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Optimizing high-speed exercise performance : effect of load.

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OPTIMIZING HIGH-SPEED EXERCISE PERFORMANCE: EFFECT OF LOAD

By

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B.M., Sichuan University, 2014
M.S., University of Louisville, 2018

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ABSTRACT

OPTIMIZING HIGH-SPEED EXERCISE PERFORMANCE: EFFECT OF LOAD

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The purpose of this study was to identify an optimal load for the knee extension exercise done with Impulse (Newnan, GA). Forty-one women and twenty-nine men made six laboratory visits, including two familiarization sessions to the knee extension exercise and four real workout sessions which entailed four 30-second exercise sets, separated by 120-second rests, against four different loads (0Kg, 3.41Kg, 5.68Kg, 7.95Kg). A Latin Squares design was used to counterbalance the sequence of the sets. Average force (AF), peak force (PF), total work (TW), Impulse value, and the number of knee extension repetitions were each analyzed with a 2 (gender) x 4 (load) ANOVA, with repeated measures for load. Alpha = 0.05 denoted statistical significance. Tukey test or Tukey-Kramer approach served as post-hoc analysis. Results showed AF, PF, TW, and Impulse value rose with increasing loads. Load 7.95Kg was the optimal load which collectively had the highest AF, PF, TW, and Impulse value.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Resistance training, also known as strength training, is a kind of physical exercise that involves the voluntary activation of specific skeletal muscles against some form of external resistance that is provided by body mass, free weights (barbells and dumbbells), or a variety of exercise modalities (machines, sprints elastic bands, manual resistance, and others) (1). Resistance training has profound effects on the musculoskeletal system and can improve the strength, anaerobic endurance, and size of skeletal muscles. General functional benefits of resistance training include increased bone, muscle, tendon and ligament strength. It also leads to improved joint function, increased bone mineral density (BMD) and bone mineral content (BMC), increased metabolism, increased fitness, improved cardiac function, improved lipoprotein lipid profiles, and reduced potential for injury.

Compared to traditional slow-speed resistance training, high-speed resistance training with low external resistance has demonstrated a positive impact on improved musculoskeletal function (2). A recent meta-analysis revealed various forms of high-speed resistance training were more effective at improving muscle function (i.e., muscle power) than traditional slow-speed resistance training (3). Impulse (Impulse Technologies; Newnan, GA) is a novel device that allows subjects to perform high-speed exercise. Compared with other traditional exercise devices that use gravity to offer resistance, Impulse is a new exercise machine that produces high-speed movements without the effect of gravity and with low resistance. The basic operation of Impulse is very simple. It is equipped with a weight sled that traverses a low-

friction 1.9m track, so repetitions occur at high rates of speed and acceleration. According to Newton's Second Law of Motion, a force applied to an object over a time produces an impulse, or change in momentum. Subjects impart forces on this device to create momentum to the system and then counter the momentum to complete each successive repetition.

Even though it is not currently used as a common exercise machine, studies to evaluate exercise performance have been done using Impulse. The reliability and reproducibility of exercise from Impulse workouts were previously established (4-6) and it is the groundwork for current and future studies. Other studies also examined the metabolic responses (7), the net energy expenditure (8), and the blood lactate concentration (9) of gravity-independent high-speed resistive exercise done with Impulse. Since Impulse does not require gravity to operate and has small mass and power requirements, it is an ideal exercise machine to be used in a low gravity environment and may potentially decrease in-flight bone and strength losses incurred by astronauts. Research showed long-duration stays on the International Space Station (ISS) were accompanied by significant effects on musculoskeletal systems, including in-flight total body BMD losses at rates of 1-3% per month (10-11).

Recently, we examined the musculoskeletal outcomes from chronic high-speed resistance exercise with the Impulse. The results of BMD, BMC, isokinetic and isometric strength, as well as bone resorption all showed positive changes from chronic Impulse training (12). However, the ideal resistance (load) to optimize exercise performance on this device has not been determined, just like what was once the case for the Wingate Anaerobic Testing (WAnT). Higher loads on Impulse should heighten force output, but it does so at the expense of sled speed, which may in turn impede power production. Since Impulse is designed for high-speed exercise, it is

important to assess performance parameters that optimize both speed and power production. The purpose of this project is to examine different loads applied to Impulse to ascertain the impact on exercise performance through evaluating the changes of average force (AF), peak force (PF), total workout (TW), Impulse value, and the number of knee extension repetitions against different loads (0Kg, 3.41Kg, 5.68Kg, and 7.95Kg) added to the sled. AF is the total cumulative forces exerted divided by elapsed time. PF is the highest instantaneous force that a subject exerts on Impulse. TW is the summation of the average force times distance product of each repetition per exercise set. Impulse value in our study is defined as the ratio of the force change of PF, from the lowest force to the highest force, to the time change. In our research, the optimal load is the one which can generate the highest AF, PF, TW, and/or Impulse value collectively.

CHAPTER II

LITERATURE REVIEW

THE OPERATION OF IMPULSE

The basic operation of Impulse is quite simple. The Impulse uses inertial forces created by means of a gravity-independent, passive weight sled traveling on a rail system. The users impart forces that create momentum to the system and then counter the momentum to complete each repetition. The weight sled, mounted on four wheels, glides on a 1.9m track with minimal fractional resistance. Successive repetitions cause a rapid reversal of the weight sled's direction of movement along the track. Acceleration and deceleration of the sled's mass creates the resistive force used for the exercise. According to Newton's Second Law of Motion,

$$f = m*a$$

$$f = \text{force; } m = \text{mass; } a = \text{acceleration}$$

The frictional resistance of the sled with four wheels is so small that the resistance is negligible. The bigger the force and smaller the mass, the greater the acceleration and faster the change in weight sled direction will be. This should lead to faster changes in sled motion, larger AF and PF, and presumably higher rates of acceleration.

