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ORIGINAL RESEARCH

THE EFFECTS OF VARYING LOAD AND REPETITION SPEED ON ENERGY EXPENDITURE DURING SQUATS

Samuel T. Barrett[1], Bryce Hastings[2], and Jinger S. Gottschall[1]

[1] The Pennsylvania State University, University Park, USA

[2] Les Mills International, Auckland City, NZ

Corresponding author: Jinger S. Gottschall

029J Recreation Hall, Department of Kinesiology, The Pennsylvania State University

University Park, PA 16802

Tel: 814.867.2318, Fax: 814.863.4755, Email: jinger@psu.edu

ABSTRACT

Introduction: A leading topic of interest in the health, fitness and wellness industry is how to maximise energy and thereby caloric expenditure in the shortest amount of time through physical activity. The goal of this study was to identify a resistance training (RT) protocol that appeals to these two demands using the traditional squat.

Methods: Fifteen participants completed four separate exercise protocols in a randomised order. Each protocol was devised with the same amount of work (force x distance) for 4 minutes using either a 20 kg, 15 kg, 10 kg, or 5 kg load at a contraction speed of 4, 3, 2, or 1 second(s) respectively. In short, we collected heart rate data and estimated energy expenditure differences between heavier load with slower repetitions and lighter load with faster repetitions.

Results: The mean physical activity energy expenditure (PAEE), calculated in kcals, was 29.3% greater during the lighter 5 kg condition with faster repetitions compared to the heavier 20 kg condition with slower repetitions. The average and maximum heart rate (HR) recordings exhibited the same trend.

Conclusion: PAEE can be maximised with faster repetitions using a light to moderate weight.

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INTRODUCTION

Resistance training (RT) provides many health benefits such as improved muscular strength, bone density, body composition, anaerobic capacity, joint flexibility, and physical function[1]. A few specific variables that have been tested to evaluate these benefits include relative muscular effort, range of motion, load, repetition speed and total work. One commonality among these variables is the direct influence on energy expenditure. Physical activity energy expenditure (PAEE) is the most variable portion of total energy expenditure (TEE) and can range from as little as 5% of the TEE to 45-50% depending on activity time as well as intensity[2]. Heart rate (HR) monitors are a valid and reliable testing method for PAEE on the basis of the linear relationship between HR and caloric expenditure[2].

One of the primary factors affecting caloric expenditure during exercise is the activity of large muscle groups. The squat is a multi-joint exercise requiring recruitment from the majority of lower limb muscles. During a squat, the relative muscular effort, defined as the muscle force required to perform a task, relative to the maximum amount of force that muscle can produce, can be controlled via both range of motion and load magnitude[3]. Bryanton et al[3] manipulated these two variables during a back squat to investigate the effect on relative muscular effort. The results showed that increasing the barbell load affected the ankle plantar flexor relative muscular effort and increasing the squat range of motion affected knee extensor relative muscular effort. To add, both load as well as range of motion affected hip extensor relative muscular effort. Another influence on energy expenditure is the rate of muscular contraction.

Based upon previous research, there is no consensus with respect to the speed of a repetition in order to maximise PAEE. For the past 25 years it has been widely accepted that resistance training, with an emphasis on PAEE, should be performed using slow muscle contractions. One argument for this reasoning claims that slow repetition speeds increase intensity[4]. Westcott et al[5] suggested that rapid contractions will result in reduced muscular effort and therefore energy expenditure due to the generation of momentum. Thus, slow repetition speed increases intensity as well as energy expenditure by prolonging repetition durations resulting in greater muscle fatigue. On the contrary, other research teams provided evidence that fast contractions have a higher PAEE rate due to the activation of the energy-inefficient fast twitch muscle fibres[6-8].

Multiple studies have attempted to resolve this discrepancy of how to maximise PAEE during resistance training. Mazzetti et al[8] tested repetition speed and compared three squat exercise protocols focused on fast versus slow muscle contraction using a plate loaded squat machine. The average rate of energy expenditure for the moderate load, explosive extension (standing phase) protocol, was significantly greater than both the moderate load, slow extension protocol and the heavy load, explosive extension protocol[8]. Recently, Buitrago et al[4] tested four different training conditions with varying loads and contraction times including strength endurance, fast force endurance, hypertrophy, and maximum strength. Again, the condition with a moderate load and explosive contraction phase consumed the most energy. In summary, Buitrago et al[4] and Mazzetti et al[8] have both determined that slow flexion (lowering phase) and explosive extension (standing phase) maximised PAEE during a squat.

