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The acute physiological responses to leg extension resistance training using drop sets versus standard hypertrophy training in the quadriceps femoris

Alex Waugh
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The acute physiological responses to leg extension resistance training using drop sets versus standard hypertrophy training in the quadriceps femoris

By

Alexander C. Waugh

A Thesis
Submitted to the Faculty of Graduate Studies through the Department of Kinesiology in Partial Fulfillment of the Requirements for the Degree of Master of Human Kinetics at the University of Windsor

Windsor, Ontario, Canada

2017

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The acute physiological responses to leg extension resistance training using drop sets versus standard hypertrophy training in the quadriceps femoris

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May 5, 2017
AUTHOR’S DECLARATION OF ORIGINALITY

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication.

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ABSTRACT

Resistance training (RT) for muscle growth (hypertrophy training – HT) theoretically optimizes the mechanical tension and time under tension (TUT) placed on working muscle, which may be key to activating hypertrophic mechanisms. After prolonged HT, specialized weightlifting techniques like drop set training (DS) – or lifting progressively reduced loads without recovery – may help overcome plateaus in strength and re-stimulate hypertrophy, but evidence for the efficacy of acute DS compared to HT is limited. This thesis compared acute anabolic, metabolic, and intensity responses between DS and HT in the quadriceps femoris using leg extensions. Thirty young males completed, in a randomized, counterbalanced, within-subjects design, a DS protocol (4 sets, 4 loads/set, 75-30% 1RM, minimal recovery between loads, 3-minute recovery intervals between sets) and, separated by at least 7 days, a HT protocol (4 sets, 75% 1RM, 3-minute recovery intervals between sets). DS provided significantly more volume and TUT than HT, and significantly higher acute changes in heart rate, Borg’s rating of perceived exertion scores, blood lactate concentrations ([L]), and reduction in maximum voluntary isometric contraction force. Following DS and HT, there were no changes in plasma [interleukin (IL)-6] and a 2% increase in [insulin-like growth factor (IGF)-1], but changes fell within normal resting values. Results from either acute bout (completed in 12 minutes or less) suggest that, while DS significantly increased RT intensity, potential changes in anabolic marker synthesis require recruitment of more skeletal muscle and increased RT duration.
DEDICATION

Dedicated to my father, and especially my mother, who have provided me with the tools, advice, support, and love to inspire me to pursue my dreams and strive for success.

I love you.
ACKNOWLEDGEMENTS

I am grateful for the help and support from everyone involved in my graduate studies. The completion of my thesis would not have been possible without them.

First, the completion of successful research in the Faculty of Human Kinetics is largely dependent on the Windsor community – and the University of Windsor’s student body in particular – who willingly volunteer to participate with the sole purpose of advancing the research endeavours of our community. With this in mind, I would like to thank everyone who volunteered as a research participant in my project; the time and effort you gave was vital to the success of my research, and will continue to be crucial to the success of the University.

Next, I would like to thank my advisor, Dr. Kenji Kenno, for his attentive care in molding and pushing me to become a better researcher, scientist, and academic. Your mentorship has been an invaluable experience and the lessons I’ve learned will help me no matter where my career takes me.

I would also like to thank my committee members, Dr. Kevin Milne and Dr. Rupp Carriveau, for their honest and critical feedback of my thesis, ensuring the successful dissemination of quality research. I’d also like to give special thanks to Dr. Milne for assisting me with the ELISA analyses.

I thoroughly appreciate the support and assistance freely given by Dr. Joel Cort, Prof. Chad Sutherland, and Mr. Don Clarke for the use of their laboratory space and resources, as well as building and modifying unique research tools and software. Your help was instrumental to the completion of this project.

I also had the pleasure of working with several staff recruited for the project. Thank you to the Medical Laboratory Assistants – Jeff Little, Jenn Graber, Sara Yablonsky, and Ashley Iles – for sharing your indispensable skills and adding depth to this project. Many thanks are also owed to all the undergraduate students – Sarah Hearn, Mandy Johnstone, Anjel Alias, Alister Ethier, Stefanie Barcic, Stephanie Chauvin, Logan Shea, Kyla Percy, and Kaitlyn Groves – who volunteered hours of their time to help complete this project. Thanks to all of you for your dedication and friendship.

Finally, I would like to thank my family and friends. Your ongoing and unwavering support, companionship, and encouragement have helped me celebrate the successful times and persevere through the difficult times. Thank you for believing in me.
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<tr>
<td>( \Delta )</td>
<td>delta change</td>
</tr>
<tr>
<td>[ ]</td>
<td>concentration</td>
</tr>
<tr>
<td>% 1RM</td>
<td>percentage of one repetition maximum load</td>
</tr>
<tr>
<td>% CV</td>
<td>percentage coefficient of variation</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>ADP</td>
<td>adenosine diphosphate</td>
</tr>
<tr>
<td>ATP</td>
<td>adenosine triphosphate</td>
</tr>
<tr>
<td>AUC</td>
<td>area under the curve</td>
</tr>
<tr>
<td>BLa</td>
<td>blood lactate</td>
</tr>
<tr>
<td>BMI</td>
<td>body mass index</td>
</tr>
<tr>
<td>bpm</td>
<td>beats per minute</td>
</tr>
<tr>
<td>Ca(^{2+}), Ca</td>
<td>calcium ion</td>
</tr>
<tr>
<td>CSA</td>
<td>cross-sectional area</td>
</tr>
<tr>
<td>DHPR</td>
<td>dihydropyridine receptor</td>
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<tr>
<td>DS</td>
<td>drop set training</td>
</tr>
<tr>
<td>DS50</td>
<td>strength training with an additional drop set of 50% 1RM</td>
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<tr>
<td>DS70</td>
<td>strength training with an additional drop set of 70% 1RM</td>
</tr>
<tr>
<td>DS90</td>
<td>strength training with an additional drop set of 90% 1RM</td>
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<tr>
<td>ECC</td>
<td>excitation/contraction coupling</td>
</tr>
<tr>
<td>ELISA</td>
<td>enzyme-linked immunosorbent assay</td>
</tr>
<tr>
<td>GH</td>
<td>growth hormone</td>
</tr>
<tr>
<td>H(^+)</td>
<td>dissociated hydrogen ion</td>
</tr>
<tr>
<td>HT</td>
<td>hypertrophy training</td>
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<tr>
<td>IGF</td>
<td>insulin-like growth factor</td>
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<tr>
<td>IL</td>
<td>interleukin</td>
</tr>
<tr>
<td>K(^+)</td>
<td>potassium ion</td>
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<tr>
<td>La, (La(^{-}) + H(^+))</td>
<td>lactate</td>
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<tr>
<td>Mg(^{2+}), Mg</td>
<td>magnesium ion</td>
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<tr>
<td>MET</td>
<td>muscle endurance training</td>
</tr>
<tr>
<td>MPS</td>
<td>muscle protein synthesis</td>
</tr>
<tr>
<td>MVIC</td>
<td>maximum voluntary isometric contraction</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>sodium ion</td>
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<tr>
<td>OD</td>
<td>optical density</td>
</tr>
<tr>
<td>PAR-Q+</td>
<td>Physical Activity Readiness Questionnaire Plus</td>
</tr>
<tr>
<td>PCr</td>
<td>phosphocreatine</td>
</tr>
<tr>
<td>pH</td>
<td>power of hydrogen</td>
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<td>REB</td>
<td>Research Ethics Board</td>
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<tr>
<td>RM</td>
<td>repetition maximum load</td>
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<tr>
<td>RT</td>
<td>resistance training</td>
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<tr>
<td>RPE</td>
<td>rating of perceived exertion</td>
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<tr>
<td>RyR</td>
<td>ryanodine receptor</td>
</tr>
<tr>
<td>SE</td>
<td>standard error</td>
</tr>
<tr>
<td>SR</td>
<td>sarcoplasmic reticulum</td>
</tr>
<tr>
<td>TUT</td>
<td>time under tension</td>
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INTRODUCTION

Resistance training (RT) is implemented in order to enhance athletic performance and body aesthetics, as well as maintain or improve neuromuscular function and individual health status (Bird, Tarpenning, & Marino, 2005; Folland & Williams, 2007). It is an exercise modality that is customizable to achieve specific training outcomes, including muscular strength, hypertrophy, and endurance (Bird et al., 2005), and each end goal will dictate the design of the prescribed training program to facilitate a particular muscular response (Bird et al., 2005). Figure 1 illustrates the 3 standard RT types: a strength training (ST) program prescribes heavy loads at moderate volume with longer recovery periods (typically equating to approximately 5 sets of 5 repetitions at 85% the lifter’s one repetition maximum (1RM) with 3 minute recovery intervals), a hypertrophy training (HT) program typically utilizes moderately heavy loads at high volume and short to moderate recovery periods (typically equating to approximately 4 sets of 10 repetitions at 70% 1RM with 90 second recovery intervals), while a typical muscular endurance training (MET) program uses light loads at moderate volume with short recovery periods (typically equating to approximately 3 sets of 15 repetitions at less than 70% 1RM with

**Figure 1.** A continuum for typical resistance training program variable recommendations targeting different training outcomes. Specific training styles along the continuum are distinguished within the boxes. RM: repetition maximum, reps: repetitions, TUT: time under tension, min: minutes. Adapted with modifications from Bird et al., 2005. Sports Medicine;35(10):841-851.
45 second recovery intervals) (Bird et al., 2005; Deschenes & Kraemer, 2002). RT programs typically utilize a combination of ST, HT and MET protocols in order to trigger initial skeletal muscle adaptation, as initial strength gains are not significantly different between low- and high-volume RT protocols within untrained individuals in the early phase of RT (Cannon & Marino, 2010).

