to determine specific pair-wise differences. An analysis of co-variance using the time of day that the subjects worked out did not yield any significant F scores for any of the dependent variables and thus the plain ANOVA was used in the analysis of these data. Significance was defined as $p \leq 0.05$. All data met or were corrected ($\log_{10}$ transformation) for the assumptions for linear statistics, and there were no order effects.

Chapter 4

Results

In Table 4.1 the results of the fatigue rating pre- to post-exercise is presented. As expected there were significant increases in fatigue after the workout. However, the time of day had no effects on the magnitude of changes that were observed.

Table 4.1. Changes (Mean±SD) in the fatigue pre to post workout (N = 12)

Pre-exercise fatigue, 0600 trial	**1.8±1.1**
Post-exercise fatigue, 0600 trial	3.0±1.1*
30 min post-exercise fatigue, 0600 trial	2.3±1.2*
Pre-exercise fatigue, 1200 trial	**1.2±0.9**
Post-exercise fatigue, 1200 trial	3.0±0.8*
30 min post-exercise fatigue, 1200 trial	2.1±0.8*
Pre-exercise fatigue, 1800 trial	**1.5±1.2**
Post-exercise fatigue, 1800 trial	3.2± 0.9*
30 min post-exercise fatigue, 1800 trial	2.4±1.2*

No effect of regular exercise time. * = $P < 0.05$ from corresponding pre-Exercise values

Table 4.2 shows the response of systolic blood pressure to the different workouts at different times. Interestingly there was a main effect for time but no pairwise differences that would dictate any advantage or disadvantage to the time of day for the workout.

Table 4.2. Changes (Mean±SD) in the systolic blood pressure (mmHg) pre to post workout (N = 12)

Pre-ex systolic blood pressure, 0600 trial	**124.6±10.3**
Post-ex systolic bp, 0600 trial	123.0±10.8
30 min post-ex systolic bp, 0600 trial	116.8±8.02
Pre-ex systolic blood pressure, 1200 trial	**127.7±10.4**
Post-ex systolic bp, 1200 trial	122.0±7.4
30 min post-ex systolic bp, 1200 trial	119.2±11.5
Pre-ex systolic blood pressure, 1800 trial	**125.1±9.4**
Post-ex systolic bp, 1800 trial	122.4±11.6
30 min post-ex systolic bp, 1800 trial	118.8±7.9

Main effect of time; however, no specific pair-wise differences.

Table 4.3 shows the heart rate response to the workout. There were no differences. There was a main effect for time but no pairwise difference to indicate a time preference. The immediate post-exercise values were significantly higher than the pre and 30 minutes post-exercise values.

Table 4.3. Changes (Mean±SD) in the heart rate (bpm) pre to post workout (N = 12)

Pre-ex heart rate, 0600 trial	**64.2±12.1**
Post-ex hr, 0600 trial	96.5±12.6*
30 min post-ex hr, 0600 trial	76.5±9.0
Pre-ex heart rate, 1200 trial	**72.5±14.9**
Post-ex hr, 1200 trial	100.0±11.3*
30 min post-ex hr, 1200 trial	83.9±13.6
Pre-ex heart rate, 1800 trial	**61.3±11.9**
Post-ex hr, 1800 trial	99.0±13.1*
30 min post-ex hr, 1800 trial	82.6±9.1

* = $P < 0.05$ from corresponding pre-exercise values.

In Table 4.4 the total work for the different times of day is presented. The amount of total work that was performed for the 0600 trial was greater than 1800 and in the 1200 trial was also greater than the 1800 workout time. Thus, from these data the two times that dominated within a work week schedule for optimal training were the early morning and lunch time workout times.

Table 4.4. Total work for the different times of day for the resistance exercise protocol. (N = 12) Sets x Reps x Intensity (lbs)

Total work, 0600 trial	41,817.0±6386.7
Total work, 1200 trial	42,255.4±4965.5
Total work, 1800 trial	38,003.7±8030.9

Main effect of trial (0600 > 1800, 1200 > 1800).