Therefore, there is disagreement about the optimal load and speed combination for resistance training exercises to maximise PAEE. The current research used a unique protocol in which the magnitude of work, the product of force and distance, was equal in all conditions. Our aim was to identify which, if any, ratio of load (force) to number of repetitions (speed and thereby total distance), has a greater average as well as maximum heart rate yielding a greater PAEE. We hypothesised that the training method with the lightest load and greatest number of repetitions will maximise PAEE due to fast muscle contractions causing the highest heart rates.

METHODS

Experimental Approach to the Problem

We collected heart rate data (average, maximum, energy expenditure calculation) during four resistance training conditions with equal work (force x distance). The load was varied with the amount of weight utilised during back squats and the distance was modified with the number of repetitions.

Table 1. Participant Characteristics

Age	30 ± 7
Height (m)	1.7 ± 0.1
Weight (kg)	66.9 ± 12.9
BMI (kg/m2)	24.0 ± 2.6

Data are means ± SD.

Participants

Fifteen participants, six men and nine women, between 18 and 40 years of age, completed the protocol (Table 1). Each individual had a minimum of two years of weightlifting experience and completed bi-weekly training sessions that included squats. All of the experimental procedures were approved by the Institutional Review Board for the involvement of human participants at The Pennsylvania State University and written consent was obtained from each individual.

Procedures

Each participant wore a Polar Team[2] heart rate monitor around the chest. Physical activity energy expenditure was calculated from the heart rate and reported in kilocalories. Prior to the start of the each experimental squat condition, the participants completed a 10-minute cycling warm up and practised each condition with the Les Mills SMARTBAR™ as well as Les Mills SMARTBAR™ weight plates (2.5 kg and 5 kg). Tape was placed on the floor to mark the stance width and angle of the feet for each participant. A metronome was used to set and maintain the pace of each repetition for the different squat conditions.

Following the cycling warm up and squat practice, participants rested to establish a baseline HR. This baseline measurement was used as a control for the amount of rest between each squat condition. Each of the four squat conditions was performed on the same day in random order for four minutes. The first condition (C20) was a 20 kg load with a four second eccentric and concentric phase for a total of 30 repetitions. The second condition (C15) was a 15 kg load with a three second eccentric and concentric phase for a total of 40 repetitions. The third condition (C10) was a 10 kg load with a two second eccentric and concentric phase for a total of 60 repetitions. The fourth condition (C05) was a 5 kg load with a one second eccentric and concentric phase for a total of 120 repetitions. These particular loads and repetition speeds were specifically designed to ensure that each condition performed the same amount of work (force x distance). The order of each of the four squat conditions was randomised for each participant. A summary of the experiment protocol is listed in Table 2.

Each participant positioned the bar under the spinous process of the C7 vertebrae. Once the feet were positioned, the metronome was started at the proper frequency for each condition. The data recording began at the start of the second repetition

Table 2. Resistance Training Protocols

Condition	C20	C15	C10	C05
Repetition Time (s)	8	6	4	2
# Repetitions (4 min)	30	40	60	120
Total Estimated Work	240	240	240	240

in order to allow each participant a practice repetition to adjust to the pacing. All squats were performed in front of a mirror, allowing each participant and investigator to monitor the consistency of range of motion such that hips were approximately five centimeters above parallel with the knees. In addition to tape being placed on the floor, the optimal squat depth for each participant was marked with tape on the mirror so that squat range of motion could be controlled for each repetition.

Statistical Analysis

Mean values ± standard deviations (SD) were calculated for the average and maximum heart rates as well as the total caloric expenditure for each condition. A repeated measures ANOVA and when appropriate, a Tukey post-hoc analysis were completed with a statistical significance defined as $p \leq 0.05$.

RESULTS

Mean PAEE was 29.3% greater with the lightest load and fastest movement speed (Table 3). On average, PAEE increased by 10% for each condition with lighter loads (20 kg, 15 kg, 10 kg, 5 kg) and faster movements speeds (8 s, 6 s, 4 s, 2 s). C05 was also significantly greater than C20 for the average and maximum HR values with differences of 12.6% and 12.9% respectively (all values, $p < 0.05$, Table 3).

In detail, there was a significant main effect for each of the measured variables. For both average and maximum heart rate, the greatest differences were between C05 and the other 3 conditions (all values, $p < 0.005$, Table 4). As expected, the greatest difference was always between the extreme conditions, C20 and C05 (all values, $p < 0.0002$, Table 4).

Table 3. Mean Values of HR and PAEE for all Conditions

Condition	Mean HR (bpm)	Max HR (bpm)	PAEE (kcal)
C20	118 ± 18*	128 ± 25*	35 ± 12*
C15	120 ± 22*	132 ± 26*	38 ± 13*
C10	127 ± 25*	137 ± 27*	42 ± 17*
C05	135 ± 23	147 ± 26	47 ± 15

Data are means ± SD. An asterisk represents a significant difference of $p < 0.05$ between the noted condition and C05 (5 kg).

