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Effects of an acute session of high- vs low-load resistance training exercise on energy balance

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Abstract

This study examined the effect of an acute session of low-load high-volume resistance training versus a more traditional high-load low-volume session on energy balance (EB). Five recreationally active males (age: 24±3 y; BMI: 25.8±1.5 kg·m^{-2}) completed three different sessions: 1) high-load (90% 1RM); 2) low-load (30% 1RM); and 3) CTRL (no exercise). Gas exchange ($\dot{V}O_2$), blood lactate, and subjective appetite perceptions were measured before each session, as well as at 0, 1, and 2 h post-exercise. Delayed onset muscle soreness (DOMS) in the quadriceps, pectorals, hamstrings, deltoids, and latissimus dorsi was measured at 24 and 48 h post-exercise. $\dot{V}O_2$ was increased following the 30% 1RM (Δ0.110 L·min^{-1}, p<0.001, d = 1.41) and 90% 1RM (Δ0.08 L·min^{-1}, p=0.002, d = 1.22) sessions compared to CTRL at 0 h post-exercise. Post-exercise energy expenditure (EE) was trending (p=0.088, $\eta_p^2 = 0.474$) to be greater following the 30% 1 RM session compared to CTRL (Δ41 kcal, p=0.091, d = 1.30). The 30% 1RM session accumulated more plasma lactate at 0 and 1 h post-exercise than both 90% 1RM (Δ5.7 mmol·L^{-1}, p<0.001, d = 2.65; Δ1.1 mmol·L^{-1}, p=0.010, d = 2.10) and CTRL (Δ13.0 mmol·L^{-1}, p<0.001, d = 7.38; Δ1.8 mmol·L^{-1}, p=0.001, d = 2.44) sessions. The 30% 1RM session subsequently resulted in lower appetite at both 0 (Δ26 mm, p=0.003, d = -0.62) and 1 h (Δ24 mm, p=0.005, d = -0.60) post-exercise compared to the 90% 1RM session, and was lower than CTRL at 0 (Δ42 mm, p<0.001, d = -1.29), 1 (Δ35 mm, p=0.001, d = -0.93), and 2 h (Δ21 mm, p=0.017, d = -1.13) post-exercise. These results demonstrate a low-load high-volume resistance training session elevates post-exercise $\dot{V}O_2$/EE, blood lactate, and decreases subjective appetite compared to high-load low-volume suggesting more positive benefits to energy balance. However, due to the COVID-19 pandemic all results remain preliminary.

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List of Abbreviations

ADP: Adenosine diphosphate
AEBSF: 4-(2-aminoethyl) benzenesulfonyl fluoride hydrochloride
ATP: Adenosine triphosphate
BMI: Body mass index
CSEP: Canadian Society for Exercise Physiology
DOMS: Delayed onset muscle soreness
DPP-IV: Dipeptidyl peptidase-4
EB: Energy balance
EDTA: Ethylenediaminetetraacetic acid
EE: Energy expenditure
EI: Energy intake
ELISA: Enzyme-linked immunosorbent assays
EPOC: Excess post-exercise oxygen consumption
GAQ: Get-Active Questionnaire
GHSR-1a: Growth Hormone Secretagogue Receptor
GLP-1: Glucagon-like peptide-1
GPR81: G-protein coupled receptor 81
MICT: Moderate-intensity continuous training
MPB: Muscle protein breakdown
MPS: Muscle protein synthesis
MVPA: Moderate to vigorous physical activity
PA: Physical activity
PASB-Q: Physical Activity and Sedentary Behaviour Questionnaire
PYY: Peptide tyrosine tyrosine
RT: Resistance training
$\dot{V}CO_2$: Carbon dioxide production
$\dot{V}O_2$: Oxygen consumption
1RM: 1-repetition maximum
4EBP1: 4E-binding protein-1
p70S6K1: 70-kDa S6 kinase 1

CHAPTER 1

Literature Review

Introduction

Recently, the Canadian Society for Exercise Physiology (CSEP) released the Canadian physical activity guidelines recommending that adults between the ages of 18-64 perform at least 150 minutes of moderate to vigorous physical activity (MVPA) per week in bouts of 10 minutes or more (Tremblay et al. 2011). Within these guidelines, moderate physical activity (PA) is defined as any activity causing an individual to break a light sweat and increase their breathing rate, such as brisk walking or biking, while vigorous PA is that which is more likely to result in loss of breath, such as jogging or cross-country skiing (CSEP 2011). These recommendations are the result of a number of studies demonstrating the beneficial effects regular PA has on a wide variety of health risks across all ages, genders, and ethnicities (Janssen 2007; Ginis et al. 2007; Paterson et al. 2007; Timmins et al. 2007). Despite the benefits of regular PA, only 15% of the Canadian population is meeting these recommendations (Colley et al. 2011). These extremely low levels of PA adherence are negatively correlated with body weight resulting in significant increases in both childhood and adult obesity in Canada over the past few decades (Masters et al. 2013; Sturm 2003). Since the 1980's, the incidence of both obesity (BMI 35-40) and morbid obesity (BMI > 40) has increased more so than cases of merely overweight (BMI 25-30) or mildly obese (BMI 30-35) (Sturm 2003).

When prescribing exercise for weight loss, MVPA mentioned in Canada's PA guidelines tends to refer to participation in some form of moderate-intensity continuous training (MICT) (Tremblay et al. 2011). This MICT consists of exercise focusing on the aerobic energy system, often on a treadmill or bike, with a set intensity between 50-75% of the participant's $\dot{V}O_{2max}$ and sessions generally lasting 20-60 min in duration (Hannan et al. 2018). This type of training has proven popular for weight management due to its high rates of caloric expenditure during training

(Ross et al. 2004). However, an additional mode of PA that is often overlooked and underappreciated in Canada's guidelines is resistance training (RT).

Resistance Training

Resistance training is classified as any exercise causing the muscles to contract against an external force, usually in a repetitive manner, with the expectation of improvements to muscular strength, mass, and/or endurance (Weil 2018). Depending upon the end goal of training, the external force of choice can be bodyweight, bands, pulleys, machines, free weights, or any object that provides resistance to the contracting muscles, and the number of repetitions can be manipulated to accentuate different physiological benefits. Current recommendations state that RT with loads of 70-85% of one-repetition maximum (1RM; maximum weight that can be lifted safely for 1 repetition) for 6-12 repetitions is ideal for maximizing muscle hypertrophy, or an increase in overall muscle size (ACSM 2009). In order to optimally improve muscular strength, performing 2-5 repetitions at loads greater than 90% of 1RM is thought to be most beneficial (Baechle et al. 2008). Skeletal muscle is comprised of highly plastic tissue that is able to adapt to changes in both contractile activity and nutritional intake (McGlory et al. 2017). Therefore, following a single bout of RT, the muscle transitions into a state of positive muscle protein balance, over time resulting in potential increases in both muscular strength and hypertrophy (McGlory et al. 2017).

Benefits of Resistance Training

In healthy, recreationally active individuals, skeletal muscle exists in a state of relative equilibrium, with muscle protein synthesis (MPS) exceeding muscle protein breakdown (MPB) in

the fed state, while the opposite is true in the fasted state (Atherton et al. 2012). MPS is simply defined as the anabolism of muscle fibers, while the opposing mechanism, MPB, is the breakdown of those fibers (Atherton et al. 2012). Muscle hypertrophy, or an increase in muscle mass following RT is a primary adaptation that occurs when there is a net state of anabolism within the muscle (Phillips et al. 1997). In the hours following a RT session, a number of signalling molecules specialized in both translation initiation and protein synthesis are activated (Kumar et al. 2009). More specifically, phosphorylation of the mechanistic target of rapamycin complex1 (mTORC1) functions to activate a number of downstream protein kinases such as 4E-binding protein-1 (4EBP1) and the ribosomal protein of 70-kDa S6 kinase 1 (p70S6K1) which initiate protein synthesis through the promotion of ribosomal binding to mRNA (Gingras et al. 1999; Holz et al. 2005), and upregulate transcription of the translational mechanisms themselves (Chauvin et al. 2014). Desired levels of muscle growth can only occur when rates of MPS exceed that of MPB, indicating that the body is in a state of positive net muscle protein balance (MPS minus MPB) (Phillips et al. 1997).

While the primary focus of RT for both researchers and the general population has always been on increases in strength and hypertrophy, some researchers have begun looking at the potential benefits RT could have on energy balance (EB) (Balaguera-Cortes et al. 2011; Goto et al. 2013; Greer et al. 2015; Robergs et al. 2007). As the name suggests, EB represents the difference between energy intake (EI), or the calories we ingest on a given day, and energy expenditure (EE), or the calories that we expend on a given day (DiPietro et al. 2017). EI is highly dependent upon the macronutrient composition of one's diet, with carbohydrates and proteins containing 4 $kcal \cdot g^{-1}$, while fats contain 9 $kcal \cdot g^{-1}$ (Weise et al. 2014). If EI exceeds EE, then that individual is said to be in a state of positive EB and sustained positive EB leads to overall weight

gain. However, if the opposite is true and EE surpasses EI, then the result is negative EB and chronically negative EB generates weight loss. As noted above, due largely in part to the lack of adherence to Canada's PA guidelines, roughly 63% of Canadians are currently considered overweight, and thus live in a sustained positive EB (PHAC, 2017). Resistance training appears to be an under-represented training modality (Ross et al. 2004) to combat this issue as recent studies suggest RT increases EE (Greer et al. 2015; Robergs et al. 2007). In addition, RT may also decrease EI (Balaguera-Cortes et al. 2011; Goto et al. 2013) demonstrating benefits to EB from both EE and EI.

Resistance Training and Exergy Expenditure

Due to the large amount of exercises and variations associated with RT, it has proven difficult to quantify EE during an acute session (Reis et al. 2011). At any point during a session, EE can be affected by the muscle groups that are targeted, number of repetitions, load, recovery time between sets, type of equipment being used, exercise order, and a number of other variables (Reis et al. 2011). However, researchers have predicted caloric expenditure for both the bench press and the back squat (common upper and lower body movements respectively) at various intensities (Robergs et al. 2007) during a RT session. Values are calculated using indirect calorimetry accompanied with a portable metronome, ensuring an exercise rate of 1 repetition every 3 seconds (Robergs et al. 2007).

Table 1: Predicted kcal·min^{-1} at 20 reps/min.

% 1-RM	Predicted kcal·min^{-1} Bench Press	Predicted kcal·min^{-1} Back Squat
40%	10.49	10.85
50%	12.41	13.56
60%	14.81	16.95
70%	15.29	17.63
80%	16.25	18.98

NOTE: Data adapted from Robergs et al. 2007

While EE has proven difficult to measure during a RT session, it has been measured for up to 48 h following exercise, exhibiting elevated rates of EE throughout this post-exercise period (Greer et al. 2015; Farinatti et al. 2016; Schuenke et al. 2002). This elevation in EE is due to elevations in oxygen consumption above resting known as excess post-exercise oxygen consumption (EPOC) (Greer et al. 2015; Farinatti et al. 2016; Schuenke et al. 2002). During short bursts of activity, such as RT, a number of anaerobic metabolic pathways are activated, including the degradation of adenosine-triphosphate (ATP) into adenosine-diphosphate (ADP), the re-phosphorylation of ADP into ATP through phosphocreatine, and the breakdown of glucose into pyruvic acid, which becomes lactate in the absence of oxygen (Schuenke et al. 2002). Following the termination of exercise, the body continues to require elevated levels of oxygen in order to assist with the continued re-phosphorylation of creatine and ADP (Donnelly et al. 2009), the replenishment of oxygen in blood and muscle (Boutcher 2011), and the disposal of accumulated

lactate through mitochondrial oxidation and liver gluconeogenesis (Astrand et al. 1986; Schuenke et al. 2002). These factors, as well as increased body temperature, normalization of blood pH, elevated heart rate, and the ongoing protein degradation and reparation occurring in the hours following RT are believed to be responsible for this period of EPOC, however the significance of each remains unknown (Laforgia et al. 2006; Schuenke et al. 2002).