Squat and Bench Press Exercise Responses within the Workout

In order to better see what might be going on inside the total workout the squat and bench press were examined. Table 4.5 presents repetitions for each time and trial for the squat. For the squat exercise, significantly more repetitions were performed in set 1 than in set 3 for each workout time yet there were no differences among them. Table 4.6 shows RPE for the squat for each time and trial. Following the same pattern as the squat, the RPE was also significantly higher in set 3 than set 1. Tables 4.7 and 4.8 show that in the bench press a similar pattern evolved with significantly higher numbers of repetitions performed in set 1 which was greater than set 2 which was greater than set 3, yet no differences between workout times. Again the RPE tracked the pattern of repetitions performed for the sets with set 3 > set 2 > set 1. The subtle differences that occurred in total work were a function of the other smaller group exercises, which contributed more total work to the 0600, and 1200 time frame when compared to the 1800 workout time frame. Interestingly the fatigue ratings were not affected by total work. In addition, the typical time subjects worked out did not influence any of the responses of the dependent variables suggesting that other circadian factors related to intensity and volume appear to mask any engrained routines. Thus, no matter what your typical time for a resistance training session, less work or a higher level of perceptual strain per unit of work occurred at the late afternoon workout time of 1800 hrs.

Table 4.5. Total Reps (Mean±SD) in the squat (N = 12)

Set 1, 0600 trial	**9.0±2.3***
Set 2, 0600 trial	7.8±2.9
Set 3, 0600 trial	7.4±2.6
Set 1, 1200 trial	**9.7±3.7***
Set 2, 1200 trial	8.1±2.8
Set 3, 1200 trial	7.6±2.8
Set 1, 1800 trial	**8.2±2.7***
Set 2, 1800 trial	7.0±3.6
Set 3, 1800 trial	6.9±3.5

* = $P < 0.05$ from corresponding Set 3 values.

Table 4.6. RPE (Mean±SD) post-exercise for the squat (N = 12)

Set 1, 0600 trial	**5.9±1.6**
Set 2, 0600 trial	6.1±2.0
Set 3, 0600 trial	6.8±1.8*
Set 1, 1200 trial	**5.5±1.2**
Set 2, 1200 trial	6.3±1.4
Set 3, 1200 trial	6.8±1.2*
Set 1, 1800 trial	**5.6±1.8**
Set 2, 1800 trial	6.3±1.7
Set 3, 1800 trial	6.5±1.4*

* = $P < 0.05$ from corresponding Set 1 values.

Table 4.7. Total Reps (Mean±SD) in the bench press (N = 12)

Set 1, 0600 trial	**8.4±2.2***
Set 2, 0600 trial	6.3±1.2
Set 3, 0600 trial	5.3±0.1
Set 1, 1200 trial	**8.5±2.1***
Set 2, 1200 trial	6.7±1.3
Set 3, 1200 trial	5.3±0.1
Set 1, 1800 trial	**8.3±1.6***
Set 2, 1800 trial	6.3±1.1
Set 3, 1800 trial	5.0±0.1

* = $P < 0.05$ from corresponding Set 2 & 3 values.

Table 4.8. RPE (Mean±SD) post-exercise for the bench press (N = 12)

Set 1, 0600 trial	**6.3±1.7**
Set 2, 0600 trial	6.4±1.9
Set 3, 0600 trial	6.8±1.5*
Set 1, 1200 trial	**5.5±1.2**
Set 2, 1200 trial	6.3±1.4
Set 3, 1200 trial	6.8±1.2*
Set 1, 1800 trial	**6.3±2.1**
Set 2, 1800 trial	6.6±1.9
Set 3, 1800 trial	7.0±1.9*

* = $P < 0.05$ from corresponding Set 1 values.

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Chapter 5

Discussion

The primary findings of this investigation were that the time frames that seem to be the best time to workout for employees is the 0600 and 1200hrs when higher total work can best be achieved with a given percentage of the 1 RM. In addition, more work can be done at a lower work per perceptual stress and this might be due to the accumulation of everyday work tasks and stresses. Interestingly, the influence of the subject's normal workout time was not seen to effect the observation that the earlier workout times are more optimal. Finally, one sees more fatigue by the end of the day than earlier and this may well be what is mediating the better or more optimal work capacity in the earlier workouts.