Table 4. Post-hoc statistical p-value for tests between each condition

	Ave HR	Max HR	kcal
C05-C10	0.0053	0.0005	0.0093
C05-C15	0.0021	0.0001	0.0002
C05-C20	0.0002	0.0001	0.0002
C10-C15	0.0467	0.0124	0.0295
C10-C20	0.0154	0.0179	0.0167
C15-C20	0.5708	0.0803	0.0354

Numbers with a $p < 0.05$ represent a significant difference between conditions.

DISCUSSION

Despite standardising the total amount of work performed for each condition, which theoretically should have yielded the same PAEE, energy expenditure based upon heart rate was different between conditions. The results from this study indicate that a resistance training program utilising lighter loads with a faster movement speed will yield the highest PAEE. This relationship suggests that muscle contraction rate exhibits a greater influence over PAEE than load.

First and foremost, if the total amount of work performed between training protocols is not the same, the protocol that yields the most work will have the highest PAEE[9,10]. This is due to the positive correlation between work, heart rate, and energy expenditure. The key components that determine the total work performed in a set amount of time are load and repetition speed. Second, muscle-endurance exercise protocols, 40-60% 1RM, will have

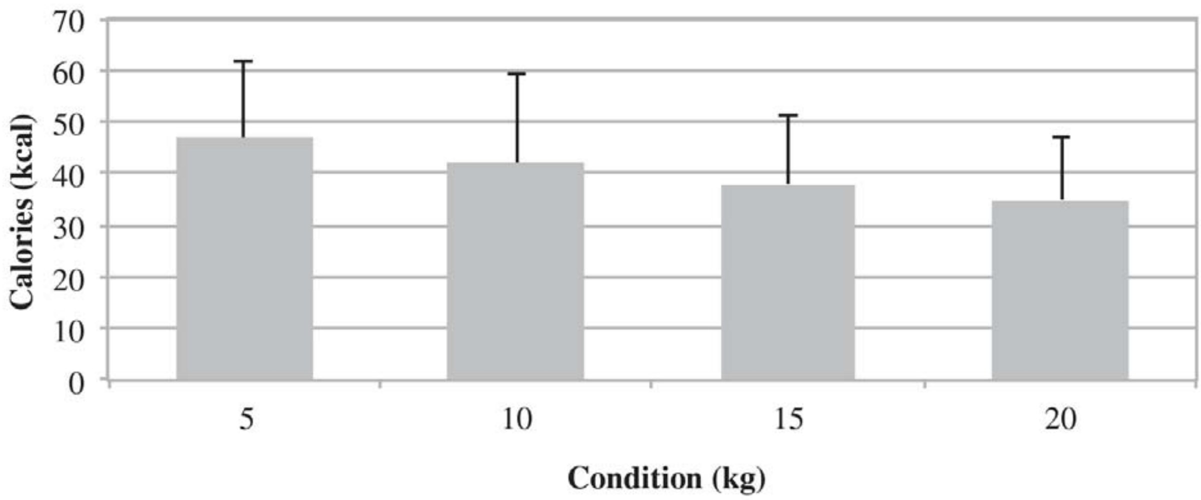

Figure 1. Energy Expenditure for Each Condition. Total kcal per condition was significantly different ($p < 0.05$) between each load and repetition frequency.

significantly higher energy expenditure contributions from both anaerobic and aerobic energy expenditure compared to that of muscle-strength exercise protocols, 70+% 1RM. The muscle-endurance protocol allows for more work to be performed through the use of a lighter load (40% 1RPM) at a higher volume compared to that of a heavier load (80% 1 RPM) at a lower volume. Therefore the optimal protocol when planning a resistance training program for weight management would be muscle-endurance exercises to maximise average heart rate and thereby PAEE with larger contributions from both aerobic and anaerobic energy systems[10]. The individual would be enhancing the total work through the use of a light-to-moderate load with faster repetitions.

The influence of load on relative muscular effort and therefore PAEE did not likely change between each condition of the present study. Bryanton et al[3] determined that squat range of motion significantly affects muscular effort of the knee extensors while the barbell load has more influence over the ankle plantar flexors. Both load and range of motion play a role in the hip extensor relative muscular effort. Since squat depth remained constant between conditions, the knee extensor relative muscular effort would have also been relatively constant and to a lesser degree the hip extensors as well[3]. The only varying relative muscular effort, and therefore PAEE, would come from the ankle extensors and possibly a small amount from the hip extensors as the loading increased. With larger muscles expending more energy to perform movements, the role of the hip and knee extensors on influencing PAEE was much larger than that of the ankle extensors[1]. Since the relative muscular effort of these muscle groups remained relatively constant across conditions, the contribution to the PAEE from relative muscular effort as a result of the load for each protocol was also relatively constant.