Due to this extended period of EPOC, and the known EE calculation of 5 kcal·L^{-1} of $\dot{V}O_2$ (Townsend et al. 2014), studies have reported that acute RT is associated with significantly greater levels of EE than other forms of MVPA, including such forms as jogging or cycling (Gillette et al. 1994; Greer et al. 2015). When matched for both exercise duration (RT: 46.1±2.3 min, cycling: 43.4±2.6 min) and EE during training (RT: 217.0±18.6 kcal, cycling: 217.0±19.5 kcal), an acute RT session consisting of pectoral flies, squats, lateral pulldowns, triceps pushdowns, and calf raises performed at 60% of 1RM resulted in greater levels of EPOC at both 12 h post-exercise (RT: ~0.046 L·min^{-1} vs cycling: ~0.015 L·min^{-1}) and 21 h post-exercise (RT: ~0.031 L·min^{-1} vs cycling: ~ -0.01 L·min^{-1}) in low to moderately physically active males (Greer et al. 2015). Although these differences may not appear substantial, EPOC was ~60 L (300 kcal) greater through 21 h post-exercise, suggesting the RT elicited a significant amount of energy post-exercise compared to cycling at a similar intensity. In addition, despite measurements only occurring up to 21h post-exercise, line of best fit indicates that RMR following an acute RT session may have remained elevated for up to 48 h post-exercise (Greer et al. 2015).

While not reporting nearly as large of an effect on EPOC, other studies have noted moderate increases in $\dot{V}O_2$ following acute bouts of RT (Farinatti et al. 2016; Thornton et al. 2002). Individual exercises such as leg press and chest flies (5 sets of 10 repetitions at ~65% 1RM) elicit 17.6±3.6 L (~88 kcal) and 10.0±2.9 L (~50 kcal) EPOC respectively within the first 40 minutes

post-exercise (Farinatti et al. 2016). In addition, performing a full body workout consisting of 2 sets of 8 repetitions at 85% 1RM for 9 exercises (bicep curls, shoulder press, chest flies, bench press, latissimus dorsi pull-downs, triceps extensions, leg curls, leg press, and leg extensions) elicited ~7.6±1.5 L EPOC (37.5 kcal) in the first 20 min post-exercise (Thornton et al. 2002).

Resistance Training and Energy Intake

Contributing to EI is the physiological regulation of appetite, which is coordinated through dynamic interactions between a number of peripheral signals and the hypothalamus of the Central Nervous System (CNS) (Hainerova et al. 2010). More specifically, both appetite-stimulating (orexigenic) and appetite-inhibiting (anorexigenic) hormones released from the gut act on the arcuate nucleus in the hypothalamus in order to regulate EI through altering perceptions of hunger and satiety respectively (Hainerova et al. 2010; Schubert et al. 2014). In terms of anorexigenic hormones, the primary focus in exercise-related research includes glucagon-like-peptide 1 (GLP-1) and peptide tyrosine tyrosine (PYY) (Hainerova et al. 2010). GLP-1 is synthesized from the precursor protein preproglucagon, and is secreted in the distal small intestine and colon by L cells (Lu et al. 2018). It exists in two equipotent forms within the body, GLP-1_{7-37} and GLP-1_{7-36}, with GLP-1_{7-36} representing the majority in circulating plasma (Drucker 2006; Orskov et al. 1994). PYY is also secreted from enteroendocrine L cells found in both the small and large intestine, and has two active forms PYY_{1-3} and PYY_{3-36} which differ in the extent of their anorexigenic effects (Cummings et al. 2007). While we know of a number of anorexigenic hormones, the only orexigenic hormone which has been thoroughly studied is ghrelin (Hainerova et al. 2010). Ghrelin is generally synthesized in the stomach by specialized endocrine cells, however, it is only with the addition of an octanoyl group in the stomach and small intestine that it transitions into its active

form, acylated ghrelin (Kojima et al. 1999). This activation is essential for both its binding to and activity upon its receptor, growth hormone secretagogue receptor (GHSR-1a) (Kojima et al. 1999). Therefore, when studying appetite regulation, changes in total ghrelin content are less relevant than that of acylated ghrelin, as only changes in its active form is reflective of overall appetite (Mackelvie et al. 2007).

Following an acute RT session, limited studies have been conducted on the overall effect on appetite-regulating hormones (Balaguera-Cortes et al. 2011; Goto et al. 2013; Laan et al. 2010). However, existing literature shows the potential for significant appetite suppression (Balaguera-Cortes et al. 2011; Goto et al. 2013). Following a full body workout consisting of 8 exercises (bench press, leg press, seated rows, leg extensions, shoulder press, leg curls, triceps extensions, and bicep curls), with 3 sets of 12 repetitions of each at 70% 1RM, acylated ghrelin was found to decrease by 20±4.1% (Balaguera-Cortes et al. 2011). Following the workout, participants were presented with an ad libitum buffet meal, and although this decrease in ghrelin did not result in a reduction of EI, there was no significant difference in EI between RT and control groups, resulting in an improvement in overall EB (Balaguera-Cortes et al. 2011). In another study consisting of 2 successive days of RT training consisting of 11 exercises per day, split into 4 lower body exercises (squats, single leg squats, leg extensions, and calf raises) in the morning and 7 upper body exercises (bench press, latissimus dorsi pull downs, shoulder press, seated rows, dumbbell pull-overs, bicep curls, and triceps press downs) in the afternoon, performed in circuit formation for 5 sets of 10 repetitions at 75% of 1RM, plasma ghrelin was found to decrease by 20.7±2.8% (Goto et al. 2013).

Considering the limited amount of research, its noteworthy that both of these studies used the 8-12 repetition range at 70-75% of 1RM for maximizing muscle hypertrophy as the enhanced physiological stress and intensity associated with this style of training compared to training with

fewer repetitions for strength was hypothesized to have the greatest hormonal effects (Balaguera-Cortes et al. 2011; Goto et al. 2013). With increasing intensity, lactate production from skeletal muscle increases exponentially, eventually accumulating in plasma when the rate of production exceeds that of removal (Cairns 2006). This accumulation of lactate may play an important role in appetite suppression (Hazell et al. 2016; Freitas et al. 2020; Islam et al. 2017a; Vanderheyden et al. 2020). Ghrelin producing gastric mucosal cells contain ample G-protein coupled receptor 81 (GPR81), which inhibit ghrelin's release through the binding of lactate (Hazell et al. 2016). Therefore, any acute RT session maximizing intensity/muscular stress has the potential to result in increased suppression of orexigenic ghrelin and thus overall hunger. Recent controversial studies have proposed that the load associated with the 8-12 rep range for maximizing muscle hypertrophy may not be as important as once believed in providing the necessary stress to improve in strength and/or hypertrophy (Morton et al. 2016), as relatively new research has demonstrated that loads as low as 30% may in fact be superior if performed to failure (Burd et al. 2010).

Low-load RT

Low-load RT is performed with any RT movement utilizing loads under 50% of an individual's 1RM (Burd et al. 2010; Morton et al. 2016). Over the past few years, a number of studies have challenged the notion that heavy loads are required to maximize increases in both muscular strength and hypertrophy (Table 2). Acute studies using low-load RT demonstrate increases in MPS (Burd et al. 2010; Fujita et al. 2007) while chronic studies have found increases in overall hypertrophy and strength similar to that of high-load RT when lifting as little as 20% of a subject's 1RM to volitional fatigue (Table 2). These findings have led a number of researchers to hypothesize that total volume of the contractions rather than load may be sufficient in full motor

unit activation and muscle fiber recruitment, which would be equally important, if not more so, than load in the stimulation of MPS (Burd et al. 2010). However, while these studies have monitored the acute effects of low-load RT at the site of the muscle fibers, not much is known about the acute effects of low-load RT on post-exercise metabolism and appetite regulation.

Low-load RT and EPOC

While several studies on RT and EPOC (Abboud et al. 2013; Faranatti et al. 2016; Greer et al. 2015; Thornton et al. 2002) have demonstrated similar results of elevated EPOC for up to 48 h post-training (Abboud et al. 2013; Greer et al. 2015), these studies all focused on exercises of 6-12 repetitions at 70-90% of the subjects 1RM. When lower loads were used the comparison was to matched work (Thornton et al. 2002) or to a pre-determined number of repetitions (Elliot et al. 1992; Haltom et al. 1999). This limitation is important as low-load RT completed to failure demonstrates benefits only when not matched for overall work (Burd et al. 2010). Therefore, no study has examined the effects of low-load RT on EPOC when performed in a way as to maximize its effect on MPS. When performed to failure, the increases in MPS seen in past studies (Burd et al. 2010) along with the accumulation of additional lactate due to increased intensity (Hazell et al. 2016) may result in substantial increases in EPOC compared to conventional high-load RT.

Low-load RT and Appetite Regulation

To date, no studies have examined the effect of low-load RT on appetite regulation. However, the increased workload and overall intensity associated with this type of training may

Table 2: Strength and Hypertrophy adaptations of high vs low-load RT. Table adapted from Schoenfeld et al. 2017.

Study	Participants	Comparison Groups (sets x reps)	Volume Equated?	Duration/ Frequency	Exercises	Hypertrophy/ Strength Measurement	Findings
Anderson et al. 1982	Y UT M (n=43)	High load: 3x6-8RM Low load: 2x30-40RM	yes	9 wk 3x/wk	bench press	1RM Bench Press	ST ↑ both groups High load: ~20% Low load: ~5%
Fink et al. 2016	Y UT M (n=21)	High load: 3x8-12RM Low load: 3x30-40RM	no	8 wk 3x/wk	UL bicep curl	MRI	CSA ↑ both groups High load: ~9% Low load: ~9%
Mitchell et al. 2012	Y UT M (n=18)	High load: 3x80%1RM Low load: 3x30%1RM	no	10 wk 3x/wk	UL leg extension	MRI	CSA ↑ both groups High load: ~7% Low load: ~7%
Ogasawara et al. 2013	Y UT M (n=9)	High load: 3x75%1RM Low load: 4x30%1RM	no	6 wk 3x/wk	bench press	MRI 1RM Bench press	CSA ↑ both groups High load: ~12% Low load: ~10%
Schoenfeld et al. 2015	Y T M (n=18)	High load: 3x8-12RM Low-load: 3x25-35RM	no	8 wk 3x/wk	full-body[a]	Ultrasound	Muscle thickness ↑ both groups High load: ~7% Low load: ~8%
Tanimoto and Ishii 2006	Y UT M (n=24)	High load: 3x80%1RM Low load: 3x50%1RM	no	12 wk 3x/wk	leg extension	MRI 1RM leg extension	ST ↑ both groups High load: ~32% Low load: ~28%

Note: Y – young; UT – untrained; T – trained; M – men; UL – unilateral; ST – strength; CSA – cross sectional area; MT muscle thickness; ↑ - increase; [a] – full body workout with bench press, military press, cable rows, barbell squat, leg press, leg extension

increase circulating blood lactate, which would act to suppress ghrelin through GPR81 (Hazell et al. 2016; Islam et al. 2017a; Freitas et al. 2020), as mentioned previously. Therefore, if lactate is found to increase, it could result in increased suppression of overall EI through reductions in orexigenic ghrelin.