Strength gains as a result of RT are illustrated in Figure 2, where initial neural stimulation may increase strength within the first session (Kamen, 2004), and where progression of neural adaptations continue to account for the first 2–4 weeks of rapid strength increases (Folland & Williams, 2007; Selvanayagam, Riek, & Carroll, 2011). Neural adaptations acquired during RT increase strength by enhancing muscle fiber activation and the firing frequency of their α motor neurons during voluntary contraction, which increases the amount of tension a muscle can produce by increasing the number of muscle fibers recruited and how often they contract, respectively (Cormie, McGuigan, & Newton, 2011). Following neural adaptations, further strength gains are primarily a result
of hypertrophy, or muscle growth, and occurs as a result of increases in muscle protein synthesis (MPS) and/or reductions in protein breakdown, resulting in augmentation of muscle contractile properties and myofibrillar size (Cannon & Marino, 2010; Hasten, Pak-Loduca, Obert, & Yarasheski, 2000; Rasmussen & Phillips, 2003).

All RT types, as Figure 3 depicts, manipulate the magnitude and duration of mechanical tension placed on working muscles. ST maximizes mechanical tension with heavy loading, and MET maximizes the time the muscle is under tension with light loading, allowing for the completion of several repetitions. HT, however, may be balancing the influence of both factors, which may be the key to activating hypertrophic mechanisms (Folland, Irish, Roberts, Tarr, & Jones, 2002; Hackett & Amirthalingam, 2015; Pearson & Hussain, 2014). When mechanical tension and time under tension (TUT) are properly balanced, motor unit recruitment may be optimized. When motor units are recruited due to increased mechanical tension and/or TUT, according to Hennemen’s Size Principle, the smallest motor units composed of Type I muscle fibers
are recruited first, but as imposed mechanical tension exceeds the force generation
capability of Type I muscle fibers, increased neural drive recruits larger, higher threshold
Type Ila and Type IIx muscle fibers, which have a larger force production capacity, faster
rate of force development, and are more capable of hypertrophy (Carpinelli, 2008;
Cormie et al., 2011). Type II motor unit recruitment can be maximized by contracting to
momentary muscular failure using the principle of mechanical overload. Whether by
fewer repetitions and a higher % 1RM or high repetitions with a lower % 1RM, a training
protocol integrating the two will result in effective momentary muscular failure, which
has been suggested to be a key factor in maximizing fiber recruitment (Burd et al., 2012a;
Carpinelli, 2008) and MPS (Burd et al., 2010b).

Contracting to momentary muscular failure during HT (using moderately heavy loads
at high volume) provides the longest duration of TUT in combination with high Type II
motor unit recruitment. This elevates metabolic stress by stimulating anaerobic
glycolysis, resulting in the accumulation of metabolic by-products (e.g. lactate (La),
hydrogen ions (H⁺), adenosine diphosphate (ADP), inorganic phosphate (Pi) (Folland et
al., 2002)). These glycolytic metabolites may be upregulating sympathetic nervous
system activity and altering hypothalamic-pituitary function, which may potentiate
anabolic hormone production (e.g. growth hormone (GH), testosterone, and insulin-like
growth factor (IGF)-1) (Goto, Ishii, Kizuka, & Takamatsu, 2005; Hackett &
Amirthalingam, 2015; Kraemer & Ratamess, 2005). Some HT studies have reported that
elevations in La and H⁺ parallel acute elevations in some of these anabolic hormones at 0,
15, and 30 minutes post-exercise (Goto et al., 2005; Kraemer & Ratamess, 2005;
Schoenfeld, 2013; West et al., 2010). In contrast, ST programs with high mechanical
tension but minimal TUT tend to show less or negligible elevations in the same hormones (Kraemer & Ratamess, 2005; Schoenfeld, 2013; Willardson, Norton, & Wilson, 2010), indicating that muscular TUT may be important in enhancing metabolic stress and anabolic hormone production.

However, research examining acute and chronic changes in circulating anabolic hormonal concentrations in response to HT have reported increases (Izquierdo et al., 2009; West et al., 2010), decreases (Raastad, Bjøro, & Hallén, 2000), and no changes (West et al., 2010) in levels of GH (Izquierdo et al., 2009; West et al., 2010), testosterone (Izquierdo et al., 2009; Raastad et al., 2000; West et al., 2010) and IGF-1 (West et al., 2010), with or without resultant muscle growth. Interestingly, research in both animal and human models indicates that an IGF-1 isoform synthesized locally in working skeletal muscle (also known as mechano-growth factor) is the most likely candidate to exert a hypertrophic effect with RT, and is thought to most likely involve satellite cell (skeletal muscle stem cell) activation and proliferation, as well as replenishment of the stem cell pool (Goldspink, 2005; Stewart & Pell, 2010).

As HT may be optimizing mechanical tension and TUT, the volume and mechanical overload associated with contractions to failure has been shown to trigger anabolic hormone release, upregulate MPS, and promote satellite cell activity (Pearson & Hussain, 2014; Rasmussen & Phillips, 2003; Schoenfeld, 2013), especially when the exercise involves unaccustomed movements, intensity, or duration. Concurrently, HT has also been shown to elevate skeletal muscle cytokine release (e.g. fibroblast growth factor, interleukin (IL)-6, 10, 15) (Schoenfeld, 2012), which has been suggested to play a potential role in the signaling, repair, and hypertrophy of damaged muscle tissue after
intense RT. In particular, muscle contraction-induced expression of IL-6 is minimal in non-overloaded muscles, but readily detectable intramuscularly in overloaded muscles (Serrano, Baeza-Raja, Perdiguero, Jardí, & Muñoz-Cánoves, 2008). Elevations of IL-6 within muscle and in circulation have also been shown acutely post-exercise (Pedersen & Febbraio, 2012), especially as training volume increases (M. D. Phillips, Mitchell, Currie-Elof, Yellott, & Hubing, 2010), and are correlated with hypertrophy over long term training (Mitchell et al., 2013). IL-6 is suggested to mediate skeletal muscle hypertrophy via activation of satellite cells, which are capable of differentiating into muscle cells and fusing into existing muscle fibers (Serrano et al., 2008). This provides the muscle fiber with the additional cellular machinery required to support increased MPS rates and subsequent muscle hypertrophy. Thus, maximizing IL-6 expression in working muscle tissue could expedite the hypertrophic process.

As the hypertrophic adaptations triggered by these mechanisms occur slowly and progressively during RT, many athletes eventually experience training plateaus (Figure 2), where standard RT protocols eventually fail to elevate the net protein synthetic rate, thereby reducing expected gains in strength and/or hypertrophy (Peterson, Rhea, & Alvar, 2005; Schoenfeld, 2012). Indeed, studies have shown reductions in response to RT in MPS, strength, and endurance with long-term repeated exposure (Gacesa, Klasnja, & Grujic, 2013; S. M. Phillips, Tipton, Ferrando, & Wolfe, 1999). In an attempt to acutely break through training plateaus, certified strength and conditioning specialists may prescribe additional periodized recovery and/or specialized weightlifting techniques during standard RT to overcome plateaus and re-stimulate MPS. Training techniques such as pyramids, supersets, forced repetitions, and drop sets (Ahtiainen & Häkkinen,
2009; Charro, Aoki, Coutts, Araújo, & Bacurau, 2010; Charro, Aoki, Nosaka, & Foschini, 2012; de Paula Simola, Harms, & Raeder, 2015; Goto et al., 2004; Hackett & Amirthalingam, 2015; Heavens et al., 2014; Kelleher, Hackney, Fairchild, Keslacy, & Ploutz-Snyder, 2010; Robbins, Young, Behm, & Payne, 2010; Schoenfeld, 2011) are designed to force the athlete to increase training volume and induce more mechanical and metabolic stress on a working muscle group than standard, multiple set HT. However, scientific data supporting the physiological responses to these specialized HT techniques as compared to standard RT programs is equivocal and limited. In particular, a drop set, or descending set, is defined as a technique where the individual initially lifts a load (e.g. 75% of their one repetition maximum (% 1RM)) to momentary muscular failure, then reduces the load in order to immediately perform an additional set to subsequent failure (Schoenfeld, 2011). The number and size of the load (% 1RM) reductions in each drop set, as well as the number of drop sets performed, can vary.