IMPULSE IS USED IN REHABILITATION AND ATHLETIC TRAINING

The Impulse was initially used for injury rehabilitation and speed development in athletes. It is an ideal exercise device for high-speed resistance exercise training. It can produce high-speed exercise repetitions with high acceleration as the users exert maximal performance. The application of linear impulse and momentum as a means

for exercise rehabilitation and physical therapy was demonstrated in the use of the Impulse Inertial Exercise System (IIES; Newnan, GA). Before Impulse can be used in the rehabilitation field, it was very important to evaluate the exercise performance of Impulse. Caruso *et al.* (5) examined the data reproducibility through test-retest measures. They recruited college-age subjects to perform repetitive knee- and hip-extension repetitions at their maximal voluntary effort. Results showed Impulse elicited reproducible intra- and inter-workout data despite the unique challenge of multi-planar and multi-joint exercise done over a large range of motion. *Philips et al.* (13) quantified the dynamics of the exercise system and evaluated its efficiency as an exercise and rehabilitative tool. Their study successfully instrumented the Impulse for future relationships to quantify exercise performance using this device. Davison *et al.* (14) examined the benefits of low-friction resistive training done with Impulse in an adolescent baseball player; the results showed significant improvements in maximum inertial rotation force and pitch velocity. The success of Impulse workouts likely resulted from the high rates of acceleration per repetition and a greater over-speed adaptation than that seen from other training modalities.

Physiologic changes to exercise done with Impulse were also demonstrated. Improvements in acceleration usually entail workouts done at intensities that elicit high blood lactate concentrations ([BLa$^-$]). Caruso *et al.* (15) assessed the impact of acceleration on [BLa$^-$]. The results showed the average acceleration values from one-minute sets served as a good predictor of change in [BLa$^-$] (15). In subservient research, Caruso *et al.* (16) examined changes of blood lactate from high-speed exercise done with Impulse over periods of time. They found [BLa$^-$] in competitive athletes rose sharply from zero- to five-minute post-exercise. To examine a workload's impact on gender-based delta [BLa$^-$] differences from supramaximal

exercise done with Impulse, Martin *et al.* (9) recruited subjects (49 women, 31 men) to finish two workouts of a standing unilateral rowing motion performed with left arms (combined shoulder extension/elbow flexion). Two types of repetitions, known as tonic and phasic repetitions, were done during different workout sessions. Their analyses of Total Work/Body Mass (TW/BM) and Total Work/Free Fat Mass (TW/FFM) data each produced significant differences for gender (women > men) and workout (tonic > phasic). Post-hoc analysis showed significant delta [BLa⁻] differences: men-phasic ≅ women phasic > women-tonic, > men-tonic. Their results indicated that delta [BLa⁻] and total work results each yielded predictable inter-gender differences, which supported the idea that the volume of total work performed exacerbates inherent metabolic differences among men and women that produces gender-based delta [BLa⁻] differences.

THE POTENTIAL FOR IMPULSE TO BE USED IN A LOWER GRAVITY ENVIRONMENT

Living on the earth has made humans physiologically and biomechanically adapted to the gravity and atmospheric environments. Leaving the earth for long-duration missions (4-6 months) aboard the International Space Station (ISS) results in the degradation of the musculoskeletal system. A study by Hawkey (10) regarding the physiological and biomechanical considerations for a human Mars mission showed astronauts lost their bone and experienced muscle atrophy at rates of 1-3% and 5% per month, respectively. Another study finished by Sibonga *et al.* (17) studying 45 individual crew astronauts revealed the averaged losses of bone mineral after long-duration spaceflight ranged between 2% and 9% across all sites, which include the calcaneus (2.9%), the lumbar spine (4.9%), the femoral neck (6.5%), the trochanter (7.8%), and the pelvis (7.7%). Thus it is important to find an effective way to help

these astronauts maintain BMD in space. Exercise training is such an effective way to increase and maintain the BMD in humans. During exercise, as muscles accelerate and decelerate body segments to oppose the pull of gravity, bones adapt in accordance to the forces exerted. The network of osteocytes within the bone sense strains and initiate the conversion of mechanotransduction stimuli into the commensurate bone remodeling response (18-19). The Impulse is an ideal exercise machine to physically stress astronauts in space. As the study we finished recently (12) showed the chronic high-speed and high-Impulse resistance exercise done with Impulse could significantly improve the calcaneal bone mineral content by 29% and density by 33%. Elevated metabolism is common to spaceflight, while in-flight exercise in microgravity may exacerbate energy costs. To minimize energy costs of exercise done in space, research regarding the energy expenditure of exercise done with Impulse needs to be examined. Davison *et al.* (7) found that circuit weight training on Impulse elicited high energy costs and a relatively higher degree of post-exercise lipolysis in women. Caruso *et al.* (8) also tested the net energy expenditure of gravity-independent high-speed resistive exercise performed on Impulse. Twenty-eight women subdivided into athletic and sedentary groups performed two workouts, either tonic or phasic repetitions. Results showed no significant intergroup or workout differences, but work volume analysis yielded a significant effect (tonic > phasic).