Low-Load RT and Energy Balance

The utilization of a lower load may provide a greater appeal to the untrained population than conventional high-load training, as they would not likely wish to move directly from virtually no exercise to more than 70% of their maximal effort. This may in fact be the greatest benefit of any training regimen, as any potential changes to EB are not received without proper adherence. However, if adhering to low-load RT, the increased number of repetitions, and thus, work performed would not only increase energy expended during exercise (Robergs et al. 2007), but may increase overall EE through an amplified effect on both lactate and EPOC (Hazell et al. 2016). Finally, if this increase in EE is accompanied by a reduction in EI through elevated levels of lactate suppressing the release of orexigenic ghrelin, then low-load RT could prove to be an ideal method for not only increasing adherence to Canada's PA guidelines, but also for transitioning Canadians to a healthier chronic negative EB.

Purpose

To determine if a low-load high-volume RT session results in a greater shift towards negative EB compared to one of high-load low-volume through a direct effect on;

i. Increasing EE through both a greater intensity and duration of EPOC
ii. Decreasing EI through lactate's suppressing effect on orexigenic ghrelin

Hypotheses

1. The increased volume and intensity in the low-load protocol will result in additional lactate accumulation and amplified EPOC (measured through increased $\dot{V}O_2$), and thus increase post-exercise metabolism and EE.
2. Increased accumulation of lactate due to a RT stimulus of greater repetitions and thus overall work will result in a suppression of active ghrelin and overall hunger.

CHAPTER 2

Effects of an acute session of high- vs low-load resistance training exercise on energy balance

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Introduction

The Canadian Society for Exercise Physiology (CSEP) produced the Canadian physical activity guidelines recommending that adults between the ages of 18-64 perform at least 150 minutes of moderate to vigorous physical activity (MVPA) per week in bouts of 10 minutes or more (Tremblay et al. 2011). Despite the well documented benefits of regular physical activity (PA), only 16% of the Canadian population is meeting these recommendations (Clarke et al. 2019). These extremely low levels of PA adherence are negatively correlated with body mass culminating in ~63% of Canadian being considered overweight or obese (Masters et al. 2013; PHAC, 2017; Sturm 2003). When prescribing exercise for weight management, MVPA mentioned in Canada's PA guidelines tends to refer to moderate-intensity continuous training (MICT) focusing on running or cycling at intensities ranging from 40 to 75% $\dot{V}O_{2max}$ for durations of 30-60 min (Tremblay et al. 2011). However, resistance training (RT) is a less highlighted mode of PA as it is often overlooked and underappreciated in Canada's guidelines (Abboud et al. 2013; Schuenke et al. 2002).

RT is classified as any exercise causing the muscles to contract against an external force, usually in a repetitive manner, with the expectation of improvements to muscular strength, mass, and/or endurance (Weil 2018). While the primary focus of RT for both researchers and the general population has often been on increases in muscle hypertrophy and strength, research has begun transitioning towards the potential benefits of RT exercise on energy balance (Balaguera-Cortes et al. 2011; Goto et al. 2013; Greer et al. 2015; Robergs et al. 2007). Energy balance represents the difference between energy intake (EI), or the calories we ingest on a given day, and energy expenditure (EE), or the calories that we expend (DiPietro et al. 2017). While the effects of MICT on energy balance are more well-known (Petridou et al. 2019), RT appears to be an under-

represented but no less effective training modality to combat the growing obesity epidemic. A single acute RT session can greatly increase EE (~20%) through a direct effect on post-exercise metabolism (Farinatti et al. 2016; Greer et al. 2015; Robergs et al. 2007; Schuenke et al. 2002) and decrease EI post-exercise through alterations in peripheral appetite-regulating hormones leading to the suppression of subjective appetite (Balaguera-Cortes et al. 2011; Goto et al. 2013).

When MICT and RT are matched for both exercise duration (RT: 46.1±2.3 min, cycling: 43.4±2.6 min) and EE during exercise (RT: 217.0±18.6 kcal; cycling: 217.0±19.5 kcal), an acute RT exercise session consisting of five sets of 5 exercises (3 upper body, 2 lower body) at 60% of one repetition maximum (1RM) resulted in greater levels of excess post-exercise oxygen consumption (EPOC) at both 12 h (0.031 $L \cdot min^{-1}$) and 21 h (0.030 $L \cdot min^{-1}$) post-exercise (Greer et al. 2015). With regards to appetite regulation and EI, a full-body workout consisting of 8 exercises (5 upper body, 3 lower body) completed for 3 sets of 12 repetitions at 70% 1RM resulted in a 20% decrease in acylated ghrelin (Balaguera-Cortes et al. 2011). In another study consisting of 2 successive days of RT training consisting of 11 exercises per day (7 upper body, 4 lower body) performed in a circuit for 5 sets of 10 repetitions at 75% of 1RM, plasma acylated ghrelin was found to decrease by 20.7±2.8% (Goto et al. 2013). While these post-exercise increases in EPOC and decreases in acylated ghrelin, suggestive of decreases of subjective appetite, indicate positive effects on energy balance, both protocols were performed with resistances of ~60-75% 1RM as this has long been believed to be the ideal range to maximize muscle hypertrophy (ACSM 2009). However, recent novel research has provided an exciting counter argument to the idea that heavy weights are necessary to maximize increases in muscle hypertrophy (Burd et al. 2010).

Low-load RT is performed with very light loads (i.e. under 50% of an individual's 1RM) for a high number of repetitions (Burd et al. 2010; Morton et al. 2016). When low-load RT was

performed at 30% 1RM to failure, there was an increased rate of myofibrillar MPS when compared to a more traditional RT consisting of higher loads (90% 1RM) with a lower number of repetitions (Burd et al. 2010). Moreover, this low-load RT has also demonstrated increased lactate accumulation post-exercise (Freitas et al. 2020) where an acute RT session consisting of 6 sets of the leg-press performed to failure generated more lactate (~3 mmol/L) when the load was moderate (70% 1RM) compared to high (90% 1RM). This increase in lactate was also found to correspond with significant reductions in subjective measures of appetite (Freitas et al. 2020). This has important potential implications as while lactate was originally considered terminal waste product of anaerobic metabolism linked to muscular fatigue (Vander Heiden et al. 2009) there is growing support for many diverse roles of lactate in physiology (Islam et al. 2017a; Vanderheyden et al. 2020). Relevant to energy balance, increases in post-exercise lactate may mediate exercise-induced reductions in overall hunger through suppression of acylated ghrelin (Hazell et al. 2016; Islam et al. 2017a; Vanderheyden et al. 2020). Furthermore, lactate accumulation (Moniz et al. 2020) as well as elevated MPS (Burd et al. 2010) may elevate EPOC and thus increase EE compared to conventional high-load RT.

Therefore, the purpose of the present study was to determine if a low-load high-volume RT session results in a greater EPOC and suppression of subjective appetite (i.e. negative energy balance) compared to one of high-load low-volume. We hypothesize low-load RT will: i) increase post-exercise EE; ii) increase lactate accumulation; and iii) decrease subjective appetite in the hours immediately following exercise.

Methods

Participants

Eleven recreationally active males volunteered to participate in this study. However, due to unfortunate circumstances related to the COVID-19 outbreak, only five were able to complete all three experimental sessions (age, 24±3 y; height, 180.4±9.6 cm; weight, 84.0±12.6 kg, BMI: 25.8±1.5 $kg \cdot m^{-2}$). The other 6 were scheduled to complete their experimental sessions by the end of April 2020. All participants were non-smokers and deemed healthy based on the CSEP Get-Active Questionnaire (GAQ; Appendix A), and recreationally active based on the Physical Activity and Sedentary Behavior Questionnaire (PASB-Q; Appendix B). All participants had a minimum of 6-months of self-reported RT experience with the exercises in question, and were not taking any drugs or nutritional supplements at the time of the study that may affect metabolism. Participants were asked to refrain from exercise within 24 h of any training session, and also agreed not to consume any caffeine or alcohol within that same period. All participants were informed of the experimental procedures, known risks, and signed an informed consent (Appendix C) form prior to data collection. Ethical approval was obtained from the Wilfrid Laurier University Ethics Committee for Research on Human Subjects (Appendix D).

Study Design

Prior to any pre-experimental or experimental sessions, participants came to the lab for a familiarization session. Following this, all participants returned for a pre-experimental session in order to determine their 1-RM for each exercise. Participants returned to the lab for three supervised experimental sessions (~4 h each) that were systematically rotated between participants. Systematic rotation consisted of assigning participants into one of six possible orders in which

experimental sessions could be completed, ensuring two participants were assigned to each. Experimental sessions consisted of full body RT sessions performed at both 30 and 90% of the participants' calculated 1RM, and a control session in which the participant remained seated in the lab (the same duration as that in which they would be exercising). Supervised sessions were at least 7 days apart, and consisted of visits to the lab on 3 consecutive days. Gas exchange measurements, appetite perceptions, and blood samples were obtained at four time points on the day of each session. Participants also returned to the lab the following two days following an overnight fast in order to test gas exchange and subjective measures of delayed onset muscle soreness (DOMS). Participants were instructed to record EI (quantity of food intake and beverage consumption) for a 3-day period in a provided food log, including the day prior to, the day of, and the day following testing. The dietary intake was then replicated in the 24 h prior to the next experimental session.

Familiarization Session

All participants completed a familiarization session in which they were screened for exclusion criteria, and introduced to the study protocol and equipment. During this session, participants were acclimatized to the exercise equipment as well as to the efforts required during each exercise protocol to reduce any learning effects in subsequent sessions. It was also during this session that participants completed both the PASB-Q and CSEP GAQ questionnaires.

Pre-experimental Session

The pre-experimental session consisted of determining each participant's 1RM for each individual exercise. This included the back squat, bench press, straight-leg deadlift, military press,

and bent-over row. Exercises were tested in the same order as performed during experimental sessions in an attempt to replicate levels of exhaustion experienced during the latter exercises. Following a warm-up, participants began with a weight of 50-70% of their estimated 1RM, after which the weight increased incrementally until they were unable to complete the lift with correct form. If a lift was not completed, two additional attempts were allowed at the participant's discretion. Their 1RM was then recorded as the largest weight they were able to lift with correct form.