Figure 4 illustrates three examples of different drop sets. The first drop set uses 3 load reductions (Figure 4A), the second drop set uses 2 load reductions (Figure 4B), and the third drop set uses 1 load reduction (Figure 4C). Drop sets can be compounded to make a drop set training (DS) protocol like the one depicted in Figure 4D, employing 4 drop sets.

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**Figure 4.** Examples of single drop sets, with 3 load reductions (A), 2 load reductions (B) and 1 load reduction (C). Multiple drop sets can be compiled to make a training protocol, such as 4 drop sets each with 3 load reductions (D). Numbers in the boxes represent load (% 1RM). Participants should train to momentary muscular failure. Arrows indicate recovery intervals. Numbers below the boxes represent drop set number.
starting at 80% 1RM, each with 3 load reductions to 50% 1RM and 2-minute recovery intervals between sets. In this example, the high relative intensity is designed to induce momentary muscular failure within 8-10 repetitions during the first 80% 1RM load, however, subsequent load reductions performed immediately without recovery allows for several inductions of momentary muscular failure within a similar repetition range due to accumulated fatigue. The drop set training protocol is theorized to amplify the hypertrophic response compared to other RT programs (Hackett & Amirthalingam, 2015; Pearson & Hussain, 2014) by increasing skeletal muscle metabolic stress without sacrificing volume or intensity (Folland et al., 2002). In this way, drop sets may be providing the additional physiological stimulus needed to re-stimulate hypertrophic mechanisms during a training plateau (Pearson & Hussain, 2014; Schoenfeld, 2011). This agrees with work by Burd et al. (2010b) and Hackett and Amirthalingam (2015) suggesting that relative intensity is important for maximizing the acute amplitude of the MPS response, and that the total volume lifted and TUT is important for maximizing the duration of the MPS response.

Additionally, an acute DS intervention may also increase the number of motor units recruited during training as a result of providing an overload stimulus that repetitively causes momentary muscular failure, which may maximally stimulate Type II fiber recruitment and subsequent hypertrophy (American College of Sports Medicine, 2009; Bird et al., 2005; de Paula Simola et al., 2015). Thus, DS may lead to enhanced fatigue without sacrificing volume while extending TUT, yet may still maximize motor unit recruitment through continual mechanical overload.
Furthermore, the metabolic stress already experienced during HT may be enhanced through DS by prolonging glycolytic metabolite accumulation produced predominantly by Type II muscle fibers. If metabolic stress partly mediates anabolic hormone production, then increasing TUT to enhance metabolite production may also lead to further increased circulating levels of these hormones. Moreover, the overload stimulus afforded by high volume and TUT during DS may generate a larger IL-6 response, enhancing satellite cell activity.

Currently, there are few studies that have examined either the acute or potential long term effects of DS routines on strength and/or hypertrophy. Two particular studies (Choi, Masuda, & Muraoka, 1998a; Choi, Takahashi, Itai, & Takamatsu, 1998b) characterized the effects of a DS leg extension protocol (Figure 5A) by comparing it to a standard ST program consisting of 5 sets at 90% 1RM (Figure 5B) completed to failure in male subjects. After training twice per week for 8 weeks, they reported DS produced larger increases in muscle cross-sectional area (CSA), average isokinetic strength, and anaerobic endurance (measured by rate of force decrement) than the ST group (Choi et

![Figure 5. Resistance training protocols employed by Choi et al. (1998a, 1998b). A) Drop set training protocol illustrating 3 drop sets each with 2 load reductions B) Strength training protocol. Numbers within boxes indicate load (% 1RM). Arrows indicate recovery interval. Numbers below the boxes represent drop set number. Sec: seconds, min: minutes.](image-url)
al., 1998b). They also observed the rate of hypertrophy in all fiber types was faster in the DS group than the ST group (Choi et al., 1998a). They concluded that DS is most effective for increasing hypertrophy and anaerobic endurance, and recommended incorporating DS into HT programs.

In 2003, Goto, Sato, & Takamatsu had young male, resistance trained subjects perform a single drop set with only one load reduction 30 seconds after the completion of a ST protocol consisting of 5 sets of leg extensions at 90% 1RM with 3-minute recovery intervals (Figure 6A). The single drop set load reduction was set at either 50% 1RM (DS50), 70% 1RM (DS70), or an additional set at 90% 1RM (DS90) (Figure 6A) to determine the effect of the inclusion of a single drop set with one load reduction on selected physiological parameters. The blood lactate (BLa) (Figure 6B) concentrations ([ ]) of the light DS conditions (DS50 and DS70) were significantly elevated compared to the DS90 and ST protocols (Goto, Sato, & Takamatsu, 2003). They also reported a
significant acute GH response to the light DS (DS50 and DS70) compared to ST alone (Figure 6C) (Goto et al., 2003). A significant positive correlation between changes in [GH] and training volume (r = .8, p < .05) was also observed (Goto et al., 2003). Their data clearly indicated the importance of a significantly reduced load during DS, and that eliminating recovery intervals without reducing load (as in DS90) does not provide the same benefits that DS has shown in previous work (Choi et al., 1998a; 1998b). This is likely due to the additional volume and TUT provided by lifting lighter loads for more repetitions in the DS50 and DS70 conditions. Also, the data suggest that performing a standard ST protocol followed by a single drop set with one load reduction elevates GH and La when the load is adequately light. Interestingly, Schoenfeld (2011) and Willardson et al. (2010) have also suggested the increased volume that DS confers, and not the drop set technique itself, may explain the observed differences. However, increases in GH may also be attributed to the increased metabolic stress (correlation between [GH] and [BLa]: r = .75, p < .05 – (Goto et al., 2003)) in the more heavily recruited Type II muscle fibers conferred by the minimal recovery interval in tandem with high volume provided by the DS protocols.
After their discovery of the acute GH responses following a standard ST protocol versus various single DS protocols in 2003, Goto et al. (2004) compared ST and their most potent DS protocol (DS50 – see Figure 6A) to the DS protocol employed by Choi et al. (1998b) (3 drop sets, each with 2 load reductions – see Figure 5A) on changes in acute [GH]. As seen in Figure 7, [GH] followed a dose-response pattern, in this case, increasing with training volume (ST – 5 sets + 0 drop sets; DS50 – ST + 1 drop set with 1 load reduction; DS – 3 drop sets each with 2 load reductions). These results are consistent with the suggestion that the magnitude of the GH response to RT is dependent on training volume and the length of recovery intervals employed in the program (Fransen & Kravitz, 2011). Taking the reported ST [GH] value as a “baseline” measurement for standard RT protocols, this result may suggest that DS may be effective in creating an amplified response to typical training programs, which might be suitable for prescription when strength gains plateau. Although recent research has reported increases, decreases, as well as no changes in GH responses to RT, which has led some to question the
physiological relevance of changes in [GH] during RT (Izquierdo et al., 2009; West et al., 2010), it should be noted that it is feasible that DS may influence changes in other relevant hormones or physiological activity yet to be studied. For example, GH has been suggested to mediate IGF-1 activity (Fransen & Kravitz, 2011) and activate satellite cell proliferation as well as upregulate MPS (Goldspink, 2005).

Figure 8 also illustrates the results of a subsequent periodization study where Goto et al. (2004) randomly assigned 16 participants to 2 leg extension RT groups (Group 1 and Group 2). Both groups first trained for 6 weeks using DS (Phase 1) and obtained similar increases across all variables measured, with 1RM strength (Figure 8A, Phase 1) and muscle CSA (Figure 8C, Phase 1) reaching statistical significance (Goto et al., 2004).