To investigate the potential use of Impulse in a low gravity environment, we continued to examine the musculoskeletal outcomes in chronic high-speed resistance exercise. The results showed that PF, peak acceleration (the ratio of peak force to sled weight), and Impulse value significantly increased over time. There were significant pre-post increases to left calcaneal BMC (+29%) and BMD (+33%). For the future studies to explore the ability of Impulse for use in low-gravity environments, it is very

important to ask which load (resistance) would optimize exercise performance by producing higher AF, PF, TW, and Impulse value. Our research is going to determine the optimal load to maximize exercise performance on Impulse. The hypothesis of our study is that the load 0Kg should be the optimal load, which could lead to faster changes in sled motion, larger PF and AF, and presumably higher rates of acceleration.

CHAPTER III

METHODS

INSTRUMENTATION OF IMPULSE

The operation of Impulse shown in Figure 1 & 2 demonstrates its simple

design. Subjects exert force on this device to impart momentum to the system and

then counter the momentum to complete each repetition. With proper timing,

successive repetitions cause a rapid reversal of the weight sled's direction of

movement along the track. A nylon cord connects an exercise attachment handle to

the sled. Pulleys above and below the sled permit multiple exercises to be performed

at a variety of angles. Barbell plates may be added to the sled to increase resistance.
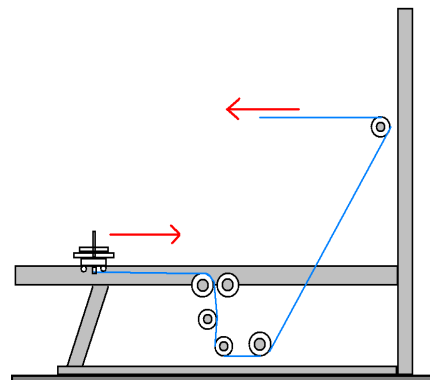
| Figure 1. Impulse | Figure 2. Schematic illustration of Impulse |

The right and left halves of Impulse are each equipped with a TLL-2K load cell

(Transducer Techniques; Temecula, CA) attached to one of the pulleys and an

infrared position sensor located midway on the underside of each 1.9m track (5). As

the sled moves along its track, the load cell and position sensor record force output

and displacement. Through integration of the sensor's time response, researchers can

quantify average acceleration and force output. The load cell and position sensor data

are sent to DI-158U signal conditioners (DATAQ Instruments; Akron, OH) and

measured by a four-channel analog data acquisition card (DAQ) at 4000Hz. Force and

work output are calculated and analyzed with Microsoft Excel. A macro is written to

perform the numeric integration of force data. Figures 3 & 4 show the load cell and

infrared position sensor of Impulse.
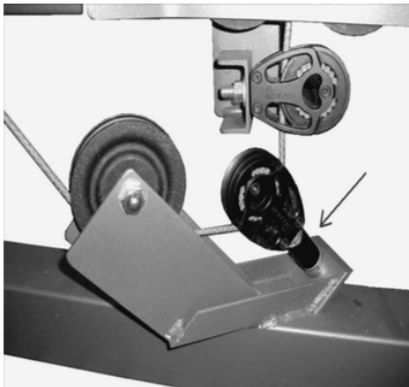
Figure 3. TLL-2K Load Cell   Figure 4. Infrared Position Sensor
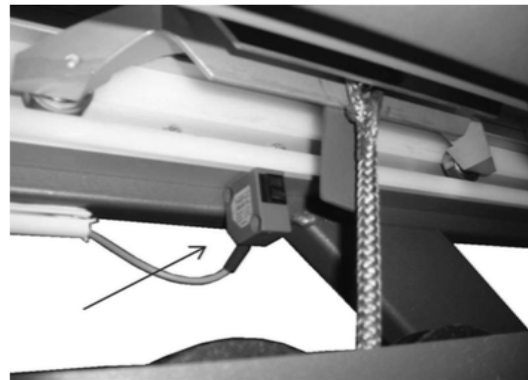
Figure 5 illustrates the block diagram overview of Impulse instrumentation:
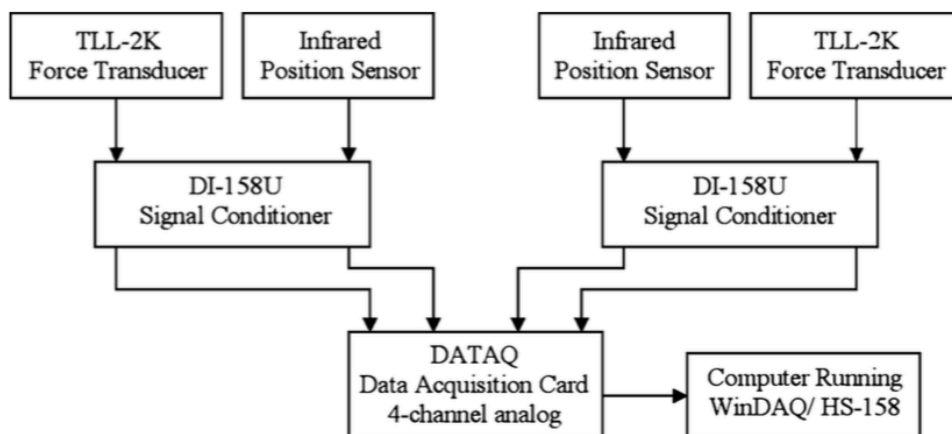
Figure 5. The block diagram overview of Impulse instrumentation

SUBJECTS

Before admittance, the Institutional Review Board (IRB) of University of

Louisville approved all procedures. All subjects filled out a self-administered medical

questionnaire to address their current health problems. All subjects were required to

be in good health and capable of performing the current study exercise protocol. They

should be free of the following conditions: diabetes, exercise-induced asthma, hypertension, tachycardia, ischemic heart disease, hyperthyroidism, musculoskeletal ailments and convulsive disorders. In addition, females of child-bearing age who wished to participate had to take and pass a home pregnancy test (if necessary) to prove their suitability to perform the proposed project's exercise protocol.