The main effect of trial was found to be significant for Total Work; the 0600hr time elicited greater total work than 1800hr and 1200hr greater than 1800hr. Previous research has suggested that there is a peak on performance, force, and power. However this previous research suggests a PM peak. Many articles have details the propensity of sport performance to peak in the afternoon in as varied performances as badminton serves to cycling time trials to swimming and shot-put (6,15,19, 20, 46,47,54,60,62). Likewise, repeatedly peak anaerobic power via the Wingate test has been shown to display a circadian rhythm with an evening acrophase (13,28,55,56,57). Again, force production studies submit similar findings with maximal voluntary contractions and peak torque acrophases in the evening. Atkinson and Reilly (5) report on two studies of theirs in which self-chosen work rates during 30-minute on a cycle ergometer bouts peaked at 1900hr; the PM peak was not accompanied but an increase in RPE suggesting, "an athlete adopts(s) greater training loads in the early evening spontaneously with out realizing it." Yet, in the present study total work has been shown to peak in the AM.

No other data appears to exist on circadian rhythms of resistance training total work. Souissi et al (55) did find that total work in a Wingate test peaked in the PM All other research on force production is limited to individual muscle groups and not part of high intensity local muscular endurance bouts. Perhaps something about the complexities of a resistance training workout are too varied and complex to simply compare to individual circadian rhythms in force or individual muscle strength.

This 0600hr peak in total work was accompanied by an RPE that was no higher than the sessions at either 1200hr or 1800hr; RPE did not reflect a circadian rhythm. And fatigue rating was greatest at 1800hr. This suggests that the morning workout would begin with less fatigue and provide greater work with less perceived difficulty. Some research as to whether RPE follows a circadian rhythm is unclear according to a review of exercise literature (6,26,47,49,54,58).

Hill et al (26) studied whether adaptations to training were specific to the time of day of training and found that, "training at a particular time of day did not result in a greater adaptation at that particular time of day." Meaning that RPE during the time of one's regular exercise is not affected by training. Mounting evidence suggests, like the present study, that RPE does not vary rhythmically throughout the day as many other physiological markers, such as heart rate, do.

A physiological parameter that does show distinct circadian rhythms is heart rate, both at rest and with exercise (19,47,49). Heart rate is also known to increase with exercise (61). The present study resulted in a main effect of time for heart rate with the pre and 30-minute post exercise heart rates being significantly lower that the heart rate immediately after exercise, just as expected (61). However the lack of circadian rhythm of resting and exercise heart rate (no specific pairwise differences for the main effect for trial) was surprising. Other studies looking at exercise and time of day, such as Deschenes et al (16,17) also found no significant difference for heart rate and time of day. It is possible that because in the present study the 1200hr and 1800hr sessions straddled the generally accepted 1400hr-1500hr heart rate peak (47,49) the peak itself was lost and resulted in no significant differences. Or as Deschenes et al (16) suggest, this could also be due the fact that the heart rate nadirs are found at early morning times that individuals do not typically work out. While heart rate is expected to follow a circadian rhythm, other parameters such as blood pressure are not as clear.

Blood pressure responded as we expected. We did not see a circadian rhythm to blood pressure at rest or after exercise. While resting blood pressure does appear to follow a circadian rhythm (42, 52), it is clear that many exogenous factors can perturb that rhythm and make it very difficult to study (47). Several studies, like the present study have attempted to find the rhythm throughout the day of both resting and post exercise blood pressure with little or no success (10,21,52). Blood pressure increases with exercise (61) and after exercise displays a reduction below pre-exercise levels called post-exercise hypotension. In the present study we found a main effect of time however no pairwise differences were found. The lack of significant blood pressure increase post exercise is likely due to the order of the exercise. This study's protocol started with the large muscle, compound movement exercises first followed by smaller muscles, isolation exercises. This order reduced the cardiovascular stress and allowed the blood pressure to decrease. It is also possible that as Fleck and Dean (21) observed in bodybuilders, there was a blunted response in blood pressure to the workout due to the subjects' fitness level. Fleck & Dean (21) compared novice-resistance trained man, described as having 6-9 months of experience on Nautilus equipment, to bodybuilders, described as having trained for 2 hours, 6 days per week, for 2 to 8 years. While none of our recreationally trained subjects were body builders, their experience was beyond that of the novice described above. As is expected post exercise, there was a drop below resting levels of blood pressure 30-min post. This post-exercise hypotension is an expected phenomenon, which typically is less marked in the morning (32).