During Phase 2, Group 1 performed 4 weeks of ST (5 sets at 90% 1RM) with an additional drop set with one load reduction to 50% 1RM (DS50), and Group 2 performed 4 weeks of the same ST, but without the additional drop set. Group 1 (DS50) demonstrated that performing 4 weeks of a single additional drop set significantly improved 1RM (Fig 8A, Phase 2) and muscular power (Fig 8B, Phase 2) compared to Group 2 (ST). Although not statistically significant ($p = .08$), DS50 saw an increase
muscle CSA, while switching to ST in Phase 2 conferred a reduction in muscle CSA (Figure 8C, Phase 2) (Goto et al., 2004). This may be physiologically meaningful, as this could infer that DS50 maintained a positive net amino acid incorporation (synthesis > breakdown) while ST conferred a negative net amino acid incorporation (synthesis < breakdown). Thus, the addition of a single drop set (DS50) with 1 load reduction to a periodized ST phase allowed lifters to improve their 1RM strength (Figure 8A) and preserve their CSA gains (Figure 8C) better than ST alone. This shows that both large and small DS protocols are effective in maintaining strength and CSA over several weeks of use.

de Paula Simola et al. (2015) also compared a barbell back squat DS protocol to a standard ST protocol on the formation of muscle fatigue markers in young male, resistance-trained subjects. Their experimental DS procedure utilized one drop set with three load reductions (for a total of 4 different loads – 85, 70, 55, and 40% 1RM), with all sets completed to momentary muscular failure and no recovery between load reductions. The ST protocol consisted of 4 sets of 6 repetitions at 85% 1RM with 3 min recovery intervals. Although not a true volume match (matching sets x repetitions x load between protocols), matching the number of sets performed between the 2 protocols still lessened the degree to which differences in volume would serve as a confounding variable. This allowed the researchers to analyze the styles of the lifting protocols without attributing any significant physiological differences between them to large differences in volume, as has been suggested (Schoenfeld, 2011; Willardson et al., 2010) about previous studies (Goto et al., 2004). It is also worth noting that the DS design promoted longer muscular TUT than ST (130-150 seconds vs. 72 seconds). They reported DS created a larger but
not significant increase in BLa (8.6 ± 1.1 mmol/L) versus ST (7.7 ± 2.8 mmol/L), however, significance may have been lost in the attempt to match the number of sets completed between the two protocols. Nonetheless, maximum voluntary isometric contraction (MVIC) force in the rectus femoris was significantly reduced compared to baseline during DS, but not during ST, suggesting that the accumulated fatigue and the absence of recovery intervals in DS resulted in greater force decrement than ST. Overall, even when volume-matched for sets, DS was a more fatiguing protocol (as measured by MVIC force decrement), and generated more metabolic by-products than ST due to the longer TUT and potentially higher repetitions completed as loads were reduced.

Collectively, DS data report an increase in TUT, elevated anaerobic metabolic by-products, and enhanced anabolic hormone production as compared to standard ST protocols. The research suggests that RT using drop sets may stimulate the potential mechanisms responsible for hypertrophy and allow the subject to overcome strength and hypertrophy training plateaus often observed over the course of standard RT programs. However, physiological evidence to potentially support this hypothesis or the efficacy of implementing an acute DS protocol in comparison to maintaining a standard hypertrophy training program (Figure 1) is limited in the strength and conditioning literature.

**PURPOSE**

The purpose of this study was to compare and contrast the acute physiological effects of DS to a standard HT protocol using leg extensions in the quadriceps femoris. Specifically, the glycolytic metabolic marker BLa, the anabolic hormone IGF-1, the exercise-induced cytokine IL-6, and exercise intensity measurements including heart rate, Borg’s rating of perceived exertion, and MVIC force production were measured pre-,
during, and post-exercise to fully characterize the physiological response of the quadriceps muscles to both an acute DS and standard HT protocol.
METHODS

Participants

This study recruited 30 male participants between the ages of 18-28 (21.57 ± 0.50, mean ± standard error (SE)), who had at least 2 months of resistance training (RT) experience at least twice per week (Charro et al., 2010; Heavens et al., 2014; Kelleher et al., 2010). This population was chosen because they are relatively healthy and familiar with the feelings of regular exercise (e.g. muscle soreness, understand feeling of higher exercising heart rates), while demonstrating moderate fitness levels. Participants were recruited from the University of Windsor campus and the local community via posters, email, social media, and word of mouth (Appendix A, Appendix B). Recruitment began only after clearance was received from the Research Ethics Board (REB) of the University of Windsor (REB# 16-031) to allow participants to engage in a RT-based study. An emergency action plan for medical emergencies during exercise testing was established (Appendix C).

Experimental protocol

Session 1 – familiarization session

The familiarization session took place in the University of Windsor’s Human Kinetics building in the Multi-Purpose Research Lab (room 202). Each session required a maximum of 70 minutes of participation time. Participants were asked to abstain from caffeine (e.g. cafffeinated coffee, energy drinks, soft drinks, teas, dark chocolate, etc.) and alcohol for 6 hours before all sessions. The participants were also asked to abstain from leg exercise for 48 hours and all exercise for 24 hours before all sessions to ensure there was no previous muscle fatigue that might interfere with RT during the study. However,
all participants were asked to maintain their normal nutritional and exercise habits outside
the time constraints and testing schedule. They completed the Physical Readiness
Questionnaire Plus (PAR-Q+, Appendix D) to ensure they were free of any known risks
that may contraindicate their ability to partake in RT exercise. Once they had been
cleared for participation, they were provided a letter of information (Appendix E) to read
pertaining to the study, and provided written informed consent (Appendix F) to
participate in RT. They also completed a participant information sheet both to collect
demographic data, including age, height, and weight; and confirm inclusion/exclusion
criteria stated during the recruitment process (Appendix G). Each participant was asked
to void their bladder, and instructed to drink 1 cup of water prior to starting
familiarization experiments to ensure adequate hydration (Heavens et al., 2014).
Participants were shown the simplified experimental design illustrated in Figure 9. All

![Diagram](image)

**Figure 9.** Experimental design showing the setup and chronology of and time between training sessions. The randomized counterbalanced study design yielded n = 30 for each of the drop set training and hypertrophy training conditions.

sessions were separated by a minimum of seven days, mainly to provide adequate time
for any muscle soreness incurred by RT to subside (Proske & Morgan, 2001). Each
participant was instructed they would be randomly assigned to either RT Group 1 or
Group 2 for Session 2. Group 1 completed RT using drop set training (DS) on Session 2
and using hypertrophy training (HT) on Session 3. Group 2 completed RT using HT on
Session 2 and using DS on Session 3. The DS and HT protocols were explained verbally and were demonstrated. A detailed description of HT and DS is found specifically in the Hypertrophy training protocol and Drop set training protocol sections in following pages.

The RT protocols used the leg extension exercise (Figure 10A-B) in order to focus on the quadriceps femoris muscles of the thigh, with the superficial muscles consisting of vastus lateralis, vastus medialis, and rectus femoris (Figure 10C). A plate-loaded leg extension machine (CGEC340, Body-Solid® Inc., IL, USA) was used to perform the

![Figure 10](image-url)
exercise (Figure 11A). A 14-inch long Olympic (i.e. 2-inch diameter) barbell sleeve adapter (OAS14, Body-Solid® Inc., IL, USA) was added to the leg extension machine’s standard size (i.e. 1-inch diameter) weight horn to add strength and stability for heavy loading using Olympic-sized weight plates (Figure 11B). A generic Olympic barbell spring collar was used to keep weight plates secure during loading (Figure 11B). The machine was anchored to the floor to prevent wobbling during heavy loading. A steel wire axle strop was integrated into the middle of the leg extension arm to which a snap hook could be attached in order to immobilize the leg extension arm for facilitation of maximum voluntary isometric contractions (MVICs) (Figure 11C). A roller-lever actuator limit switch was also positioned on the frame of the leg extension machine,
whereby moving the leg extension arm through an adequate angular displacement during the exercise would close its circuit and emit both a buzzing sound and light, indicating that adequate range of motion was achieved for that repetition (Figure 11D).

Three-repetition maximum dynamic leg extension strength testing (3RM), bilateral MVIC testing, and antecubital and fingertip blood sampling procedures were thoroughly explained to them both verbally and in writing. Participants were also familiarized with the Borg rating of perceived exertion (RPE) scale (Appendix H), and heart rate monitor (Model E40, Polar Electro, Kempele, Finland) used during testing sessions. Participants were permitted to drink water throughout all RT procedures ad libitum, which the investigators provided.

Each participant’s 3RM was determined using a standard skeletal muscle 3RM procedure for the quadriceps (McCurdy, Langford, Cline, Doscher, & Hoff, 2004) that was previously approved as a Standard Operating Procedure (SOP) cleared by the Department of Kinesiology’s REB and the University of Windsor’s REB. The participant’s 3RM was used to mathematically predict their 1RM using the Brzycki equation to minimize any chance of skeletomuscular injury potentially incurred by performing a true 1RM test (Nascimento, Cyrino, & Nakamura, 2007). Briefly, participants were familiarized with the plate-loaded leg extension machine used throughout the study (Figure 11A). After seating the participant, the seat back of the machine was adjusted for their comfort and to ensure proper lifting mechanics. The seat settings were recorded for each participant to ensure consistency across sessions. All participants had their hips and trunk secured to the seat and were asked to refrain from holding the handle bars located on either side of the seat pan in order to ensure that only
the quadriceps were being used to lift the weight, encourage consistent lifting form, and
to reduce variability between participants in stabilizing force applied through the arms by
holding the handle bars. Padded comfort belts were used (EL881, Kuny’s™ Leather
Manufacturing Company, Leduc, AB, CA) to secure participants in the chair. The belt
securing the hips was modified by integrating 14 inches of seatbelt material to increase
the total length of the belt. The belt securing the trunk was unmodified. Participants
completed 5-10 repetitions using light weight (about 50% of their estimated 1RM) on the
first set with a one-minute recovery period followed by a set of 5 repetitions at 70% of
their estimated 1RM. A 2-3-minute recovery period was taken between each subsequent
set. After increasing the weight by 20%, the first 3RM attempt was made on the third
trial. For each successful trial that 4 repetitions were completed, 10-20% more weight
was added, based on the ease with which the participant completed the 3RM test. All
participants attained their 3RM within 6 trials, including the warm-up sets. The 3RM test
was used to estimate 1RM using the Brzycki equation (Nascimento et al., 2007).
Predicted 1RM was used to design each participant’s experimental loading protocol
according to the RT procedures described in following pages.