STUDY PROCEDURES

Each subject made six visits to our laboratory spaced three to five days apart. Once the informed consent and medical questionnaire is obtained from the subjects, the first two visits will entail the collection of their anthropometric data, as well as familiarization to exercise done on the Impulse. Anthropometry includes the measurement of the subject's body mass and body composition via bioelectrical impedance analysis (BIA; RJL Systems, MI). BIA is an easy, non-invasive, relatively inexpensive way to determine the fat-free mass (FFM) and total body water (TBW) in subjects without significant fluid and electrolyte abnormalities, when using appropriate populations, age equations and established procedures (20-21). Before all subjects come in for the first lab visit, they will be reminded to stay hydrated to decrease the inaccuracy of BIA. Familiarization will entail performing practice knee extension repetitions on Impulse. Before subjects start knee extension, a cuff is worn around the distal shank to connect the subject to the sled. As the knee extends ~10-15°, the sled will travel rapidly with an acceleration to the end of the track (Figures 6 & 7). As the sled travels, the knee flexes back to the initial joint angle. Before the sled reaches the end of the track the next repetition occurs. During the first two familiarization sessions, the subjects will perform the knee extension at a submaximal level of effort, which doesn't require subjects to produce highest speed and knee extension repetitions until they become accustomed to the movement and the exercise

11

device. The first two visits are anticipated to last 20-30 minutes; after the second visit,

subjects should be well versed in the current study exercise. In the unlikely event they

still cannot perform the exercise correctly, subjects will be asked to perform an

additional familiarization session.

Figure 6 & 7: Demonstration of Knee Extension Exercise

Each of the final four visits will begin with subjects performing a five-minute

warm-up on a stationary cycle ergometer (Ergotest; Stockholm, Sweden) against one

kilopound of resistance as they pedal at a self-selected pace. For their final four visits

subjects will perform four 30-second knee extension sets separated by 120-second rest

periods on Impulse against different loads (0Kg, 3.41Kg, 5.68Kg, and 7.95Kg) added

to its weight sled (1 Kg). They will perform exercise against only one load per set. All

sessions will last about 15-20 minutes. The sequence of the four loads will be

counterbalanced over the four workouts to utilize a Latin Squares design, which is

often used in experiments as a balanced two-way classification scheme (22). Knee

extension sets will be done exclusively with subjects' left legs as they stand upright.

Subjects will hold onto a pair of stationary bicycle handles for support/stabilization as

they perform each set. They will be instructed to exert maximal effort and also receive

vocal encouragement during each set. Analysis of our data will compare exercise performance parameter results obtained with the four different loads (0Kg, 3.41Kg, 5.68Kg, and 7.95Kg) to determine the optimal resistance for exercise done on Impulse.

MEASUREMENTS

During their first visit to the lab, we will measure subjects' anthropometric data, which include body weight (Kg), height (cm), body composition (%), free fat mass (Kg), total left leg length (cm), upper left leg length (cm), and lower left leg length (cm). Body composition (%) and free fat mass (Kg) will be measured via bioelectrical impedance analysis (BIA; RJL System, MI). For the third through sixth lab visits, we will measure the average force (AF, in Newtons), peak force (PF, in Newtons), total work (TW, in Joules), Impulse value (Newtons/seconds), and the number of repetitions of knee extension of all four sets of each load (0Kg, 3.41Kg, 5.68Kg, and 7.95Kg). The values of AF, PF, and TW for each load will be read directly by the software (DATAQ Instruments; Akron, OH). The number of repetitions of knee extension will be counted manually. To calculate the Impulse value, we will apply the following formula:

$$\text{Impulse value} = \Delta F / \Delta T$$

The Impulse value will be calculated from the repetition that yields the highest PF per set. ΔF denotes the change in force for that repetition, while ΔT represents the length of time required to go from the lowest to highest force values for that repetition.

DATA ANALYSIS

We will employ a 2 (gender) x 4 (load) ANOVA to each of the dependent variables (AF, PF, TW, Impulse value, and the number of knee extension repetitions) pertinent to speed and power production. Prior to that analysis we will examine our data set for adherence to ANOVA assumptions (normality, independence, and

homogeneity of variance) and assess our data for outliers with Z-scores. We will also

use the Tukey post-hoc test when significant inter-load differences are said to exist. In

case our data collections yield different numbers of male and female participants, we

will use the Tukey-Kramer test as a post-hoc when significant inter-gender

differences are said to exist.

CHAPTER IV

RESULTS

Seventy-three subjects (41women and 32 men) signed our project's IRB-approved consent form and medical questionnaire to participate. Two male subjects dropped out due to injuries obtained during other sports activities and one male subject dropped out voluntarily for personal reasons. Seventy subjects (41 women and 29 men) finished our research project and were included in the data analysis. All subjects were college students or athletes in good physical condition. Table 1 shows the anthropometric information (mean $\pm$ sem) for both female and male subjects. Subjects were moderately fit (body fat percentages: 29.6 ± 1.1 for women and 17.1 ± 1.2 for men; body mass: 69.1 ± 2.1Kg for women and 82.7 ± 3.0Kg for men). All assumptions (normality, independence, and equal variances) for 2 (gender)* 4 (load) ANOVAs with repeated measures for load were met and Z-scores identified no outliers.