It appears that one's usual workout time does not influence the success of a workout as defined by total work. Rather the present study found that an AM workout, 0600 or 12000hrs offer a greater total work. A greater total work while also starting with less fatigue and feeling less exertion during the workout would appear to be the ideal situation and what the findings in this study point to occurring earlier in the day rather than later. Contrary to many circadian rhythms that peak in the PM this study appears to name the AM as the ideal time to workout for best results.

Appendix A

Human Performance Laboratory
CONSENT FOR PARTICIPATION IN A RESEARCH PROJECT
University of Connecticut

Responsible Investigators: William J. Kraemer, Ph.D. and Heather N. Husmer, B.S.
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Study Title: *The Effects of Time of Day on the Quality of a Resistance Training Workout*

Invitation to Participate: You are invited to be in this study to determine how the time of day affects your body's responses to a weight training workout.

Before you decide to be a part of this study, you need to understand the purpose, procedures, risks and benefits involved so you can make an informed decision. This consent form provides information about the research study. A member of the research study team will be available to answer your questions and provide further explanations. If you agree to take part in the study, you will be asked to sign this consent form. This process is known as informed consent. Your decision to take part in the study is completely voluntary, you are free to choose whether or not you will take part in this study, and you may withdraw from the study at any time.

To be a study subject you must be a healthy man or non-pregnant, non-lactating, woman between 18-40 years of age, who is motivated to participate an investigation to determine what time of day is best to weight train. Additional requirements for participation in this study include: 1) being a non-smoker 2) no current medical conditions, 3) no previous bone or muscle problems or previous injuries that would prevent free movement about the shoulder, hip, knee or ankle, or that would increase the risk of injury during running, walking, lifting weights, 4) no ongoing back problems, pain, or sensitivity such as herniated spinal discs or sciatica.

Purpose of the Study: The purpose of this investigator will be to determine if the workout quality (as measured by number of reps, average force and power output, and total work (sets X reps X resistance), fatigue level, perceptual responses to the workout, and physiological stress (heart rate and blood pressure) vary with the workout time of day.

Description of Procedures: Prior to participating in the study, you will be asked to undergo medical screening, which will include a medical history that will be evaluated by a physician.

If you volunteer for this study, you will be asked to report for a total of 6 study days in which three will be for familiarization and preliminary testing and three for weight training sessions done at different times of the day. Each laboratory session will take about 90-120 minutes for a total of about 12 hours of your time.

You will be asked for your age, and we will measure your body weight and height on a standard physician's scale. In addition we will also determine your percent body fat using a skinfold technique. This means we will use a caliper that can measure the thickness of a "pinch" of your surface body fat at three sites. The sites of the skinfolds will be: for men: chest, abdomen and thigh, for women: triceps (back of your upper arm), suprailiac (top of your hip) and middle of your thigh.

Strength Assessment. You will be tested to determine your maximum weight lifting ability on each of the above exercises. You will perform warm-up lifts at progressively increasing weights, interspersed with rest periods. Your one repetition maximum lift (1RM) for each exercise will be determined when the heaviest weight completed through a full range of motion using proper technique has been attained. This will be accomplished during your three days of familiarization. These data will allow us to set your workout resistance for each of the exercises listed below in the workout protocol.

You will do the same workout on three separate days at three different times i.e., 0600, 1200 or 1800 hrs. This will be done in a random order (by chance what the order of the time of day is). We will ask you to keep a similar work day for each of the test workouts and will ask you to record your work day activities. We will also ask you to record your activities, diet, and sleep patterns for three days prior to the testing day. You will use the diet and activity logs to help to replicate each study day.

Blood Pressure using a stethoscope and a blood pressure cuff, resting heart rate (Polar heart rate monitor), fatigue rating on a 10-point scale will be obtained before the workout, after the workout and 30 minutes following the workout. We will also measure the number of repetitions, average power, heart rate and ratings of perceived exertion, and average force for each set of every exercise.