Experimental Session

Participants arrived at the lab at 0800 h and remained in lab for ~ 4 h (Figure 1.) Upon arrival, participants were provided with a standardized breakfast consisting of 7 $kcal \cdot kg^{-1}$ body mass Chocolate Chip Clif Bar (CLIF Bar, Emeryville, CA; 68% carbohydrate, 17% fat, and 15% protein) to be consumed within 15 min. Following an additional 20 minutes of seated rest, pre-exercise gas exchange was taken continuously from 0835 h – 0850 h, followed by a pre-exercise blood draw taken at 0850 h. Exercise commenced at 0900 h and consisted of a standardized warm-up of dynamic stretching followed by two sets of back-squat, bench-press, and deadlift performed at 50 and 70% 1RM with 60 s of rest between sets (~10 min), 3-sets of back-squat, bench-press, deadlift, military press, and bent-over row performed to volitional fatigue at the set intensity with 90 s rest (~45-min), and a cool down of static stretching (~5-min). During the control session, this time was spent seated in lab. Upon cessation of exercise, participants remained seated in lab until 1200 h, with post-exercise samples of gas exchange, appetite perceptions, and blood draws taken at 1000 h, 1045 h, and 1145 h. Participants then returned to the lab at ~0800 h the following two

days following an overnight fast in order to test gas exchange and subjective measures of DOMS ~24 and 48 h post-training.

Gas Exchange

Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured continuously using an online breath-by-breath gas collection and analysis system (MAX II, AEI technologies, Pittsburgh, PA, USA). Prior to data collection the gas analyzer was calibrated with gases of known concentrations and with a 3-L syringe for flow. Each participant wore a fitted silicon facemask (7400 series Vmask, Hans Rudolph Inc. KS, USA) to ensure comfort and prevent leaking during gas measurements. Heart rate (HR) was also recorded using an integrated HR monitor (FT1, Polar Electro, QC, Canada). Energy expenditure was determined using the known calculation of 5 kcal·L^{-1} of $\dot{V}O_2$ (Townsend et al. 2014), and RMR was determined using resting $\dot{V}O_2$ values at 24 and 48 h post-exercise.

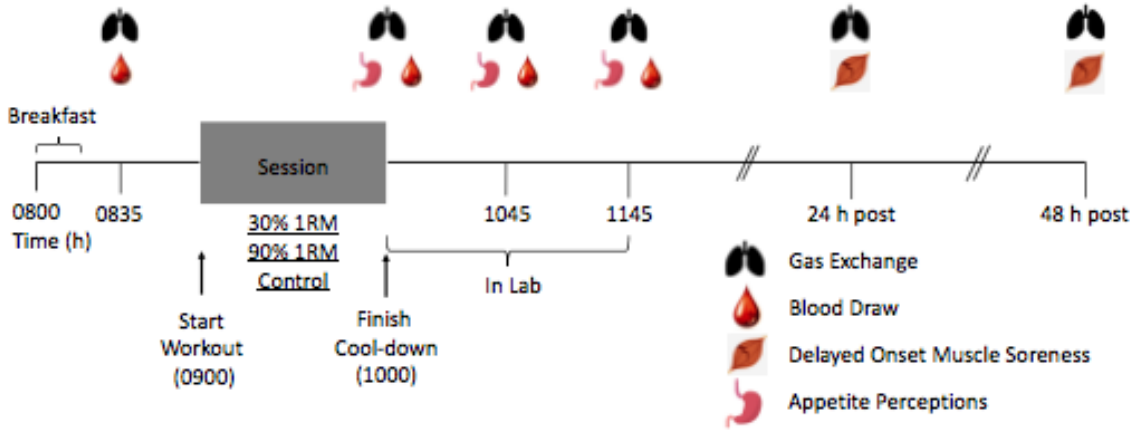

Figure 1: Visual representation of experimental session timeline.

Appetite Perceptions

Appetite perceptions were assessed using Visual Analog Scales (VAS) (Flint et al. 2000) for perceptions of hunger (i.e., "How hungry do you feel?"), satisfaction (i.e., "How satisfied do you feel?"), fullness (i.e., "How full do you feel?"), and prospective food consumption (i.e., "How much do you think you can eat?") on a 100-mm scale anchored at each end with contrasting statements (i.e., "not at all" and "extremely"). The mean values of the four appetite perceptions were used to calculate an overall appetite score after inverting the values for satisfaction and fullness (Stubbs et al. 2000).

Blood Sampling Protocol

Venous blood samples were collected from an antecubital vein while participants were in a supine position for the determination of plasma acylated ghrelin, active GLP-1, and PYY_{3-36}. Samples were taken concomitantly with gas exchange measurements prior to each RT session at 0835h, as well as following exercise completion at 1000 h, 1045 h and 1145 h. Two 3 mL whole blood samples were collected into separate pre-chilled Vacutainer tubes coated with K2 ethylenediaminetetraacetic acid (EDTA; 5.4 mg) at each time point. To prevent degradation of acylated ghrelin by proteolytic enzymes, 120 μL of 4-(2-aminoethyl) benzenesulfonyl fluoride hydrochloride (AEBSF) was added to whole blood immediately after sample collection. Addition of 30 μL of DPP-IV inhibitor to the secondary tube was also used to prevent inactivation of $GLP\text{-}1_{7-36}$, $_{7-37}$ and ex-vivo conversion of PYY_{1-36} to PYY_{3-36}. Lastly, 128 μL of aprotinin was added to prevent the degradation of PYY_{3-36} by proteolytic enzyme activity. All tubes were then gently inverted 10 times and centrifuged at 3000 g for 10 min at 4°C, after which the plasma supernatant was aliquoted into microcentrifuge tubes. Plasma from the acylated ghrelin vacutainer were

acidified by the addition of 100 μL of HCl per 1 mL of plasma (Islam et al. 2017a). All samples were then stored at –80°C for subsequent analysis via commercially available enzyme-linked immunosorbent assays (ELISA) to determine plasma concentrations of acylated ghrelin, active GLP-1, and PYY_{3-36}. This analysis will be conducted once laboratory clearance after COVID-19 is approved and all participants have completed the study.

Delayed Onset Muscle Soreness

Muscle soreness was evaluated using a 100-mm visual analogue scale representing "no soreness at all" (0 mm) on the left side and "extremely sore" (100 mm) on the right (Chen et al. 2006). Participants were asked to report their level of soreness on the line while the researcher palpated over the quadriceps, pectorals, hamstrings, deltoids, and latissimus dorsi respectively. Each score was analyzed individually as well as in summation in order to measure soreness at the level of each muscle, but as an overall muscle soreness level as well. Muscle groups were selected as they are the primary agonists in each of the five movements being utilized in our training protocol.

Energy Intake

Free-living EI was recorded for a 3-day period using dietary logs that were provided to each participant (Appendix E). On the day prior to an experimental session, participants were asked to begin recording their EI, and continue recording until the end of the day following the session. Additionally, participants were required to replicate their EI on the day prior to all subsequent sessions. Detailed instructions were provided, including a sample log, to ensure accurate measurement and recording. Dietary intake analysis was not finalized due to the COVID-

19 pandemic (specialized software located in the Energy Metabolism Research Laboratory), but will be concluded upon re-opening of the Laurier campus.

Statistical Analysis

All data were analyzed using PRISM (GraphPad Software, San Diego, CA). Two-way repeated measure ANOVAs were conducted to analyze differences in pre- and post-exercise values of $\dot{V}O_2$ (3 sessions x 6 time points), resting metabolic rate (RMR) (3 sessions x 2 time points), lactate (3 sessions x 4 time points), and subjective perceptions of appetite (3 sessions x 4 time points), with Tukey's post-hoc testing where necessary. Paired t-tests were used to analyze the EPOC, lactate AUC, and DOMS between exercise sessions. The lactate and appetite AUC calculations were calculated using the trapezoid method. Partial eta-squared (η_p^2) values were calculated to estimate the effect sizes (small: 0.01, medium: 0.06, and large: 0.14) for main effects and interactions where necessary. Cohen's *d* were calculated to estimate effect size (small 0.2, medium 0.5, large 0.8, very large 1.3) for individual group's pre- to post-testing differences. Statistical significance was accepted as $p < 0.05$, and $p < 0.10$ was interpreted as "approaching significance" or "trending". All group data are presented as means ± SD.

Results

Five participants completed all three experimental sessions (age, 24±3 y; height, 180.4±9.6 cm; weight, 84.0±12.6 kg, BMI: 25.8±1.5 $kg \cdot m^{-2}$). As less than half of the participants were able to complete the data collection phase, some outcome variables (appetite-regulating hormones, energy intake) were not analyzed. Thus, results will be limited to VO_2, energy expenditure, subjective measures of appetite, and DOMS.

Oxygen Consumption

There was a session x time interaction (p=0.038, $\eta_p^2 = 0.355$; large) for $\dot{V}O_2$ (Figure 2a) where both the 30% 1RM (Δ0.110 L·min^{-1}, p<0.001, d=1.41) and 90% 1RM (Δ0.08 L·min^{-1}, p=0.002, d=1.22) sessions were elevated at 0 h compared to CTRL (Figure 2a). The difference between the 30% session and CTRL was approaching significance at both 1 h (Δ0.05 L·min^{-1}, p=0.054, d=1.26) and 2 h (Δ0.05 L·min^{-1}, p=0.062, d=1.06) post-exercise. There was no difference in EPOC between the 30% and 90% sessions at 0 h (Δ0.03 L·min^{-1}, p=0.355, d=0.71), 1 h (Δ0.04 L·min^{-1}, p=0.186, d=0.80), or 2 h (Δ0.03 L·min^{-1}, p=0.365, d=0.57), or between the 90% and CTRL sessions at 1 h (Δ0.01 L·min^{-1}, p=0.697, d = 0.43) or 2 h (Δ0.03 L·min^{-1}, p=0.478, d=0.44). -

Post-exercise Energy Expenditure

There was a trending main effect of condition (p=0.088, $\eta_p^2 = 0.474$; large) for post-exercise EE (Figure 2b) where the difference between the 30% 1RM session and CTRL was approaching significance (Δ41 kcal, p=0.091, d=1.30). There were no differences in post-exercise EE between the 30% 1RM session and 90% 1RM session (Δ21 kcal, p=0.559, d= 0.64) or the 90% 1RM session and CTRL (Δ20 kcal, p>0.999, d=0.54). For RMR, there was no session x time interaction (p=0.788, $\eta_p^2 = 0.076$; medium) and no main effect of session (p=0.485, $\eta_p^2 = 0.214$; large) or time (p=0.700, $\eta_p^2 = 0.057$) across the 2 days post-exercise (24 h post-exercise: CTRL 0.28 L·min^{-1} ± 0.06 L·min^{-1}, 30% 1RM 0.32 L·min^{-1} ± 0.0 L·min^{-1}, 90% 1RM 0.30 L·min^{-1} ± 0.02 L·min^{-1}; 48 h: CTRL 0.29 L·min^{-1} ± 0.02 L·min^{-1}, 30% 1RM 0.29 L·min^{-1} ± 0.03 L·min^{-1}, 90% 1RM 0.29 L·min^{-1} ± 0.05 L·min^{-1}).