Table 1. Anthropometric Measurements of Female and Male Subjects

	Height (cm)	Total LL (cm)	ULL (cm)	LLL (cm)	Weight (Kg)	BF (%)	FFM (Kg)
Female (41)	164.5 $\pm$ 1.7	87.1 $\pm$ 0.9	44.4 $\pm$ 0.7	39.0 $\pm$ 0.5	69.1 $\pm$ 2.1	29.6 $\pm$ 1.1	47.8 $\pm$ 1.1
Male (29)	178.7 $\pm$ 1.2	90.0 $\pm$ 0.8	45.0 $\pm$ 0.7	42.2 $\pm$ 0.6	82.7 $\pm$ 3.0	17.1 $\pm$ 1.2	67.7 $\pm$ 1.6

Table 2. Average Force of Female and Male Subjects

	0Kg (N)	3.41Kg (N)	5.68Kg (N)	7.95Kg (N)
Female (41)	36.5 $\pm$ 1.4	66.9 $\pm$ 2.6	80.3 $\pm$ 3.3	89.7 $\pm$ 3.4
Male (29)	42.3 $\pm$ 2.0	76.5 $\pm$ 3.7	91.3 $\pm$ 4.1	103.7 $\pm$ 4.8

N, Newton.

We collected and analyzed average force (AF, in Newton's), peak force (PF, in Newton's), total work (TW, in Joules), Impulse value (in Newton/Second, N/s), and the number of knee extension repetitions for both female and male subjects (Table 2-6). The mean AF values (Table 2) of female subjects for different loads (0Kg, 3.41Kg, 5.68Kg, and 7.95Kg) were 36.5N, 66.9N, 80.3N, and 89.7N while the mean AF values for male subjects were 42.3N, 76.5N, 91.3N, and 103.7N. The two-way interaction of gender and loads showed male subjects had higher average force than female subjects for each load (P=0.022). Post-hoc analysis, Tukey-Kramer approach, showed inter-gender differences at each load with male subjects' values for each load significantly higher than those for female subjects.

Table 3. Peak Force of Female and Male Subjects

	0Kg (N)	3.41Kg (N)	5.68Kg (N)	7.95Kg (N)
Female (41)	375.2 $\pm$ 19.0	659.8 $\pm$ 33.6	763.2 $\pm$ 38.4	814.8 $\pm$ 40.2
Male (29)	481.1 $\pm$ 28.6	855.9 $\pm$ 54.2	1006.1 $\pm$ 58.7	1062.4 $\pm$ 60.4

N, Newton.

Table 3 shows the PF (peak force) data of our female and male subjects. There was a two-way interaction for PF (P<0.0001) of gender that higher load had higher PF. The post-hoc analysis, Tukey-Kramer approach, showed men had significantly higher PF values for each of the four loads examined.

Table 4. Total Work for 30-second session of Female and Male Subjects

	0Kg (J)	3.41Kg (J)	5.68Kg (J)	7.95Kg (J)
Female (41)	34906.1 $\pm$ 3411.1	62830.5 $\pm$ 5705.9	74869.2 $\pm$ 6281.9	83369.5 $\pm$ 6626.8
Male (29)	36168.8 $\pm$ 2879.9	63793.2 $\pm$ 4031.0	75871.0 $\pm$ 4710.4	87248.7 $\pm$ 5506.9

J, Joule.

Table 4 shows our TW (total work) data participated by gender and load. Our TW ANOVA showed that there wasn't a significant difference by gender (P=0.807). However, there was a significant difference between loads (P<0.0001), as higher loads, the higher the TW (7.95Kg > 5.68Kg > 3.41Kg > 0Kg). There was not a two-way interaction for TW (p=0.753).

Table 5. Impulse Value of Female and Male Subjects

	0Kg (N/s)	3.41Kg (N/s)	5.68Kg (N/s)	7.95Kg (N/s)
Female (41)	8954.0 $\pm$ 538.3	13554.7 $\pm$ 787.2	15022.6 $\pm$ 851.1	15522.4 $\pm$ 837.3
Male (29)	10965.8 $\pm$ 691.8	17815.0 $\pm$ 1366.7	19300.4 $\pm$ 1200.6	19803.8 $\pm$ 1223.1

N/s, Newton/second.

Table 5 shows Impulse values displayed by gender and load. There was a two-way interaction for this dependent variable (P=0.042). The post-hoc analysis, Tukey-Kramer approach, showed that the higher the load, the higher the Impulse value, and that each load yielded significant inter-gender differences.

Table 6. Number of Knee Extension Repetitions of Female and Male Subjects

	0Kg	3.41Kg	5.68Kg	7.95Kg
Female (41)	66.7 $\pm$ 2.3	57.6 $\pm$ 1.9	53.1 $\pm$ 1.7	49.9 $\pm$ 1.5
Male (29)	71.0 $\pm$ 2.3	60.3 $\pm$ 1.8	55.9 $\pm$ 1.6	52.4 $\pm$ 1.5

Table 6 shows the number of knee extension repetitions for both female and male subjects. The two-way ANOVA showed there wasn't a significant difference between gender (P=0.243). However, there was a significant difference between loads (P<0.0001) whereby higher loads had fewer repetitions. The post-hoc analysis, Tukey test, for loads indicated that load 0Kg had higher number of repetitions than 3.41Kg, 5.68Kg, and 7.95Kg. There was not an interaction for this dependent variable (P=0.389).