The basis for higher heart rates as well as energy expenditure from faster contractions, despite lighter loading, is likely due to the reliance on faster muscle fibre activation and fast fatigable motor units[6,8]. The fast twitch muscle fibres compared with slow twitch muscle fibres are energy inefficient upon activation[7,8]. The fast contraction rates invoked a higher ratio of fast to slow twitch muscle fibre activation resulting in the disproportionate average heart rate and energy expenditure under the same loading compared to slow contractions. The reason these faster contraction rates recruit a larger portion of the energy inefficient fast muscle fibres is because they are capable of involving higher threshold motor units[8,11,12]. Additionally, the greater the threshold of activation that is required of these motor units, the more fibres they innervate, further perpetuating the inefficiency of energy required to perform the movement[8,13].

Hunter et al[9] performed a study to compare the energy expenditure of two different resistance training protocols consisting of a super slow training protocol and a traditional training protocol. The same exercises were performed for both protocols in the same order. The super slow protocol performed one set of 8 repetitions at 25% 1RM for each exercise with a 10 second concentric phase and a 5 second eccentric phase. The traditional training protocol required two sets of 8 repetitions at 65% 1RM for each exercise. Each set was paced to 30 seconds with 60 seconds of rest between sets and both the concentric and eccentric portions of each repetition approximately 1 second in duration. The protocol of this study was similar to our own on the basis that the two conditions used different loads and repetition speeds but were completed in the same amount of time. Unlike our protocol, the total amount of work was exceptionally higher for the traditional training protocol through the use of both a heavier load and faster repetition speed. The results of this previous study showed that the traditional training protocol invoked a much higher heart rate response and expended 48% more energy, however, the extent to which each variable contributed to that additional energy expenditure remains unclear.

Given the parameters of the current study, the results supported the theory that fast contraction rates maximise average heart rate and PAEE. Increasing the load by itself will likely increase the PAEE given that it will require noticeably more effort to perform the same number of repetitions as a lighter load due to an increase in total work. In the case that the increase in loading is proportional to the decrease in the number of repetitions performed, the intensity will in fact be significantly less in terms of the total PAEE as proven by the results of this study where it was the lightest loading that resulted in the greatest PAEE.

In summary, our results parallel the assumptions of previous research about the influence of rate of contraction on PAEE while using a more direct and controlled protocol by incorporating unique conditions with equal work[4,14]. In addition to standardising the amount of work being performed, every condition was performed by each participant in the same amount of time, using the same loads. Despite the work not being individualised through the use of 1RM percentages, the quickest contraction speeds still yielded the highest average heart rate as well as PAEE for each participant. Taken together, the mode for maximising PAEE through the use of high volume explosive repetitions has received further support and confirmation.

Limitations and Future Studies

Despite the relatively straightforward results gathered from this study, there were limitations. For instance, we did not strictly regulate the range of motion. Squat depth was monitored by observation of hip height and knee angle thus the amount of error is sensitive to the perspective of both the participants and the study supervisors. Furthermore, the precision of each participant's ability to follow the metronome's rhythm for each protocol was also susceptible to error.

Additional measures could be incorporated in future studies to generate supplemental findings including the use of an optimal percentage of each individual's 1RM, measurements of oxygen consumption and blood lactate concentrations, and surface muscle activity recordings. Studies that find this optimal percentage or range of percentages of 1RM may yield greater potential for PAEE while oxygen consumption and blood lactate concentration measurements may provide a better understanding of the extent to which both the aerobic and anaerobic energy systems contribute to the total PAEE. Surface muscle recordings could provide a comparison about the global activity of the hip, knee, and ankle extensors during these various conditions.

Conclusions and Practical Applications

Together, the results of this study and previous studies suggest that the top two considerations when designing a weight management RT program may be the total work performed and the rate of contraction for each repetition. Specifically, maximising the total work through the use of a light-to-moderate load with faster repetitions.

This is critical to all healthcare professions including physicians, personal trainers and fitness instructors in an effort to reduce the obesity epidemic. A weight management program utilising this information would likely prescribe an interval based RT program (25-60% 1RM depending on experience level) with concentric and eccentric contractions performed as fast and safely as possible (approximately 1 second). The exercise duration would be based on the capability of the individual and would increase as exercise adaptations occur. Total work performance will be maximised and dictated by prescribing the optimal combination of moderate load and higher repetition frequency.

CONFLICT OF INTEREST

Dr. Jinger S. Gottschall is a co-owner of FITOLOGY, LLC group fitness and cycling studio where the data was collected. Les Mills International was supportive of the current study but did not have access to the original data.

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