After completion of the 3RM, leg extension MVICs were completed using a
standard protocol that was previously approved as a SOP and cleared by the Department
of Kinesiology’s REB and the University of Windsor’s REB to assess peak force and
force decrement following each set during the DS and HT protocols. The MVIC setup
consisted of a load cell (Interface, AZ, USA) with one side anchored to a steel beam on
the frame of the leg extension machine, and a snap hook attached to the other side for
quick release, which hooked to the steel wire axle strop that was integrated into the leg
extension arm of the machine to immobilize it during bilateral force application (Figure 12). The setup created a knee flexion angle of 65º when the leg extension arm was fully extended. When the participant extended at the knee, the isometric force exerted against the shin pad was detected by the load cell, digitized, and read on computer software. The load cell was calibrated for accuracy before completing any testing by hanging 2-inch diameter weight plates ranging from 2.5 pounds to 100 pounds to the load cell, and adjusting the gain setting on the software to match the actual load. To stabilize the body during contractions, their trunk and hips were strapped against the seat, and they were asked to place their arms on their trunk. Participants were verbally encouraged (using a pre-written dialogue – Appendix I) to ramp up to their maximum exertion and hold the contraction for approximately 3 seconds against the shin pad. The force signal was digitized and stored on a computer offline, and subsequently analyzed. Participants completed 3 MVIC trials during Session 1 for familiarization with the protocol. During Sessions 2 and 3, they completed 3 MVIC trials pre-exercise and a single MVIC

Figure 12. Setup of load cell apparatus for leg extension maximum voluntary isometric contraction test. An isometric contraction is performed against the leg extension machine’s shin pad with the knee in 65º of flexion.
immediately following each of the 4 completed sets of leg extensions to assess force decrement and muscle fatigue. All MVICs measured were normalized to the peak MVIC value generated pre-exercise, and all MVIC peak values generated during RT were expressed as %PRE force. Only a single MVIC was performed after each set of leg extensions to minimize any additional fatigue not a result of the leg extension training protocol.

Lastly, participants completed an abbreviated, simulated HT and DS session that familiarized them with both the HT and DS protocols. This was accomplished by completing a shortened version of each of the HT and the DS protocols with loads that were light enough to lift without difficulty. The minimal difficulty of the simulated protocol did not require recovery intervals between sets. A detailed description of HT and DS is found specifically in the Resistance training protocols section in the following pages.

Following Session 1, participants in both Groups 1 and 2 were scheduled for training Sessions 2 and 3 with a minimum of 7 days between testing sessions.
Sessions 2 and 3 – training/testing sessions

Testing sessions took place in the University of Windsor’s Human Kinetics building in the Multi-Purpose Research Lab (room 202). Prior to the participant’s arrival, they had been assigned to either Group 1 (DS → HT) or Group 2 (HT → DS) (Figure 9). A detailed chronology of experimental events for Sessions 2 and 3 for both HT and DS is illustrated in Figure 13. Data collected during HT and DS sessions for each participant were recorded in their own respective data sheets (Appendix J, Appendix K).

Upon arrival and after a 10-minute resting period, participants had a resting venous blood sample drawn using previously cleared protocols (REB#10-036, 09-197, and 28-877) by a registered practicing medical laboratory assistant (MLA). Briefly, blood samples were used to measure levels of insulin-like growth factor (IGF)-1 and interleukin (IL)-6 before and after completion of each of the RT protocols.

![Figure 13](image-url)
A pre-exercise resting venous blood sample of approximately 5 mL was collected from the antecubital vein (arm) after 10 min of rest (Figure 14). Protective gloves were worn during all blood collections and discarded immediately after blood was drawn. A latex-free tourniquet was applied to either the left or right arm and tightened in order to aid in the visualization of antecubital veins. Once a suitable site was found, it was cleaned with an alcohol wipe. Once dried, the MLA inserted a sterile small-gauge needle into the antecubital vein and blood was collected into heparinized Vacutainer® tubes (Becton Dickinson©, NJ, USA) for later analysis. After blood collection, the site of puncture was cleaned of any blood and a bandage was applied or a cotton ball was taped in place with firm pressure until clotting occurred. This procedure was repeated in the contralateral arm 15 minutes post-exercise, as previously published data has reported peak blood elevations within 15 minutes of the last RT set for IGF-1 (McKay et al., 2009) and IL-6 (M. D. Phillips et al., 2010). Blood samples were centrifuged at 1000 x g (5804 R, Eppendorf, Hamburg, Germany) for 15 minutes within 30 minutes of collection and plasma was
aliquoted, labelled, and stored in a New Brunswick™ Innova® U725 upright freezer (Eppendorf, Hamburg, Germany) at -80ºC in the Tissue Lab (room 221) of the Human Kinetics building under lock and key. All samples were stored in duplicate and coded by number to match each participant’s unique identification code, and coding was only known to the researchers involved to ensure anonymity of participant data.
After the antecubital blood sample was collected, resting blood lactate (BLa) concentrations ([ ]) were measured using a standard technique currently used in the Physical Activity and Cardiovascular Research Lab for BLa collections and previously cleared (REB #09197 and 30455) for both resting and exercising BLa samples with a BLa analyzer (Lactate Scout+, EKF Diagnostics, Wales, UK) and a single use safety lancet (Fisherbrand®, Thermo Fisher Scientific., Waltham, MA, USA) (Figure 15).

Figure 15. Blood lactate collection and analysis protocol. 1) The Lactate Scout+ analyzer (A), Lactate Scout Sensor strips (B), Fisherbrand® 1.8mm depth, 21-gauge safety lancet (C), and Fisherbrand® sterile alcohol prep pad (D), which were used for obtaining a single blood droplet and analyzing it for lactate concentrations. 2) The participant’s fingertip was cleaned with the alcohol wipe while the investigator wore protective gloves and safety glasses prior to sampling. 3) Drying of the fingertip with a single use paper towel prior to sampling to avoid contamination of the lactate strip by alcohol. 4) The use of the Fisherbrand® single use safety lancet, which was held against the fingertip and pressed until it clicked. It was disposed of into the sharps container after a single use (only simulated in this photo). 5) The first blood drop was cleared away to avoid contamination of the sample by damaged tissue. 6) The Lactate Scout Sensor strip being touched to the single droplet of blood on the fingertip. Once the droplet had touched the strip adequately and a reading was given by the Lactate Scout+, the testing strip was disposed of into the sharps container. 7) The fingertip being cleaned with a new alcohol wipe post sample. The Fisherbrand® safety lancet and lactate testing strip were disposed of into the sharps container (8). The alcohol wipes and paper towels were disposed of into the biohazardous waste container (9). All areas used were disinfected post-testing with liquid disinfectant.
The tester, wearing goggles and protective gloves, wiped the fingertip of the participant with an alcohol wipe and dried the area with a single use paper towel. The tester then pricked the fingertip using a single use Fisherbrand® 1.8mm depth, 21-gauge safety lancet for the collection of a single drop of capillary blood from the fingertip onto a disposable BLa test strip, which was inserted into the Lactate Scout+. Immediately following collection, the tester wiped the finger with a new alcohol wipe. Following the recording of the BLa value from the Lactate Scout+, the disposable BLa testing strip was immediately disposed of into a sharps container. The Fisherbrand® single use safety lancet was also disposed of into the sharps container. Fingertip BLa measurements were conducted approaching the 2-minute mark of the 3-minute recovery interval between each set of leg extensions. This time point was specifically chosen in order to facilitate the diffusion of intramuscular lactate ([La]) into the bloodstream, which would provide a more accurate estimation of the true intramuscular [La] produced by the leg extensions. Each fingertip BLa measurement was collected from different fingers.