CHAPTER V

DISCUSSION

The purpose of this study was to determine the optimal resistance (load) for

the knee extension exercise done on Impulse. The results of both male and female

subjects showed peak force (PF), average force (AF), total work (TW), and Impulse

value all increased with greater loads. The highest AF, PF, TW, and Impulse value

were generated with the highest load, which was 7.95Kg. Our post-hoc analyses also

showed the 7.95Kg load had higher values (AF, PF, TW, and Impulse value) than a

load of 5.68Kg, which in turn produced higher than a load of 3.41Kg, which in turn

was greater than 0Kg (7.95Kg>5.68Kg>3.41Kg>0Kg). In our study, 7.95Kg is the

optimal load to maximize exercise performance, which rejected our hypothesis that

0Kg was the optimal load that could generate the highest average and peak forces, and

highest rate of acceleration. Our hypothesis was based partly on the view of Newton's

second law of motion that with higher force and lower mass, there will be a higher

acceleration which would lead to higher AF, PF, TW, and Impulse value. This was

also the viewpoint of the inventor of the Impulse who is a mechanical engineer.

However, from an exercise physiology point of view, our body recruits more muscle

fibers and generates a higher force when a higher load is applied leading to higher AF,

PF, TW, and Impulse value. There were no plateaus for AF, PF, TW, and Impulse

values, which means that higher loads than 7.95Kg may produce even higher AF, PF,

TW, and Impulse values. For future studies, higher loads may be warranted for

investigation. Loads higher than 7.95Kg may produce higher exercise performance

with higher values of AF, PF, TW, and Impulse Value. They may also lead to a U-

shape influence, with decreasing exercise performance secondary to increasing loads. Even though 7.95Kg may not be the "optimal load" if there are higher loads that can elicit better exercise performance, it is still a sufficient load to improve exercise performance. According to the study conducted by Caruso *et al.* (12), during which load 3.41Kg was the only load that used for every subjects for every exercise session, 3.41Kg had a positive influence on BMD and BMC. The number of knee extension repetitions decreased significantly as the loads increased. At the 3.41Kg load, both female and male subjects completed about 2 reps per second, which is similar to the study that Caruso *et al.* (12) published. As subjects became accustomed to the Impulse, they may increase their repetition rate. What is interesting is there was no significant difference for TW between male and female subjects, even though men had significantly higher AF, PF, Impulse value, and number of repetition values than their female counterparts. Differences between genders may be a function of the number of subjects (29 men and 41 women) who participated in our project, as larger samples may allow smaller effect sizes to elicit statistical significance. This study is an extension of research by Caruso *et al.* (12) which examined the musculoskeletal outcomes from chronic high-speed, high Impulse resistance exercise. During the aforementioned research project, subjects (n=13) finished 30 training sessions each entailing three 60-second sets of the standing knee extension, standing hip extension, and seated calf press exercises with their left legs (12). For the standing knee extension exercise, both our research and the aforementioned research project examined the same movement, except that subjects in our project did 30-second sets. The results of the prior research project showed there were significant improvements to the calcaneal bone mineral content (+29%) and density (+33%), as well as a suppression of bone resorption (12). To study the influence of different loads and

determine the optimal load to maximize exercise performance done with Impulse, we conducted the current study. Our results showed higher loads produced generally better exercise performance measures. For the future research, the influence of each load (0Kg, 3.41Kg, 5.68Kg, and 7.95Kg) and other higher loads for bone mineral density (BMD) and bone mineral content (BMC) could be done to determine which load optimizes exercise performance that lead to increases in BMD and BMC at the same time.

There are various studies done to determine optimal loads for different exercise modalities, including WAnT for bicycle ergometer, modified WAnT for rowing ergometer, and free weights. Determinations of an optimal load/resistance to elicit the highest possible power output is very important for an exercise device to be used to train athletes. For example, a Monark cycle ergometer is used for WAnT, in which subjects pedaled against a resistance equal to 0.075 kp $\cdot$ kg^{-1} body mass (23). Later, Evans and Quinney (24) studied male physical education students and varsity athletes using a modified Monark ergometer, which showed the optimal resistance to yield the highest mean power was 0.098 kp $\cdot$ kg^{-1} of body mass. Research conducted by Dotan and Bar-Or (25) sought to define the optimal loads for eliciting maximal power-outputs in the leg and arm modes of the 30s WAnT. They used a Fleisch cycle ergometer to test 18 female and 17 male physical education students and found an inverted-U relationship between load and mean power, meaning the optimal resistance provided the best force-velocity combination as they pedaled. The optimal loads to yield highest mean power were 52.3 and 51.4 g $\cdot$ kg^{-1} on the Fleisch ergometer, or 0.0872 and 0.0857 kp $\cdot$ kg^{-1} on the Monark ergometer for the leg and 28.8 and 36.9 g $\cdot$ kg^{-1} on the Fleisch ergometer, or 0.0480 and 0.0615 kp $\cdot$ kg^{-1} on the Monark ergometer for the arm tests done by women and men, respectively (25). However, the

peak power increased as the resistance increased and did not appear to plateau, which

suggested that peak power probably occurred at a higher load. Research done by

Patton, Murphy, and Frederick (26) using 19 healthy military male subjects who were

tested with a Monark cycle ergometer, showed the mean resistance settings that

elicited the highest peak power and mean power outputs were 0.096 and 0.094 kp·kg^{-1}