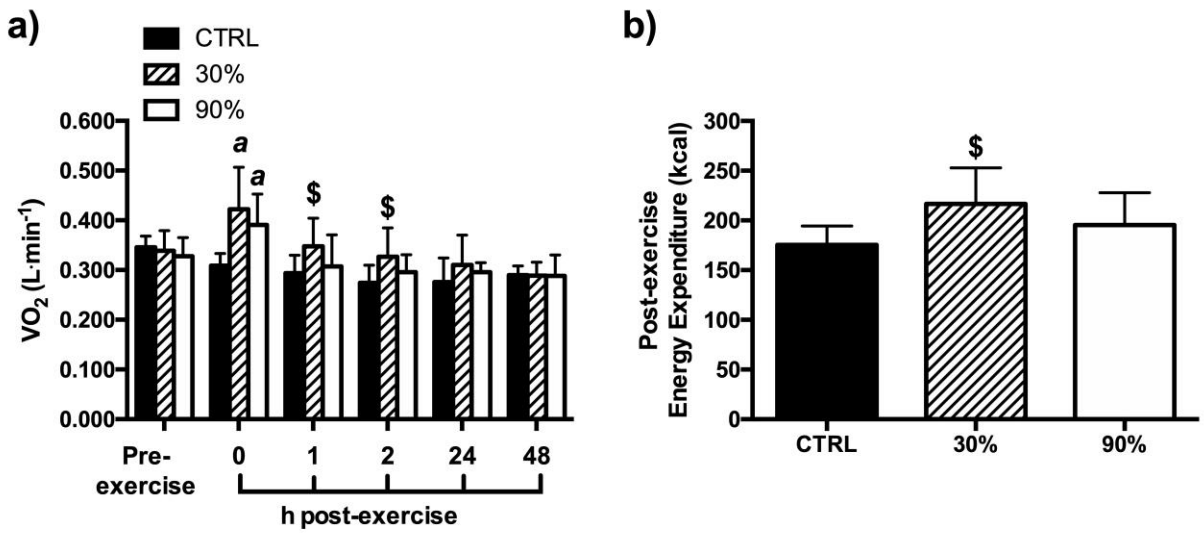

Figure 2: a) Comparison of $\dot{V}O_2$ (L·min^{-1}) between conditions. **b)** Total energy expenditure (kcal) 2h post-exercise across conditions. Note: ***a*** - significantly greater than CTRL. ***$*** - approaching significance (p<0.100).

There was a significant condition by time interaction (p<0.001, $\eta_p^2 = 0.962$; large), where the 30% 1RM session accumulated more lactate (Figure 3a) at 0 and 1 h post-exercise than both 90% 1RM (Δ5.7 mmol·L^{-1}, p<0.001, d=2.65; Δ1.1 mmol·L^{-1}, p=0.010, d=2.10) and CTRL (Δ13.0 mmol·L^{-1}, p<0.001, d=7.38; Δ1.8 mmol·L^{-1}, p=0.001, d=2.44) sessions. The 90% 1RM session also increased lactate compared to the CTRL session at 0 h post-exercise (Δ7.3 mmol·L^{-1}, p<0.001, d=4.18). The 30% 1RM session lactate AUC (Figure 3b) was higher compared to both the 90% 1RM (p=0.001, d=2.89) and CTRL (p<0.001, d=6.54) sessions whereas the 90% session was also higher compared to CTRL (p=0.007, d=5.03).

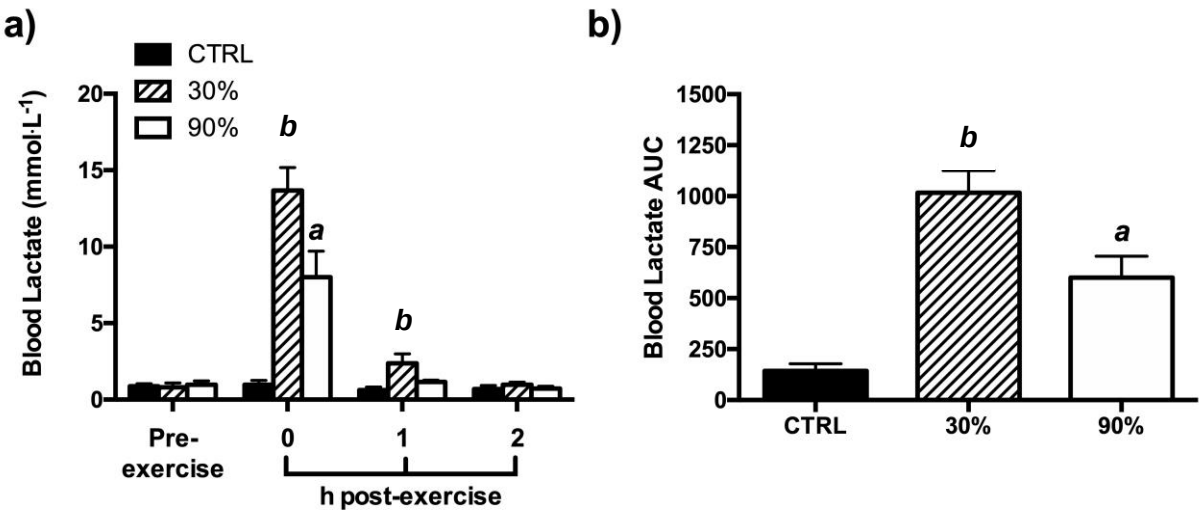

Figure 3: a) - Comparison of blood lactate concentration (mmol·L^{-1}) between conditions. **b)** Total lactate area under the curve (AUC) across conditions. NOTE: ***a*** **-** significantly greater than CTRL. ***b*** **-** significantly greater than 90% and CTRL.

Subjective Perceptions of Appetite

There was a significant session by time interaction (*p*=0.009, $\eta_p^2 = 0.283$; large) where the 30% 1RM session had lower appetite at 0 (Δ42 mm, *p*<0.001, *d*=-1.29), 1 h (Δ35 mm, *p*=0.001, *d*=-0.93), and 2 h (Δ21 mm, *p*=0.017, *d*=-1.13) post-exercise compared to CTRL session (Figure 4a), and at 0 h (Δ26 mm, *p*=0.003, *d*=-0.62) and 1 h (Δ24 mm, *p*=0.005, *d*=-0.60) compared to the 90% 1RM session (Figure 4a). The difference between the 30% 1RM session and 90% 1RM was approaching significance 2 h post (Δ17 mm, *p*=0.062, *d*=-0.77). The 30% 1RM session appetite AUC (Figure 4) was lower compared to CTRL session (*p*=0.020, *d*=-2.10) but not the 90% 1RM session (*p* =0.113, *d*=-1.20).

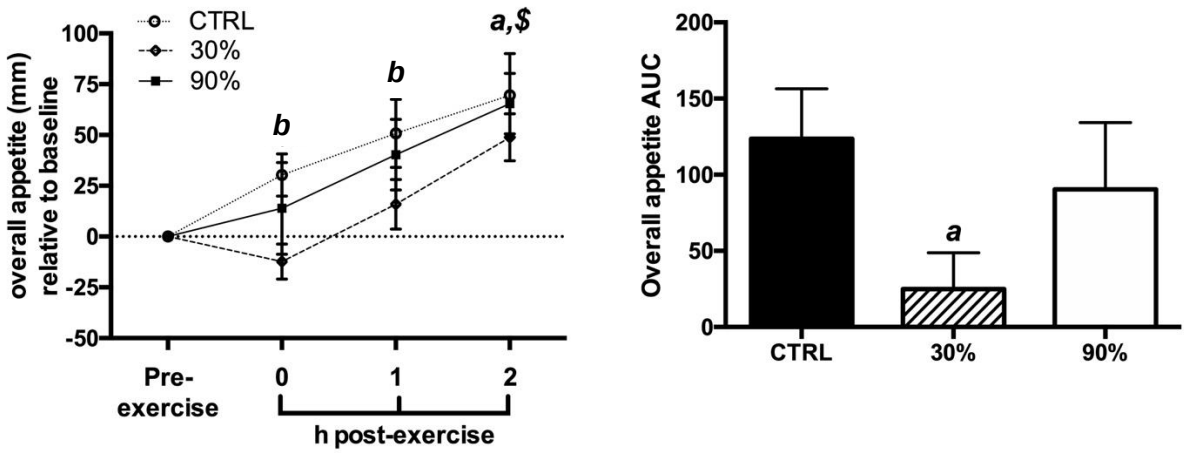

Figure 4: Comparison of subjective appetite for each condition. Total subjective appetite area under the curve (AUC) across conditions. ***a***, significantly less than CTRL. ***b***, significantly less than 90% and CTRL. ***$***, approaching significance (p<0.10).

Delayed Onset Muscle Soreness

There were no session x time interactions for DOMS across any muscle group (p=0.151-0.923, η_p^2 = 0.020 – 0.376) or main effect of time (p=0.409-0.985, η_p^2 = 0.000 – 0.175). There were main effects of session (p<0.015, η_p^2= 0.652-0.985) across each muscle group (Table 3) where the 30% 1RM session was significantly higher than 90% 1RM session in the quadriceps (Δ46.8 mm, p<0.001, d=8.95) and latissimus dorsi (Δ12.4 mm, p=0.010, d=2.79). The 30% 1RM session was also increased compared to the CTRL session in the quadriceps (Δ66.7 mm, p<0.001, d=12.93), hamstrings (Δ46.0 mm, p=0.019, d=2.33), and latissimus dorsi (Δ29.4 mm, p=0.017, d=2.42). The 90% 1RM session was also significantly higher than CTRL session in the quadriceps (Δ19.9 mm, p=0.024, d=2.19) and hamstrings (Δ22.1 mm, p=0.019, d=2.33).

Table 3: Comparison of DOMS (mm) for primary muscle groups across sessions. Taken both 24 and 48 h post-exercise.

Muscle	24 h	48 h	P-values, Effect Sizes
Quadriceps	CTRL: 0 ± 0	CTRL: 0 ± 0	[a] $P<0.001$, $d = 6.03$
	30%: 65.0 ± 10.9*#	30%: 68.4 ± 12.2*#	[b] $P=0.024$, $d = 1.24$
	90%: 21.8 ± 14.1#	90%: 18.0 ± 19.2#	[c] $P<0.001$, $d = 8.95$
Hamstrings	CTRL: 0 ± 0	CTRL: 0 ± 0	[a] $P=0.116$, $d = 1.42$
	30%: 43.8 ± 29.1	30%: 48.2 ± 38.6	[b] $P=0.019$, $d = 1.13$
	90%: 23.8 ± 17.5#	90%: 20.4 ± 23.3#	[c] $P=0.376$, $d = 0.76$
Pectorals	CTRL: 0 ± 0	CTRL: 0 ± 0	[a] $P=0.053$, $d = 1.62$
	30%: 47.8 ± 18.1	30%: 35.0 ± 32.2	[b] $P=0.134$, $d = 1.24$
	90%: 29.4 ± 20.2	90%: 26.0 ± 26.4	[c] $P=0.115$, $d = 1.16$
Latissimus Dorsi	CTRL: 0 ± 0	CTRL: 0 ± 0	[a] $P=0.017$, $d = 1.74$
	30%: 41.2 ± 15.8*#	30%: 17.6 ± 6.9*#	[b] $P=0.097$, $d = 1.12$
	90%: 17.0 ± 12.8	90%: 17.0 ± 18.8	[c] $P=0.010$, $d = 2.79$
Deltoids	CTRL: 0 ± 0	CTRL: 0 ± 0	[a] $P=0.092$, $d = 1.42$
	30%: 46.0 ± 27.3	30%: 33.6 ± 30.6	[b] $P=0.192$, $d = 0.97$
	90%: 31.2 ± 28.8	90%: 14.8 ± 16.0	[c] $P>0.999$, $d = 0.99$

Note: Data are mean ± standard deviation. NOTE: *, significantly different from 90% session. #, significantly different from CTRL session. [a], CTRL vs 30% 1RM. [b], CTRL vs 90% 1RM. [c], 30% 1RM vs 90% 1RM.