**Resistance training protocols**

Following blood sampling and a 10-minute break, the participant’s resting heart rate and RPE were recorded. Subsequently, they completed a warmup consisting of 2 sets of 12 repetitions of lightly loaded (30% 1RM) leg extensions. Initial quadriceps strength was quantified by completion of three 3-second MVIC tests. After 5 minutes of additional rest to ensure full recovery, participants assigned to Group 1 performed the DS protocol, and participants assigned to Group 2 performed the HT protocol.
**Hypertrophy training protocol**

Participants performed 4 sets of leg extensions at 75% 1RM – chosen because this load resides within the traditional HT load (70-85% 1RM) and repetition range (6-12 repetitions) (Bird et al., 2005). Thus, they were instructed to complete 8-12 repetitions per set, or as many repetitions as possible until momentary muscular failure (Figure 16).

![Figure 16. Hypertrophy training protocol for RT depicting 4 sets. Numbers within boxes represent percentage of the lifter’s 1-repetition maximum load. Numbers between arrows represent recovery interval length. Numbers below boxes represent set number.](image)

The total number of successful and unsuccessful repetitions were recorded. A successful/unsuccessful repetition was operationally defined as the ability/inability to move the given load through the previously defined range of motion. Once momentary muscular failure was achieved following each set of leg extensions (labelled 1, 2, 3, and 4 in Figure 16), the participant’s heart rate was recorded and they were asked to indicate their RPE. At the same time, the MVIC snap hook from the load cell apparatus was attached to the shin pad, and a single 3-second MVIC was performed to assess force decrement and muscle fatigue (Figure 12). The snap hook was then detached and the participant recovered for 3 minutes between each set while remaining seated on the leg extension machine, and was allowed to move their legs freely in passive recovery. At the 2-minute mark of the 3-minute recovery period, a fingertip BLa measurement was taken as described above (REB #09-197, 30-455 – Figure 15). At the end of the 3-minute recovery period, heart rate was recorded again to assess heart rate recovery. This series of leg extensions, along with heart rate, MVIC, RPE, and BLa data collection was repeated during set 2, 3, and 4. Participants were verbally encouraged throughout the RT protocol.
using a pre-written dialogue (Appendix I). Fifteen minutes after the final set and collection of all heart rate, RPE, MVIC, and BLa data, a post-exercise venous blood sample was also collected as described above (REB#10-036, 09-197 and 28-877 – Figure 14). During the 12 minutes post-exercise after the La fingertip blood sample and before IGF-1/IL-6 antecubital blood collection, participants were allowed to passively recover by sitting or walking around the lab and could drink water ad libitum, as an active recovery session before the antecubital blood sampling could have compromised any post-RT changes in IGF-1 and IL-6 plasma levels. Figure 13 shows the detailed timeline of experimental data collection events for the HT and DS protocols.

**Drop set training protocol**

Starting intensity for DS equated to 75% 1RM while aiming to complete 8-12 repetitions, or as many repetitions as possible until momentary muscular failure (Figure 17). A starting intensity of 75% 1RM was chosen since it is the lowest reported starting

![Figure 17](image)

**Figure 17.** Drop set training protocols illustrating 4 drop sets each with 3 load reductions. Based on performance of sets 1 and 2, participants would subsequently receive the upper or lower protocol for sets 3 and 4, with the upper protocol consisting of slightly heavier weights than the lower protocol. Numbers within boxes represent percentage of the lifter’s 1-repetition maximum load. Numbers between arrows represent recovery interval length. Numbers below boxes represent set number.
intensity for drop sets in the available literature (Choi et al., 1998b; Goto et al., 2004; Melibeu Bentes et al., 2012), and matches the traditional HT load (70-85% 1RM) and repetition range (6-12 repetitions) (Bird et al., 2005). Participants rested only long enough after momentary muscular failure to allow the experimenter to reduce the % 1RM load and were instructed to immediately start the next set. The intensity of subsequent sets was reduced by increments of 10% 1RM while completing as many repetitions as possible to momentary muscular failure. Starting intensity was reduced with each subsequent drop set (labelled 2, 3, and 4 in Figure 17) to facilitate consistent completion of 8-12 repetitions while accounting for accumulated fatigue. The total number of successful and unsuccessful repetitions were recorded. Once each drop set was completed (labelled 1, 2, 3, and 4 in Figure 17), the participant’s heart rate was recorded and they were asked to indicate their RPE. At the same time, the MVIC snap hook from the load cell apparatus was attached to the shin pad, and a single 3-second MVIC was performed to assess force decrement and muscle fatigue (Figure 12). After completion of the MVIC, the snap hook was detached and the participant recovered for 3 minutes between each set while remaining seated on the leg extension machine, and could move their legs freely in passive recovery. At the 2-minute mark of the 3-minute recovery period, a fingertip BLa measurement was taken as described above (REB #09-197, 30-455 – Figure 15). At the end of the 3-minute recovery period, heart rate was recorded again to assess heart rate recovery. This heart rate, MVIC, RPE, and BLa data collection was repeated during sets 2, 3, and 4. Participants were verbally encouraged throughout the RT protocol using a pre-written dialogue (Appendix I). Fifteen minutes following completion of the final drop set and collection of all heart rate, RPE, MVIC, and BLa data, a post-exercise venous
blood sample was collected as described above (REB#10-036, 09-197 and 28-877 – Figure 14). During the 12 minutes post-exercise after the La fingertip blood sample and before IGF-1/IL-6 antecubital blood collection, participants were allowed to passively recover by sitting or walking around the lab and could drink water ad libitum, as an active recovery session before the antecubital blood sampling could have compromised any post-RT changes in IGF-1 and IL-6 plasma levels. Figure 13 shows the detailed timeline of experimental data collection events for the HT and DS protocols.

Data analyses

Training volume

Training volume-load was operationally defined as training load • number of successful repetitions completed. Total training volume was obtained by calculating the product of each training load and the number of repetitions completed for those loads, and summing all the resultant volumes together. HT volume-load ($V_{HT}$) was calculated using the following formula:

$$V_{HT} = L \cdot (R_1 + R_2 + R_3 + R_4)$$

where $L = \text{load}$, $R_i = \text{number of successful repetitions completed on the ith set}$ (Appendix J).

DS volume ($V_{DS}$) was calculated using the following formula:

$$V_{DS} = ((L_{1.1} \cdot R_{1.1}) + (L_{1.2} \cdot R_{1.2}) + (L_{1.3} \cdot R_{1.3}) + (L_{1.4} \cdot R_{1.4})) + ((L_{2.1} \cdot R_{2.1}) + \ldots + (L_{2.4} \cdot R_{2.4})) + ((L_{3.1} \cdot R_{3.1}) + \ldots + (L_{3.4} \cdot R_{3.4})) + ((L_{4.1} \cdot R_{4.1}) + \ldots + (L_{4.4} \cdot R_{4.4}))$$

where $L_{ij} = \text{load lifted on the ith set and jth drop set}$; $R_{ij} = \text{number of successful repetitions completed on the ith set and jth drop set}$ (Appendix K).
Time under tension

Time under tension (TUT) was defined as the number of seconds a muscle was neuromuscularly active during RT, as measured via raw electromyography (EMG) recordings (Appendix L, M). Total TUT for HT (TUT_HT) was obtained by calculating the intervals of time the quadriceps were active for using the following formula:

$$TUT_{HT} = TUT_1 (t_2-t_1) + TUT_2 (t_2-t_1) + TUT_3 (t_2-t_1) + TUT_4 (t_2-t_1)$$

where $TUT_i = TUT$ for the $i$th set, $t_1 = time of onset of muscle activation$, and where $t_2 = time of onset of muscle deactivation$. Intervals were obtained by visual inspection of the EMG tracing (Appendix L).

Total TUT for DS (TUT_DS) was obtained by calculating the intervals of time the quadriceps were active for using the following formula:

$$TUT_{DS} = ((TUT_{1.1} (t_2-t_1)) + (TUT_{1.2} (t_2-t_1)) + (TUT_{1.3} (t_2-t_1)) + (TUT_{1.4} (t_2-t_1))) + ((TUT_{2.1} (t_2-t_1)) + ... + (TUT_{2.4} (t_2-t_1))) ... + ((TUT_{3.1} (t_2-t_1)) + ... + (TUT_{3.4} (t_2-t_1))) + ((TUT_{4.1} (t_2-t_1)) + ... + (TUT_{4.4} (t_2-t_1)))$$

where $TUT_{i.j} = TUT$ for the $i$th set and $j$th drop set, $t_1 = time of onset of muscle activation$, and where $t_2 = time of onset of muscle deactivation$. Intervals were obtained by visual inspection of the EMG tracing (Appendix M).

Maximum voluntary isometric contraction force

MVIC force was operationally defined as the peak/max one-second moving average output value detected by the load cell when performing a MVIC. The peak/max one-second moving average output value was operationally defined as the peak MVIC value obtained within a filtered, smoothed, and averaged 1-second epoch of the signal. After being detected by the load cell, the force signal was digitized and stored offline on
a computer. The signals were analyzed using a custom LabView program. The signal was smoothed using a low pass filter. Where the maximum MVIC values were observed, one-second epochs were established, and the maximum value during this epoch was obtained. All data were normalized to each participant’s maximum obtained value pre-exercise.