of body weight. Research done by Heiser (27) showed similar results as those of

Dotan and Bar-Or (25). Heiser studied 8endurance athletes, 4 power athletes, and 10

untrained men on a Monark cycle ergometer, applying resistance settings ranging

from 0.075 to 0.105 kp·kg^{-1}. For all three groups, both mean and peak power rose

with greater resistance. However, the rise in mean power from 1.1 to 1.3 Watt·kg^{-1}

was not significant. The significant rise in peak power with increasing resistance

suggested the optimal force was greater than 0.105 kp·kg^{-1} (27). Three studies (25-27)

showed, the optimal load for peak power was higher than that needed to maximize

mean power. As Inbar *et al.* (28) concluded, the load needed to yield the highest mean

power is 20% to 30% higher than originally suggested and seems to depend on the

training level of the subjects, being highest among athletes, especially those who

engaged in exercises that require high power. The general guidelines with the Monark

ergometer recommend a force of 0.090 kp·kg^{-1} be used with adult non-athletes and

0.100 kp·kg^{-1} with adult athletes (28). Research conducted by Pazin *et al.* (29)

examined the influence of the effect of training history on optimum loading for

maximizing muscle power output. Forty healthy young males with different levels of

strength and power (strength- and speed-trained athletes, physically active, and

sedentary non-athletes) were tested during a 6-second maximal cycling sprint test (29).

Their results showed strength-trained and sedentary participants, respectively, had the

highest and lowest forces and power outputs (p < 0.001) (29).

To determine the optimal loading for rowing ergometers, a modified WAnT protocol was used by Koutedakis *et al.* (30) to measure the performance in junior rowers. They applied 8% of subjects' body mass which was suggested by their pilot study as the most appropriate resistance. Eight elite junior oarsmen and sixteen club level rowers were tested for upper body strength and for mean, peak and minimum power outputs. Results indicated that mean power and power difference expressed in absolute values (Watts) could classify junior oarsman into appropriate groups. Research done by Mandic *et al.* (31) also used a modified WAnT to determine the optimal resistance to elicit the highest peak 5s and 30s power output (PO) during a 30s test on a rowing ergometer. During their research, a relative load factor (RLF) was used to determine the amount of resistance to be applied based on body mass (BM), and their subjects were grouped by light-weight (LW) and heavy-weight (HW). Their results showed the highest peak 5s PO were elicited by 0.109 and 0.102 kg $\cdot$ kg^{-1} BM for LW and HW male rowers and 0.111 and 0.076 kg $\cdot$ kg^{-1} BM for LW and HW female rowers, respectively. While the RLF settings to optimize the highest mean 30s PO were 0.102 and 0.095 kg $\cdot$ kg^{-1} BM for LW and HW male rowers and 0.103 and 0.068 kg $\cdot$ kg^{-1} BM for LW and HW female rowers, respectively. A similar study conducted by Forbes *et al.* (32) determined the optimal load for arm crank anaerobic testing in men and women. They also examined the highest peak 5s and mean 30s PO by gender and training backgrounds (athletic and recreationally active men; athletic and recreationally active women). Their results showed 0.075 and 0.070 kg $\cdot$ kg^{-1} BM were the optimal loads to elicit the highest peak 5s PO in trained and active men and 0.065 and 0.060 kg $\cdot$ kg^{-1} BM for trained and active women. Lower RLF of 0.060, 0.065, and 0.070 kg $\cdot$ kg^{-1} BM elicited higher mean 30s PO than higher RLF (0.080, 0.085, and 0.090 kg $\cdot$ kg^{-1} BM) for trained males. A 0.080 kg $\cdot$ kg^{-1} BM RLF was

lower than other RLF for active men. Mean 30s PO was greatest at RLF of 0.050 kg ·

kg^{-1} BM for both trained and active females. Their results showed the optimal RLF

was different for eliciting peak 5s and mean 30s PO during an arm crank WAnT and

dependant on gender and training status. These rowing ergometer studies showed

body mass (LW and HW), relative load factor (RLF), and training status had

significant effects on power output.

In addition to the studies discussed previously, there has been research done to

determine the optimal load for resistance training with free weights. Three most

common resistance training exercises with free weights include the jump squat (JS),

squat (S), and power clean (PC). To determine the optimal load that maximizes power

output in each lift, the percentage of subjects' one repetition maximum (1RM) was

used. Results showed the load that maximized power output in JS ranged from 0% to

60% of 1RM (33-34), 50-70% of 1RM for the S (35), and 70-80% of 1RM for the PC

(36). Cormie *et al.* (37) studied twelve male athletes who participated in four testing

sessions of 1RM, JS, S, and PC tests. Their results indicated the optimal load for

power output for JS, S, and PC occurred at various percentages of 1RM: the optimal

load for JS was 0% of 1RM and 80% of 1RM for PC; Peak power in the S was

maximized at 56% of 1RM. Li (38) specified the optimal load for peak power

production during JS should be lighter (< 30% of 1RM), moderate for S (from 30% to

70% of 1RM), and heavier for PC (> 70% of 1RM).