Discussion

To our knowledge, this is the first study to investigate the effects of RT load on energy balance through an evaluation of both EE (post-exercise metabolism) and subjective appetite (proxy for EI) (Vatansever-Ozen et al. 2011). The preliminary findings of this study were: i) no significant differences in EE or EPOC between low-load RT and high-load RT groups; ii) low-load RT induced elevated levels of blood lactate compared to high-load RT at both 0 and 1 h post-exercise as well as total lactate AUC; iii) low-load RT resulted in reduced ratings of subjective hunger compared to high-load RT in the hours immediately following exercise; and iv) low-load RT resulted in increased DOMS in both the quadriceps and latissimus dorsi compared to high-load RT. While the original study design had a purpose of investigating EB through more measures (appetite-regulating hormones, energy intake), due to our limited sample size collected to date due to COVID-19, not all analysis has taken place.

Energy Expenditure

RT has long been an under-represented training modality compared to MICT when studying EE. This may stem primarily from the higher EE per unit of time training for MICT (Donnelly et al. 2004). While the present study did not measure EE during exercise, we demonstrate a low-load RT session at 30% 1RM resulted in 216 kcal expended within the first 2 h post-exercise compared to 195 kcal following a RT session at 90% 1RM and 175 kcal following a non-exercise CTRL within the same time period. While not statistically significant, effect size (d=0.64; medium) and a trending main effect suggest a modest yet consistent difference between high and low-load sessions. This slight increase in EE following the low-load session (~20 kcal/h) appears to have remained elevated for up to 24 hours (Figure 2a). A number of recent studies have

demonstrated RT's ability to induce large increases in EE (≥300 kcal greater than MICT when matched for workout duration) through both during exercise EE as well as an elevated EE post-exercise (Farinatti et al. 2016; Greer et al. 2015; Robergs et al. 2007; Schuenke et al. 2002). The increases in post-exercise metabolism or EPOC are a result of the body attempting to recover from the physiological stresses of exercise, and has been found to be directly correlated with exercise intensity (Borsheim et al. 2003; Moniz et al. 2020; Thornton et al. 2002). While seemingly insignificant within a two-hour period, elevations in EE seen following the low-load session rival those following high-intensity interval training (exercise known for its substantial EPOC response) (Islam et al. 2017b; Moniz et al. 2020; Townsend et al. 2014). One key limitation in past research comparing RT load and its effect on EPOC is that workouts are often matched for overall work (Hunter et al. 2003; Murphy et al. 1992; Olds et al. 1993; Ratamess et al. 2007; Thornton et al. 2002). Numerous studies have reported findings indicating that RT sessions incorporating higher loads result in a greater magnitude of EPOC compared to those of lower loads (Hunter et al. 2003; Thornton et al. 2002), or have reported no significant differences between the two (Murphy et al. 1992; Olds et al. 1993; Ratamess et al. 2007). The primary difference between the current study and past studies on RT load and EPOC is that the current study did not match RT sessions for overall work. This is important to note, as the larger increases in blood lactate, heart rate, body temperature, and ventilation associated with increased intensity are hypothesized to account for a portion of the prolonged EPOC response (Moniz et al. 2020). To our knowledge, no past research on RT and EPOC has utilized low-loads performed to failure in an attempt to maximize physiological stress (Burd et al. 2010).

Another potential factor in the post-exercise metabolism following the 30% 1RM session is the significant energy cost associated with protein synthesis and this could be involved in the

prolonged EPOC response (Moniz et al. 2020). When matching for overall work during RT, a low-load group (30% 1RM) resulted in significantly reduced levels of muscle protein synthesis (MPS) compared to a high-load group (90% 1RM) performed to volitional fatigue following 3 sets of unilateral leg extension (Burd et al. 2010). However, when also performed to volitional fatigue, the low-load group found the same magnitude of increase in MPS as the high-load group, although for a longer duration, resulting in similar gains in muscle hypertrophy (Burd et al. 2010; Mitchell et al. 2012). Therefore, when prescribing RT for weight management, it seems counterproductive to utilize a RT protocol known to result in reduced physiological stress and muscle protein synthesis. While the present study reported no significant differences between high and low-load groups, the trending main effect of session suggests that a larger sample size may yield more significant results.

Blood Lactate

Lactate is a common by-product of muscle glycolysis and is formed primarily from pyruvic acid in the absence of oxygen (Schuenke et al. 2002). The present study found significant increases in lactate (↑ 71%, Δ5.7 $mmol \cdot L^{-1}$) following a low-load RT session at 30% 1RM compared to a high-load session at 90% 1RM. It is well documented that post-exercise elevations in blood lactate are directly correlated with increases in EPOC (Farinatti et al. 2013; Moniz et al. 2020; Schuenke et al. 2002). Following exercise termination, the body requires elevated levels of oxygen in order to assist with the disposal of accumulated lactate through mitochondrial oxidation and liver gluconeogenesis (Astrand et al. 1986; Schuenke et al. 2002). While the magnitude of its effect is not currently known (Laforgia et al. 2006), this elevated oxygen requirement is known to contribute to the rapid EPOC response (Farinatti et al. 2013; Moniz et al. 2020). In addition to its

role in EPOC, our primary interest in lactate for the present study was its potential role in appetite-regulation and subjective appetite perceptions (see below).

Subjective Perceptions of Appetite

Although not as well documented in RT, exercise intensity has been demonstrated to be an important modulator of post-exercise responses in subjective appetite (Deighton et al. 2013; Freitas et al. 2020; Hazell et al. 2016; Islam et al. 2017a; Matos et al. 2018; Panissa et al. 2016). The present study found that a full-body RT session performed at a low-load (30% 1RM) resulted in significantly reduced subjective perception of appetite (↓ 70%) compared to an identical RT session performed at a high-load (90% 1RM). This aligns with the results of past studies which have demonstrated that a RT session performed at a moderate load of 70% 1RM resulted in significantly reduced ratings of subjective hunger compared to a RT session with a high-load of 90% 1RM (Freitas et al. 2020).

While the exact mechanisms behind this increase in hunger are not well understood, several potential mechanisms have been proposed (Hazell et al. 2016) and one worth discussing is the role of blood lactate accumulation on exercise-induced appetite suppression (Hazell et al. 2016; Islam et al. 2017a; Vanderheyden et al. 2020). Gastric mucosal cells are enriched with G-protein coupled receptor 81 (GPR81) which inhibit the release of orexigenic ghrelin through the binding of lactate (Hazell et al. 2016). Recently, a correlation was found between post-exercise elevations in blood lactate and AUC of appetite scores (r = -0.48; P = 0.006) following 3 exercise sessions of varying intensity (Islam et al. 2017a) supporting that increased blood lactate accumulation may play a role in appetite suppression post-exercise. In addition, when participants ingested sodium bicarbonate pre-exercise as a means to accumulate more lactate than a placebo condition during/following

exercise, increased blood lactate in the sodium bicarbonate condition (+2.7 mmol/L versus placebo) tended to reduce overall appetite perceptions (-20% versus placebo) further implicating lactate as a key mediator of exercise-induced appetite suppression (Vanderheyden et al. 2020). This could help to explain the results of the present study which found significantly greater increases in blood lactate following low-load 30% 1RM RT session compared with high-load 90% 1RM session ($\Delta 5.7$ mmol·L^{-1}). Unfortunately, as plasma samples could not be properly analyzed due to the COVID-19 outbreak we do not have any data regarding the orexigenic hormone ghrelin as planned. However, we expected to see increases in lactate and decreases in ghrelin which would link to suppressed perceptions of appetite as previously documented (Freitas et al. 2020; Hazell et al. 2016; Islam et al. 2017a; Vanderheyden et al. 2020).

Delayed Onset Muscle Soreness

DOMS is classified as a type 1 muscle strain, commonly presenting with stiffness, tenderness, and pain upon movement and/or muscle palpation (Cheung et al. 2003). Although the physiological causes of DOMS are not entirely understood, it is primarily associated with high force muscular work (Cheung et al. 2003) and is arguably the most practical marker of muscle damage (Damas et al. 2018). The present study found DOMS to be significantly greater in both the quadriceps and latissimus dorsi following the 30% 1RM session compared to both the 90% 1RM session and CTRL. In addition, DOMS was significantly greater in the quadriceps and hamstrings following the 90% session compared to CTRL. While this can be an indication of increased muscle damage, and thus an increased magnitude of change to the force-generating capacity of the muscle post-recovery (Damas et al. 2016; Paulsen et al. 2012), the validity of DOMS as an index of muscle fiber damage has been questioned (Yu et al. 2004). The severity of

DOMS has been found to be negatively correlated with the trained state of the muscle (Connolly et al. 2003) and is more common following bouts of exercise unfamiliar to the individual (Cheung et al. 2003). Specifically, when comparing 8-weeks of RT in naïve and pre-trained groups, both demonstrated similar responses in muscle hypertrophy while DOMS was only experienced by the naïve group (Flann et al. 2011). While all participants in the present study had >6 months experience with both the back squat and bent-over row (exercises targeting the quadriceps and latissimus dorsi respectively), each expressed that they had never performed either with loads as low as 30% 1RM to volitional fatigue. Therefore, it is entirely possible that the increased DOMS found following the low-load 30% 1RM session may be more representative of the session's novelty and less so of muscle protein damage and eventual hypertrophy. However, a larger sample size with a more diverse RT background may help clarify this moving forward.

Strengths

The primary strength of the present study is that it is the first the compare the effects of RT load on energy balance through both post-exercise EE as well as subjective appetite (a proxy for EI). Though we also collected blood samples to analyze appetite-regulating peptides as well as objective measures of EI (24h dietary recalls for the day of the experimental session and the day following), these will be analyzed and included when data collection on the full set of participants can be completed. In recent years, research on RT has transitioned towards its potential capacity to combat the growing obesity epidemic through increased post-exercise metabolism and appetite suppression (Freitas et al. 2020; Greer et al. 2015). Individually, both are paramount in achieving chronic negative energy balance. However, as both are equally important in the energy balance equation, the most effective training modality would be one that could have the greatest effect on

both variables. An additional strength is that we are the first to test the effects of low-load RT performed to failure on either post-exercise metabolism or appetite suppression. The increased volume and intensity associated with this modality (Burd et al. 2010; Mitchell et al. 2012) were hypothesized to augment the post-exercise effects on both variables through increased lactate accumulation. Therefore, the results of the present study offer a great deal of insight towards low-load RT to failure as the optimal paradigm to transition to a negative energy balance, and thus provide a much-needed means of weight management.