In the weight room you will asked to perform the workout which will consist of the following exercises as percentages of the 1 RM:

Smith Machine Squat 3 sets at 85% of 1 RM
Bench Press 3 sets at 80% of 1 RM
Seated Rows 3 sets at 80% of 1 RM
Leg Curls 3 sets at 80% of 1 RM
Lat Pull Down 3 sets at 80% of 1 RM
Knee Extensions 3 sets of 80% of 1 RM

Arm Curls 3 sets of 75% of 1 RM
Calf Raises 3 sets of 85% of 1 RM
Upright Rows 3 sets of 80% of 1 RM

Risks and Inconveniences:

Risks Associated with Exercise. The weight training workout is one that is a standard protocol to develop strength and local muscular endurance. Even though the exercise protocols are designed for any healthy adult and you will be closely monitored you during all of the exercise tests, there is the risk that you may become injured. The researchers have extensive experience in conducting exercise studies, and they will do everything possible to reduce the chance of injury. Every effort will be made to make this study safe for you through supervision, screening, monitoring while testing, familiarization and technique instruction, and proper warm-up and cool-down practices. However, if at anytime during exercise training or testing you experience pain, unexpected discomfort, soreness, headache, loss of concentration, dizziness, unusual fatigue or difficulty breathing you should immediately inform one of the supervising researcher team and stop the exercise. You are free to stop at any time during any test during the study.

The performance of resistance exercise can entail a certain degree of risk from overexertion and/or accident. With strength minimal risks exist for muscle strain or pulls of the exercised muscles, muscle spasm, and in extremely rare cases, muscle tears. Some muscle soreness may be experienced 24 to 48 hours after exercise, and this should completely subside within a few days and have no long-lasting effect. All personnel involved in the testing are currently certified in CPR.

Benefits: You will receive no direct benefits as a result of your participation in the study. Your data will be explained to you and it may give you insights as to the time of day that best suits your psychological and/or physiological responses.

Economic Considerations: No money will be given for your participation.

Confidentiality: All of the data collected will remain confidential and you will never be identified by name in any reporting of the results. Further, the results will not be shared with any person outside of the investigation without your consent. The results for this study will be kept in locked cabinets under the supervision of Dr. William Kraemer and Ms Heather Husmer. You should also know that the UConn Institutional Review Board (IRB) and the Office of Research Compliance may inspect study records as part of its auditing program, but these reviews will only focus on the researchers and not on your responses or involvement. The IRB is a group of people that reviews research studies to make sure they are safe for participants".

In Case of Injury: If you become sick or injured as a result of the study, you should immediately notify the researchers, who will contact the medical monitor. As such, you should contact Dr. William Kraemer at 860-486-6892 or home phone 860-429-0690 or Ms Heather Husmer at 860.766.2827.

The University of Connecticut does not provide insurance coverage to compensate you if you are injured during the research study. However, you may still be eligible for compensation. If you are injured, you can file a claim against the State of Connecticut seeking compensation. For a description of this process, or available compensation options, please contact the Office of Research Compliance at the University of Connecticut at 860-486-8802.

Voluntary Participation: You do not have to be in this study if you do not want to. If you agree to be in the study, but later change your mind, you may drop out from the study at any time.

Questions: Take as long as you like before you make a decision. We will be happy to answer any question you have about this study. If you have further questions about this project or if you have a research-related problem, you can contact the principal investigator at UCONN (William J. Kraemer, Ph.D., 860-486-6892. If you have any questions concerning your rights as a research subject, you may contract the University of Connecticut Institutional Review Board (IRB) at 860-486-8802.

Authorization:

I have read this form and decided that ______________________________ will
(your name)

participate in the project described above. Its general purposes, the particulars of involvement and possible hazards and inconveniences have been explained to my satisfaction. My signature also indicates that I have received a copy of this consent form.

Signature: ____________________________________

Date: _______________________________________

____

Signature of Primary Investigator Phone

Or

____

Signature of Person Obtaining Consent Phone

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