Differences among studies that may help explain discrepancies in optimal

loads for WAnT, rowing ergometer, the resistance training with free weights (JS, S,

and PC) and our own study include 1): body mass and relative load factor (RLF) were

used in WAnT and rowing ergometer, and the percentage of 1RM was used for free

weights, while we applied the same loads for all subjects, and 2): training status was

considered in WAnT and rowing ergometer, whereas our study did not. As Pazin *et al.* (28) pointed out, selecting the optimal load based on total body mass is reasonable for practical purposes. However, fat-free mass or muscle mass may be better alternatives. For future studies done with Impulse, body mass and RLF should also be studied. On the other hand, training status should be considered as well. In our research, we had subjects with various training backgrounds. Some subjects who were athletic and recreationally active could generate higher AF, PF, TW, and Impulse value than relative sedentary subjects. Also, for subjects who were trained as athletes, their sports may influence their learning and it took less time to master the current study exercise. To determine how training background influences the exercise performance done with Impulse, more future studies need to be conducted.

Impulse is a potential device to be used for recreational training, athletic training, and lower gravity environments. 7.95Kg was the optimal load to elicit the best exercise performances for our research. Further studies needed to define the effect of different loads on bone mineral density (BMD) and bone mineral content (BMC) for Impulse to be used in the lower-gravity environment to maintain bone health. The relative load factor and training backgrounds should be determined as for Impulse to be used by different people.

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CURRICULUM VITA

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Education
    Sichuan University
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Allergy and Immunology Research Assistant (08/2015-07/2016)
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- Performed Western blot, PCR and other molecular assays to help develop new vaccines
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Neuroscience Research Assistant (08/2011-07/2012)
Sichuan University, Department of Neuroscience
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Work Experience

Cardiac Rehabilitation Internship, Healthy Lifestyle Center, Jewish Hospital, Kentucky One Health, Louisville KY (04/2017-08/2017)

- Ran the exercise class: aerobic, resistance training, and stretching classes
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Chinese Tutor, Learning Resource Center University of Louisville (02/2017-current)
- Certified Tutor (Level one), International Tutor Training Program Certification
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Sales Representative, Randox Laboratories Ltd. (06/2014-07/2015)
- Helped promote sales of medical diagnostic equipment for hospitals in Shanghai
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Clinical Rotations in West China Hospital of Sichuan University (07/2012-12/2012)
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Publications

- **Bai L**, Selimovic EA, Mueller RE, Beatty SR, Carter KA, Symons TB, Pantalos G, Caruso JF. Optimal load during high-speed high-impact exercise. British Journal of Sports Medicine. (In Preparation).

- Salas J., **Bai L.**, Vargas L.J. Schultze S.M., Garland M.R., McEnroe C.B., Caruso J.F. (2018). Performance-based correlates to vertical jump height and power values in women. Isokinetics and Exercise Science. (In Preparation).

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Abstracts/Presentations

- **Bai L**., Selimovic E., Mueller R., Beatty S., Carter K.A., Symons T.B., Pantalos G., Caruso J.F. Optimal load during high-speed high-impact exercise. Annual Conference of the American College of Sports Medicine. Minneapolis, Minnesota. June 2nd, 2018. (Accepted for Presentation, presenter)

- Vargas L.J., Daunis M.K., Bayers T., **Bai L.**, Symons T.B., Caruso J.F. Comparative responses to squats done with free weights and an exoskeleton. Annual Conference of the American College of Sports Medicine. Minneapolis, Minnesota. May 31st 2018. (Accepted for Presentation).

- RE Mueller, **L Bai**, LJ Vargas, IT O'Brien, CB McEnroe, MR Garland, SM Schultze, SR Beatty, JF Caruso. Intermittent Palm Cooling's Impact on Resistive Exercise Performance. Spring Research Conference. Louisville Kentucky, March 24th, 2018.

- **L Bai**, EA Selimovic, RE Mueller, SR Beatty, KA Carter, TB Symons, G Pantalos, JF Caruso. Optimal Loads for High-Speed Resistive Exercise. Spring Research Conference. Louisville Kentucky, March 24th, 2018. (Presenter)

- **L Bai**, EA Selimovic, R Mueller, S Beatty, KA Carter, TB Symons, G Pantalos, JF Caruso. Optimal Load for High-speed Exercise. Southeast Chapter of the American College of Sports Medicine. Chattanooga, Tennessee. February 17th, 2018. (Presenter)

- Vargas L.J., Daunis M.K., Bayers T., **Bai L.**, Symons T.B., Caruso J.F. Comparative responses to squats done with free weights and an exoskeleton. Southeast Chapter of the American College of Sports Medicine. Chattanooga, Tennessee. February 17th, 2018.

- Parmar PJ, Caruso J.F., Voor M.J., Jaggers J.R., **Bai L.**, Selimovic E.A. Musculoskeletal outcomes from chronic high-speed high-impact resistance exercise. 68th International Astronautical Conference. Adelaide Australia. September 25th-29th, 2017.

- **Bai L.**, Caruso J.F., Voor M.J., Jaggers J.R., Selimovic E.A. Musculoskeletal outcomes from chronic high-speed high-impact resistance exercise. Kentucky Chapter of the National Strength and Conditioning Association. Georgetown, Kentucky. April 22nd, 2017. (Presenter)

- Muntis F., Symons T.B., **Bai L.**, Selimovic E., West J.O., Bouchet A., Dawson S., White E., and Caruso J.F. The addition of electrolytes to a carbohydrate-based sport drink: effect on aerobic exercise performance. Kentucky Chapter of the National Strength and Conditioning Association. Georgetown, Kentucky. April 22nd, 2017.

- Dawson S., **Bai L.**, Selimovic E., Muntis F., Symons T.B., White E., and Caruso J.F. Optimal load during high-speed high-impact exercise. Kentucky Chapter of the National Strength and Conditioning Association. Georgetown, Kentucky. April 22nd, 2017.

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