Limitations

Although the present study has many strengths, it is not without its limitations. Most limitations are directly related to the COVID-19 outbreak prohibiting human-to-human interaction in a research lab setting. Due to these unfortunate circumstances, six recruited participants were unable to properly complete all experimental sessions (despite being scheduled in March/April) and data at present only includes 5 participants. In addition, plasma samples taken at four separate time-points during each session were unable to be analyzed due to lack of access to the lab during COVID-19 and the costs associated with running the commercially available ELISA kits are more appropriate on complete data sets. Therefore, peripheral hormone concentrations of ghrelin, PYY, and GLP-1 have yet to be determined. Finally, while the EI data was collected from all 5 participants who completed the study thus far, lack of access to the laboratory during COVID-19 for longer than 15 min at a time precluded this analysis as only our main laboratory computer has the appropriate nutritional analysis software. Additionally, as we chose not to match its RT sessions for overall work, it is inevitable that there was a discrepancy in workout length (90%: 26.5 ± 1.1 min, 30%: 35.9 ± 2.3 min) despite our best efforts during pilot testing when designing

the protocols. As it has been pre-determined that EPOC can be affected by workout duration (Borsheim et al. 2003), this may have contributed to the minor differences in $\dot{V}O_2$ noted in the present study. Another limitation was that participants were provided with an unstructured 5-minute cool-down following exercise completion and as such potential discrepancies in stretching could have altered the severity of DOMS experienced in the following days independent of the sessions themselves. Additionally, the present study did not include a gas exchange measurement before breakfast during each experimental session so changes from the baseline RMR could not be performed. As the thermic effect of food is known to encompass ~10% of total daily energy expenditure (Trexler et al. 2014), having the pre-experimental measure of gas exchange so soon following breakfast may have slightly elevated resting values of $\dot{V}O_2$ (though this effect would have similarly affected all sessions so it is likely minimal). Another limitation stems from the inability to monitor each participant working to failure. As the performance of reduced repetitions would limit the overall physiological response to exercise (Thornton et al. 2002), any participant stopping before true "failure" could provide outlying data. A final limitation was that EE was not measured during experimental sessions due to the multidirectional nature of the RT exercises, as the silicon mask and data collection tubes associated with gas exchange measurements could not be properly utilized.

Conclusion

The present study found that a low-load high-volume RT session resulted in elevated post-exercise $\dot{V}O_2$/EE compared to a high-load low-volume RT session in the hours immediately following exercise. In addition, low-load RT resulted in significantly elevated levels of lactate and suppressed subjective ratings of appetite for up to 2 h post-exercise. While peripheral appetite

hormones and dietary food logs could not be analyzed, lower subjective hunger ratings have been linked to reductions in EI in previous research (Vatansever-Ozen et al. 2011). Overall, results demonstrate that a low-load high-volume RT session results in a greater shift towards negative energy balance compared to one of high-load low-volume. However, due to the COVID-19 pandemic all results remain preliminary, and a larger sample size may help to yield more significant results.

CHAPTER 3

Future Directions and Knowledge Translation

Due to the COVID-19 pandemic suspending all human-to-human contact, the Exercise Metabolism Research Laboratory was closed in the middle of data collection on Friday, March 20th 2020. Therefore, the future direction of the present study is simply to continue with recruiting and data collection whenever possible in order to attain the intended n of 12. When examining the preliminary results thus far, it is clear that low-load RT performed to failure has tremendous potential as a mode of shifting an individual towards a negative energy balance. It has already shown significant reductions in subjective hunger (a proxy for EI) compared to high-load RT, and while no significance was found for post-exercise EE, the trending main effect and medium effect size suggest this may change when more participants are included. Overall, once finalized with >12 participants the potential results of the present study would not only be novel to the field of RT and weight management, but could be incredibly practical to the general public.

Weight Loss

Small weights... BIG RESULTS!

01 Whats the problem?

16% Percentage of Canadians meeting Canadian physical activity guidelines

63% Percentage of Canadians currently considered overweight or obese

02 What we did:

Compared two **Resistance Training** sessions for their effects on *Metabolism* and *Hunger*

High-load
90% 1RM

vs

LOW-LOAD
30% 1RM

5 Exercises
3 Sets
As many reps as possible!

Measurements taken at 0, 1, 2, 24, and 48h post-exercise

What we found:

Low-load resistance training resulted in...

More repetitions performed each set

25 vs **4**

More calories expended post-exercise

216 vs **195**

Significant reductions in HUNGER

70%

Results suggest low-load resistance training is more beneficial for energy balance. However future research is still required.

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Appendix A

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer YES or NO to each question before you become more physically active. If you are unsure about any question, answer YES.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	2 Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	3 Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	4 Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

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Get Active Questionnaire – Reference Document

ADVICE ON WHAT TO DO IF YOU HAVE A **YES** RESPONSE

Use this reference document if you answered YES to any question and you have not consulted a health care provider or Qualified Exercise Professional (QEP) about becoming more physically active.

1 Have you experienced ANY of the following (A to F) within the past six months?	
A A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity? ☐ YES	Physical activity is likely to be beneficial. If you have been treated for heart disease but have not completed a cardiac rehabilitation program within the past 6 months, consult a doctor – a supervised cardiac rehabilitation program is strongly recommended. If you are resuming physical activity after more than 6 months of inactivity, begin slowly with light- to moderate-intensity physical activity. If you have pain/discomfort/pressure in your chest and it is new for you, talk to a doctor. Describe the symptom and what activities bring it on.
B A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher? ☐ YES	Physical activity is likely to be beneficial if you have been diagnosed and treated for high blood pressure (BP). If you are unsure of your resting BP, consult a health care provider or a Qualified Exercise Professional (QEP) to have it measured. If you are taking BP medication and your BP is under good control, regular physical activity is recommended as it may help to lower your BP. Your doctor should be aware of your physical activity level so your medication needs can be monitored. If your BP is 160/90 or higher, you should receive medical clearance and consult a QEP about safe and appropriate physical activity.
C Dizziness or lightheadedness during physical activity ☐ YES	There are several possible reasons for feeling this way and many are not worrisome. Before becoming more active, consult a health care provider to identify reasons and minimize risk. Until then, refrain from increasing the intensity of your physical activity.
D Shortness of breath at rest ☐ YES	If you have asthma and this is relieved with medication, light to moderate physical activity is safe. If your shortness of breath is not relieved with medication, consult a doctor.
E Loss of consciousness/fainting for any reason ☐ YES	Before becoming more active, consult a doctor to identify reasons and minimize risk. Once you are medically cleared, consult a Qualified Exercise Professional (QEP) about types of physical activity suitable for your condition.
F Concussion ☐ YES	A concussion is an injury to the brain that requires time to recover. Increasing physical activity while still experiencing symptoms may worsen your symptoms, lengthen your recovery, and increase your risk for another concussion. A health care provider will let you know when you can start becoming more physically active, and a Qualified Exercise Professional (QEP) can help get you started.

After reading the ADVICE for your YES response, go to Page 2 of the *Get Active Questionnaire* – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

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Get Active Questionnaire – Reference Document

ADVICE ON WHAT TO DO IF YOU HAVE A **YES** RESPONSE

Use this reference document if you answered YES to any question and you have not consulted a health care provider or Qualified Exercise Professional (QEP) about becoming more physically active.

2 Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active? ☐ YES

If this swelling or pain is new, consult a health care provider. Otherwise, keep joints healthy and reduce pain by moving your joints slowly and gently through the entire pain-free range of motion. If you have hip, knee or ankle pain, choose low-impact activities such as swimming or cycling. As the pain subsides, gradually resume your normal physical activities starting at a level lower than before the flare-up. Consult a Qualified Exercise Professional (QEP) in follow-up to help you become more active and prevent or minimize future pain.

3 Has a health care provider told you that you should avoid or modify certain types of physical activity? ☐ YES

Listen to the advice of your health care provider. A Qualified Exercise Professional (QEP) will ask you about any considerations and provide specific advice for physical activity that is safe and that takes your lifestyle and health care provider's advice into account.

4 Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active? ☐ YES

Some people may worry if they have a medical or physical condition that physical activity might be unsafe. In fact, regular physical activity can help to manage and improve many conditions. Physical activity can also reduce the risk of complications. A Qualified Exercise Professional (QEP) can help with specific advice for physical activity that is safe and that takes your medical history and lifestyle into account.

After reading the ADVICE for your YES response, go to Page 2 of the *Get Active Questionnaire* – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

WANT ADDITIONAL INFORMATION ON BECOMING MORE PHYSICALLY ACTIVE?

- **csep.ca/certifications**
  CSEP Certified members can help you with your physical activity goals.
- **csep.ca/guidelines**
  Canadian Physical Activity Guidelines for all ages.

Appendix B

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CSEP-PATH: PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR QUESTIONNAIRE (PASB-Q)
ADULT (18 AND OVER)

Please answer the following questions based on what you do in a typical week. To increase accuracy, you may wish to log your physical activity and sedentary behavior for one week prior to answering the questions.

Aerobic Physical Activity

1. Frequency: In a typical week, how many days do you do moderate-intensity (like brisk walking) to vigorous-intensity (like running) aerobic physical activity ?

____ days/week

2. Time or Duration: On average for days that you do at least moderate-intensity aerobic physical activity (as specified above), how many minutes do you do?

____ minutes/day

Total: Multiply your average number of days per week by the average number of minutes per day.

____ minutes/week

Muscle Strengthening Physical Activity

3. In a typical week, how many times do you do muscle strengthening activities (such as resistance training or very heavy gardening)?

____ times/week

Perceived Aerobic Fitness

4. In general, would you say that your aerobic fitness (ability to walk/run distances) is:

____ Excellent ____ Very Good ____ Good ____ Fair ____ Poor

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Sedentary Behaviour

5. On a typical day, how many hours do you spend in continuous sitting: at work, in meetings, volunteer commitments and commuting (i.e., by motorized transport)?

☐ None ☐ < 1 hour ☐ 1 to < 2 ☐ 2 to < 3

☐ 3 to < 4 ☐ 4 to < 5 ☐ 5 to < 6 ☐ > 6

6. On a typical day, how many hours do you watch television, use a computer, read, and spend sitting quietly during your leisure time?

☐ None ☐ < 1 hour ☐ 1 to < 2 ☐ 2 to < 3

☐ 3 to < 4 ☐ 4 to < 5 ☐ 5 to < 6 ☐ > 6

Total Sedentary Behaviour (add responses to questions 5 and 6)____ hours/day

7. When sitting for prolonged periods (one hour or more), at what interval would you typically take a break to stand and move around for two minutes?

☐ < 10 minutes

☐ 10 to < 20 minutes

☐ 20 to < 30 minutes

☐ 30 to < 45 minutes

☐ 45 to < 1 hour

☐ 1 to < 1.5 hours

☐ 1.5 to < 2 hours

☐ > 2 hours

Appendix C

CONSENT TO PARTICIPATE IN RESEARCH

LETTER OF INFORMATION

Date: _____

Title of Study: **The Effects of Low vs. High-Load Resistance Training on Energy Balance (REB #____)**

Dear _____:

You are being invited to participate in a research study conducted by Dr. Tom J. Hazell and Daniel Grisebach (BA Kin), Abigail Broad (BA Kin), and Seth McCarthy (BKin) from the Energy Metabolism Research Laboratory.