**Biochemical analyses**

There were 120 plasma samples collected (aliquoted in duplicate) during the study. Samples were thawed on ice and analyzed for IGF-1 and IL-6 proteins using commercially available enzyme-linked immunosorbent assay (ELISA) kits per the manufacturer’s instructions (DG100 and D6050, respectively, R&D Systems, Inc., Minneapolis, MN, USA). Samples, standards, and controls were run in duplicate. The concentrations of all blood markers were uncorrected for changes in plasma volume since these are the concentrations to which potential target tissues would have been exposed. Three 96-well microplates were required to complete the assays for each protein. ELISAs for IGF-1 and IL-6 were run on separate days.

IGF-1 was quantified per the manufacturer’s instructions (DG100, R&D Systems, Inc., Minneapolis, MN, USA). Standards, blanks, and unknown samples were added to three 96-well microplates pre-coated with a monoclonal antibody specific for human IGF-1. Plasma samples were pretreated to release IGF-1 from binding proteins, and thus were diluted by a factor of 100. The plates were washed after a 2-hour incubation period at 2-8°C, and an enzyme-linked polyclonal antibody specific to IGF-1 conjugated to horseradish peroxidase was added to the wells. Following a second 1-hour incubation period at 2-8°C and another wash, a substrate solution was added to the wells to allow colour to develop for 30 minutes in the dark. Colour development was terminated by the
addition of sulfuric acid. The optical density (OD) of each well was read at 450 nm on a microplate reader (Synergy™ HT, BioTek Instruments, Inc., VT, USA). Software capable of generating a log-log curve fit was used to create a standard curve (Gen5™ version 1.11.5, BioTek Instruments, Inc., VT, USA). A background correction step was included in the analysis (i.e. the mean OD of the control sample was subtracted from the mean OD of the standards and unknown samples). The concentrations of the unknown samples (in ng/mL) were interpolated from the standard curve and multiplied by the dilution factor 100. All samples fell within the range of the standard curve. Of the 120 samples, 36 measured between 75 ng/mL and 150 ng/mL, and 84 samples measured between 150 ng/mL and 300 ng/mL. Inter-assay percentage coefficient of variation (%CV) was 0.89%. Intra-assay %CV was 2.06%. This assay recognizes only natural and recombinant human IGF-1, with the manufacturer reporting no significant cross-reactivity or interference of 14 other binding proteins.

IL-6 was quantified per the manufacturer’s instructions (D6050, R&D Systems, Inc., Minneapolis, MN, USA). Standards, blanks, and unknown samples were added to three 96-well microplates pre-coated with a monoclonal antibody specific for human IL-6. Plasma samples were not diluted. The plates were washed after a 2-hour incubation period at room temperature, and an enzyme-linked polyclonal antibody specific to IL-6 conjugated to horseradish peroxidase was added to the wells. Following a second 2-hour incubation period at room temperature and another wash, a substrate solution was added to the wells to allow colour to develop for 25 minutes in the dark. Colour development was terminated by the addition of sulfuric acid. The OD of each well was read at 450 nm on a microplate reader (Synergy™ HT, BioTek Instruments, Inc., VT, USA). Software
capable of generating a four-parameter logistic (4PL) curve fit was used to create a standard curve (Gen5™ version 1.11.5, BioTek Instruments, Inc., VT, USA). A background correction step was included in the analysis. The concentrations of the unknown samples (in pg/mL) were interpolated from the standard curve. Samples with a mean OD that was outside the lower bound of the curve were given a value of 0. There were no samples that yielded a mean OD that was outside the upper bound of the curve. Of the 120 samples, 61 measured less than or equal to 0 pg/mL, 57 measured between 0 pg/mL and 3.13 pg/mL, and 2 measured between 6.25 pg/mL and 25 pg/mL. Inter-assay %CV was 12.24%. Intra-assay %CV was 14.08%. This assay recognizes only natural and recombinant human IL-6, with the manufacturer reporting no significant cross-reactivity or interference of 37 other factors.

**Experimental design and statistical analysis**

The study used a randomized, counterbalanced, repeated measures design. A repeated measures design was used to minimize the inter-individual variability of the hypertrophic response to resistance training (Kelleher et al., 2010; West et al., 2010), which may be very large (Hubal et al., 2005). The repeated measures design also allowed all participants to participate in both conditions and counterbalancing controlled for any potentially confounding carry-over effects due to testing order (i.e. Group 1: DS → HT, or Group 2: HT → DS). Using a repeated measures design, the minimum sample size necessary to detect significant changes was 24 participants, with alpha set at 0.05, power set at 0.7, and effect size estimated at 0.8. The study successfully recruited 32 participants with a 93.75% retention rate, resulting in a total of 30 participants completing the study.
Reasons for participant dropout included chronically high (> 5 mmol/L) BLa levels and voluntary withdrawal.

Statistical analyses were performed using IBM SPSS Statistics for Mac version 24.0 (IBM Corp., Armonk, NY). All data including descriptive statistics are presented as means and standard errors (SE). Data was analyzed using a 2 (Training Type: DS, HT) × 2 (Time: pre-exercise, post-exercise) repeated measures ANOVA to test the differences in concentrations of IGF-1 and IL-6 during DS and HT at the specified time points. In addition, a 2 (Training Type: DS, HT) × 5 (Time: pre-exercise, set 1, set 2, set 3, set 4) repeated measures ANOVA tested the differences in, heart rate, RPE, BLa, and MVIC force production during DS and HT at the specified time points. Lastly, a one way repeated measures ANOVA tested the differences in training volume and TUT during DS and HT.

Most of the data met the assumption of normality, however, even when certain data violated this assumption, the ANOVA is remarkably robust to deviations from normality, and transformations to non-normal data were unnecessary. Most of the data also met the assumption of sphericity, however, when the assumption of sphericity was violated, $F$ statistics were reported using the Greenhouse-Geisser Epsilon correction factor. Mean differences were considered statistically significant where $p < .05$. When a significant $F$ value was found, pair-wise comparisons were performed using a Bonferroni post hoc procedure. A partial eta-squared test ($\eta^2_p$) was performed on each interaction to test the effect size for any statistical effect found.
Participant confidentiality

Participants’ personal information and testing results were stored confidentially. Digital data was secured on a password-protected computer and backed up on an external hard drive. Hard copies of data were locked in the principle investigator’s office. All personal data was stored under a unique participant identification number, rather than the participant’s name. The lead investigator and the laboratory assistants were the only ones to have access to the personal data. Participants were notified that they were free to withdraw from the investigation at any point in time.
RESULTS

Descriptive statistics

Male participant characteristics are outlined in Table 1.

Table 1. Male participant characteristics (n = 30).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.57 ± 0.50</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.79 ± 0.01</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.74 ± 1.76</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>24.59 ± 0.42</td>
</tr>
<tr>
<td>Leg extension 1RM (kg)</td>
<td>206.36 ± 5.73</td>
</tr>
</tbody>
</table>

Training volume

Leg extension training volume (expressed as volume-load (total kilograms lifted) (A) and total number of repetitions completed (B)) for hypertrophy training (HT) and drop set training (DS) are found in Figure 18. There was a significant main effect of

![Figure 18](image)

**Figure 18.** Total leg extension training volume using hypertrophy training (HT, black; n = 30) versus drop set training (DS, white; n = 30). A: Volume is expressed as total kilograms lifted on the left, and B: total number of repetitions on the right. Values are means ± SE. "a": p < .05 between HT and DS.

Training Type for total volume load (F (1, 29) = 434.134, p < .001, η²_p = .937). Total volume load was 2.24 times greater in DS (17,333.75 kg ± 587.15 kg) compared to HT (7721.63 kg ± 281.898). There was also a significant main effect of Training Type for total number of repetitions (F (1, 29) = 842.405, p < .001, η²_p = .967). Total number of repetitions was 3.35 times greater in DS (168.07 ± 4.25) compared to HT (50.13 ± 1.3).
**Time under tension**

Time under tension (TUT) experienced by the quadriceps per set of exercise and per workout for HT and DS are found in Figure 19. There was a significant main effect of Training Type on TUT ($F(1, 29) = 2074.926, p < .001, \eta^2_p = .986$). TUT was 3.12 times greater in DS (195.80 s ± 3.32) compared to HT (62.79 s ± 2.14).