PURPOSE OF THE STUDY

The purpose of this study is *to examine how the load and overall volume of a resistance training session effects energy balance*.

PROCEDURES

Each participant will visit the lab for a familiarization session (15 min), 2 pre-experimental sessions (~1 h), and 3 experimental sessions (~4.5 h each) in a systematically rotated order. Total time commitment for each participant will be ~15.75 h. During the familiarization session participants will be screened using the GAQ (Get Active Questionnaire), provide written informed consent, and become acclimated with the experimental procedures (resistance training equipment and blood draw procedures). Pre-experimental sessions will consist 1RM testing for each individual exercise. The first session will determine the 1RM for the back squat (BS), military press (MP), and bent-over row (BR). The second session will determine the 1RM for the straight-leg deadlift (DL) and bench press (BP). Following a warm-up, participants will begin with a weight of 50-70% of their estimated 1RM, after which the weight will increase incrementally until they are unable to complete the lift with correct form. All testing will be done under direct supervision of the researcher, who has taken courses in both CSEP (Canadian Society for Exercise Physiology) and Canfitpro personal training certification.

Experimental sessions (separated by 7 days) will require participants to arrive at the lab at 0800 h and will remain in lab for ~ 4 h. Upon arrival, participants will be provided with a standardized breakfast (Chocolate Chip Clif Bar; 7 kcal·kg−1) to be consumed within 15 min. Water will be provided ad libitum throughout the session. Following an additional 20 minutes of seated rest, pre-exercise gas exchange will be taken continuously from 0835 h – 0850 h, followed by a pre-

exercise blood draw taken at 0850 h. Gas exchange measurement consists of measuring the O_2 and CO_2 concentrations in expired air to determine how much O_2 you are consuming and how much CO_2 you are producing. Exercise will commence at 0900 h and will consist of a standardized warm-up of dynamic stretching (5-10-min), 3-sets of BS, BP, DL, MP, and BOR performed to volitional fatigue at 30/90% 1RM (~45-min), and a cool down of static stretching (~5-min). During the control session, this time will be spent seated in lab. Participants will then remain seated in lab until 1200 h, with post-exercise samples of gas exchange, appetite perceptions, and blood draws taken at 1000 h, 1100 h, and 1200 h. A total of 12 blood draws (4 per session) will be conducted for each participant, consisting of a total of 24 x 3 mL vials (2 x 3 mL vials / blood draw). Participants will then return to the lab at ~0800 h the following two days following an overnight fast in order to test gas exchange and subjective measures of DOMS (Delayed Onset Muscle Soreness) ~24 and 48 h post-training.

POTENTIAL RISKS AND DISCOMFORTS

As a result of your participation in this study you may experience mild muscle soreness/fatigue typical of an exercise session. There is also the possibility of damage to bones, ligaments, or other soft tissue due to the performance of compound resistance training movements with a heavy load. There is also a possibility of mild discomfort during phlebotomy. Although safe when done by certified and trained individuals, there is a small risk of bruising at the puncture site following a blood draw. The following safeguards will be used to minimize any *risks:*

- All participants will be screened prior to any exercise to ensure they are healthy and fit enough to withstand any physical effects of the exercise such as muscle cramping or soreness.
- Participants will be closely monitored during all exercise sessions by a qualified/experienced personal trainer who will work to ensure proper form is being used at all times in order to reduce the risk of injury.
- All researchers tasked with venipuncture are fully certified and have undergone extensive practice and training to do so.
- Any bruising at the puncture site will be reduced by applying pressure on the site for several minutes after the needle is withdrawn.
- You will be asked to exercise strenuously shortly following the blood draw. For most participants this will pose no additional risk, however, it is possible that exercise may increase bruising around the needle puncture site. Applying pressure to the site will help offset any additional risk, and exercise will not commence until the puncture site has stopped bleeding.
- Any inflammation will be addressed with a warm compress until fully alleviated.
- All equipment will be properly sterilized following each use.

POTENTIAL BENEFITS TO SUBJECTS AND/OR SOCIETY

Participants may benefit from the participation in this research project by gaining a better understanding of their muscular fitness based on the results of their 1RM testing. Participants will also gain insight into how the structure of their workouts can affect their eating habits and caloric expenditure which may prove helpful in the future. The research will contribute to the body of literature/knowledge on appetite regulation and post-exercise metabolism following resistance

training. Few studies have investigated low-load resistance training in the field of post-exercise metabolism, and to our knowledge, none have been done on low load-resistance training and appetite regulation. Therefore, this has the potential to lead to improved weight loss strategies.

CONFIDENTIALITY

The confidentiality/anonymity of your data will be ensured by all participants being assigned a study number upon recruitment to the study. This study number will have no identifiable features linking it to the participant. The data will be stored in a locked office /on a password protected computer/ on a password-protected recording device located at *the Exercise Metabolism Research Lab*.

- The de-identified data will be kept for *5* years and will then be destroyed by the principal investigator.
- Identifying information will be stored separately from the data and will be kept for *5* years and will then be destroyed by the principal investigator.
- The *anonymous* data will be stored indefinitely and may be reanalyzed in the future as part of a separate project (i.e., secondary data analysis).
- While in transmission on the internet, the confidentiality of data cannot be guaranteed.
- Only aggregate results will be published/presented.

PARTICIPATION AND WITHDRAWAL

Your participation in this research study is completely voluntary. You may withdraw at any time without any repercussions. If you are a student, please be assured that withdrawing will not have any impact on your status at Wilfrid Laurier University. You may also refuse to answer any questions you feel are inappropriate and still remain in the study. The investigators may withdraw you from this research if circumstances arise which warrant doing so (i.e. difficulty scheduling, repeatedly missing scheduled sessions, etc.).

FEEDBACK OF THE RESULTS OF THIS STUDY

If you would like a copy of a lay summary of the results please check the box below. The results from this study will be reported in general terms in the form of speech or writing that may be represented in manuscripts submitted for publication in scientific journals, or oral and/or poster presentations at scientific meetings, seminars, and/or conferences. We plan to publish this study in an academic journal. The information published in a journal or subsequent studies will not identify you in any way. Copies will be available upon request.

☐

SUBSEQUENT USE OF DATA

This de-identified data may be used in subsequent studies (with no link to your personal information). You will receive a copy of the consent form after it has been signed and do not waive any legal rights by signing it.

This letter is yours to keep. If you have any questions about this research project feel free to call:

Dr. Tom Hazell 519-884-1970 x3048

Further, if you have any questions about the conduct of this study or your rights as a research subject you may contact Dr. Jayne Kalmar, Research Ethics Board (REB) Chair (REBchair@wlu.ca / 519-884-0710 x 3131). This project has been reviewed and approved by the REB – Approval #____.

Sincerely,

Daniel Grisebach (gris0190@mylaurier.ca), MKin Student
Seth McCarthy (mcca1479@mylaurier.ca), MKin Student
Abigail Broad (broa6880@mylaurier.ca), MKin Student
Derek Bornath (born3950@mylaurier.ca), PhD Student
Dr. Tom Hazell (thazell@wlu.ca), Associate Professor

Energy Metabolism Research Laboratory
Department of Kinesiology and Physical Education
Wilfrid Laurier University

Title of Study: **The Effects of Low vs. High-Load Resistance Training on Energy Balance (REB #____)**

Consent Statement

Principal Investigators: Dr. Tom Hazell, Daniel R. Grisebach

I have read the accompanying "Letter of Information" and have had the nature of the study and procedures to be used explained to me. All of my questions have been answered to my satisfaction.

By signing below, I agree to participate in this study

NAME (please print): _____

SIGNATURE: _____

DATE: _____

NAME OF PERSON OBTAINING INFORMED CONSENT (please print):

_____

SIGNATURE OF PERSON OBTAINING INFORMED CONSENT:

_____

DATE: _____

Appendix D

September 20, 2019

Dear Daniel Grisebach

REB # 6216
Project, "The Effects of Low vs. High-Load Resistance Training on Energy Balance."
REB Clearance Issued:September 20, 2019
REB Expiry / End Date: August 31, 2020

The Research Ethics Board of Wilfrid Laurier University has reviewed the above proposal and determined that the proposal is ethically sound. If the research plan and methods should change in a way that may bring into question the project's adherence to acceptable ethical norms, please submit a "Request for Ethics Clearance of a Revision or Modification" form for approval before the changes are put into place. This form can also be used to extend protocols past their expiry date, except in cases where the project is more than four years old. Those projects require a new REB application.

Please note that you are responsible for obtaining any further approvals that might be required to complete your project. Laurier REB approval will automatically expire when one's employment ends at Laurier.

If any participants in your research project have a negative experience (either physical, psychological or emotional) you are required to submit an "Adverse Events Form" within 24 hours of the event.

You must complete the online "Annual/Final Progress Report on Human Research Projects" form annually and upon completion of the project. ROMEO will automatically keeps track of these annual reports for you. When you have a report due within 30 days (and/or an overdue report) it will be listed under the 'My Reminders' quick link on your ROMEO home screen; the number in brackets next to 'My Reminders' will tell you how many reports need to be submitted. Protocols with overdue annual reports will be marked as expired. Further the REB has been requested to notify Research Finance when an REB protocol, tied to a funding account has been marked as expired. In such cases Research Finance will immediately freeze funding tied to this account.

All the best for the successful completion of your project.

(Useful links: ROMEO Login Screen ; REB Students Webpage; REB Connect Webpage)

Yours sincerely,

Jayne Kalmar, PhD
Chair, University Research Ethics Board
Wilfrid Laurier University

Please do not reply directly to this e-mail. Please direct all replies to reb@wlu.ca

Appendix E - Daily Food Log

Instructions:

1. Record all food intake for a 3-day period (day before, day of, day after session)
2. Try to consume foods that you would typically eat as part of your regular diet.
3. Keep your recording sheets with you at all times. (Snacks are typically consumed unpredictably and, as a result, it is impossible to record them accurately unless your recording forms are nearby.)
4. Use a small food scale if you have one or standard-measuring devices (measuring cups, measuring spoons, etc.) to record the quantities consumed, as accurately as possible. If you do not eat all of the item re-measure what's left and record the difference.
5. Record combination foods separately (i.e., hot dog, bun, and condiments) and include brand names of food items (list contents of homemade items) whenever possible.
6. For packaged items, use labels to determine quantities.

Example:

Time of Day (i.e. 8:15 am, 12:30 pm)	**Food Item** (include brand name if possible)	**Quantity** (i.e. g, mL, cups, etc.)	**Notes** (i.e. ingredients & amounts if possible)
9:30 am	Eggs	2 whole	½ tsp salt, ½ cup cheese, ½ tsp butter
9:30 am	Egg whites	½ cup	-
10:15 am	Tropicana orange juice	1 cup	-
11:05 am	Apple	1 whole	-
1:50 pm	Domino's Pizza	4 slices	Pepperoni, mushroom, cheese
1:50 pm	Pepsi	300 mL	-

DAY ___(day before session) Date: _____

Time of Day (i.e. 8:15 am, 12:30 pm)	**Food Item** (include brand name if possible)	**Quantity** (i.e. g, mL, cups, etc.)	**Notes** (i.e. ingredients & amounts if possible)