**Figure 19.** Time under tension (TUT) measured in seconds throughout leg extension training using hypertrophy training (HT; n = 30) versus drop set training (DS; n = 30). Numbers within boxes indicate TUT for described set. Number at top of bar indicates total TUT for the protocol. Values are means ± SE. "a, p < .05 between HT and DS.
Heart rate responses after each set of resistance training (RT) and after each recovery interval for HT and DS are found in Figure 20. No significant differences in heart rate were found between HT and DS pre-exercise (71.40 ± 2.06 vs 73.37 ± 2.04; \( p = .233 \)). There was a significant Training Type \( \times \) Time interaction effect for heart rate (\( F(2.923, 84.761) = 18.390, p < .001, \eta^2_p = .388 \)). As illustrated in Figure 20, heart rate was significantly higher in DS compared to HT at set 1 (132.97 ± 3.13 vs 122.40 ± 2.35; \( p = .003 \)), set 2 (139.10 ± 3.39 vs 124.1 ± 3.26; \( p < .001 \)), set 3 (145.87 ± 3.56 vs 124.97 ± 3.07; \( p < .001 \)), and set 4 (148.57 ± 3.64 vs 131.13 ± 3.42; \( p < .001 \)).
For HT, heart rate increased significantly from pre-exercise to set 1 ($p < .001$), and from set 3 to set 4 ($p = .01$), and increased, but not significantly, from set 1 to set 2 ($p = 1$), and from set 2 to set 3 ($p = 1$). The difference in heart rate between set 1 and set 4 and between set 2 and set 4, however, were significant ($p = .012$ and $p = .008$, respectively).

For DS, heart rate increased significantly from pre-exercise to set 1 ($p < .001$), from set 1 to set 2 ($p = .001$), and increased, but not significantly, from set 2 to set 3 ($p = .346$), and from set 3 to set 4 ($p = 1$). The difference in heart rate between set 2 and set 4, however, was significant ($p < .001$).
Borg ratings of perceived exertion

Borg’s rating of perceived exertion scores (RPE) following each set of exercise for HT and DS are found in Figure 21. All participants were assigned a RPE score of 6 pre-exercise by default, so there was no difference in RPE between HT (6 ± 0) and DS (6 ± 0) pre-exercise. There was a significant Training Type × Time interaction effect for RPE (F(4, 116) = 13.666, p < .001, \( \eta_p^2 = .320 \)). As illustrated in Figure 21, RPE was significantly larger in DS compared to HT at set 1 (14.98 ± .32 vs 13.10 ± .32; \( p < .001 \)), set 2 (16.57 ± .32 vs 13.97 ± .33; \( p < .001 \)), set 3 (16.82 ± .35 vs 14.70 ± .35; \( p < .001 \)), and set 4 (17.08 ± .39 vs 15.47 ± .39; \( p = .001 \)).
For HT, RPE increased significantly from pre-exercise to set 1 ($p < .001$), from set 1 to set 2 ($p < .001$), and from set 3 to set 4 ($p = .009$). RPE trended towards a significant increase from set 2 to set 3 ($p = .055$).

For DS, RPE increased significantly from pre-exercise to set 1 ($p < .001$), and from set 1 to set 2 ($p < .001$), and increased, but not significantly, from set 2 to set 3 ($p = 1$), and from set 3 to set 4 ($p = 1$). The difference in RPE between set 2 and set 4 was also not significant ($p = .956$).
**Blood lactate**

Changes in blood lactate (BLa) concentrations ([ ] ) following each set of exercise for HT and DS are found in Figure 22. No significant differences in [BLa] were observed between HT and DS pre-exercise (1.65 ± .05 vs 1.66 ± .08; *p* = .94). There was a significant Training Type × Time interaction effect for [BLa] (*F* (4, 116) = 45.754, *p* < .001, *η²*₁ = .612). As illustrated in Figure 22, [BLa] was significantly larger in DS compared to HT at set 1 (7.32 ± .25 vs 4.13 ± .13; *p* < .001), set 2 (8.44 ± .35 vs 5.57 ± .22; *p* < .001), set 3 (8.88 ± .35 vs 6.88 ± .28; *p* < .001), and set 4 (9.01 ± .34 vs 7.35 ± .31; *p* < .001).

*Figure 22.* Changes in blood lactate concentration (expressed in millimoles per litre (mmol/L)) after each set of leg extension exercise using hypertrophy training (HT, closed markers; *n* = 30) versus drop set training (DS, open markers; *n* = 30). PRE: pre-exercise. Values are means ± SE. *a*: *p* < .05 between HT and DS. *b*: *p* < .05 from previous set. All measurements were significantly different from PRE.
For HT, [BLa] increased significantly from pre-exercise to set 1 \( (p < .001) \), from set 1 to set 2 \( (p < .001) \), and from set 2 to set 3 \( (p < .001) \), and increased, but not significantly, from set 3 to set 4 \( (p = .326) \). The difference in [BLa] between set 2 and set 4, however, was significant \( (p < .001) \).

For DS, [BLa] increased significantly from pre-exercise to set 1 \( (p < .001) \), from set 1 to set 2 \( (p = .005) \), and increased, but not significantly, from set 2 to set 3 \( (p = .447) \), and from set 3 to set 4 \( (p = 1) \). However, the difference in [BLa] between set 1 and set 4 was significant \( (p < .001) \) and the difference in [BLa] between set 2 and set 4 trended towards significance \( (p = .076) \).
Maximum voluntary isometric contraction force

Mean changes in maximum voluntary isometric contraction (MVIC) force output following each set of exercise for HT and DS are found in Figure 23. MVIC normalized to %PRE MVIC resulted in no significant difference observed between HT and DS ($p = 1$). There was a significant Training Type $\times$ Time interaction effect for MVIC ($F(2.586, 84.461) = 30.591, p < .001, \eta^2_p = .513$). As illustrated in Figure 23, MVIC was significantly lower in DS compared to HT at set 1 ($83.51 \pm 2.44$ vs $95.24 \pm 1.31; p < .001$), set 2 ($78.97 \pm 2.44$ vs $96.88 \pm 2.18; p < .001$), set 3 ($74.13 \pm 3.03$ vs $94.37 \pm 2.32; p < .001$), and set 4 ($71.17 \pm 3.39$ vs $99.45 \pm 2.48; p < .001$).
For HT, MVIC decreased significantly from pre-exercise to set 1 \( (p = .011) \), and increased significantly from set 3 to set 4 \( (p = .025) \). MVIC at set 1 was not significantly different from set 2 \( (p = 1) \), set 3 \( (p = 1) \), or set 4 \( (p = .695) \). MVIC at set 2 was not significantly different from pre-exercise \( (p = 1) \), set 3 \( (p = .104) \) or set 4 \( (p = .904) \). MVIC force at set 3 was not significantly different from pre-exercise \( (p = .221) \). MVIC force at set 4 was not significantly different from pre-exercise \( (p = 1) \).

For DS, MVIC decreased significantly from pre-exercise to set 1 \( (p < .001) \), and trended towards a significant decrease from set 1 to set 2 \( (p = .058) \). MVIC then decreased significantly from set 2 to set 3 \( (p = .022) \) and decreased, but not significantly, from set 3 to set 4 \( (p = 1) \). The differences in MVIC between set 1 and all other sets were significant (or trending toward significance) \( (set 2: p = .058, set 3: p < .001, set 4: p < .001) \). The differences in MVIC between set 2 and all other sets were significant (or trending toward significance) \( (set 3: p = .022, set 4: p = .012) \). MVIC was significantly different between pre-exercise and set 4 \( (p < .001) \).
IGF-1

Evaluation for the presence of human insulin-like growth factor (IGF)-1 in 120 plasma samples collected pre- and post-exercise in both HT and DS (Figure 24) was completed using a commercially available enzyme-linked immunosorbent assay (ELISA) kit (DG100, R&D Systems, Inc., Minneapolis, MN, USA). There was a significant main effect of Training Type for IGF-1 ($F(1, 29) = 15.681$, $p < .001$, $\eta^2_p = .351$); the mean plasma [IGF-1] was significantly higher in DS than HT (172.99 ± 6.13 vs 162.56 ± 6.18).

There was also a significant main effect of Time for IGF-1 ($F(1, 29) = 8.869$, $p = .006$, $\eta^2_p = .234$); the mean [IGF-1] significantly increased from pre- to post-exercise (165.96 ±
6.03 vs 169.58). These main effects were not qualified by a Training Type × Time interaction ($F(1, 29) = .083, p = .775, \eta^2_p = .003$).
IL-6

Evaluation for the presence of human interleukin (IL)-6 in 120 plasma samples collected pre- and post-exercise in both HT and DS (Figure 25) was completed using a commercially available ELISA kit (D6050, R&D Systems, Inc., Minneapolis, MN, USA). Plasma [IL-6] increased from 0 pg/mL pre-exercise to > 0 pg/mL post-exercise in 13 participants, however, there were no significant main or interaction effects to report.
DISCUSSION AND CONCLUSION

During typical hypertrophy training (HT) consisting of 4 sets at 75% of the lifter’s one repetition maximum load (1RM), individuals often experience training plateaus (Figure 2), where the continuation of HT results in little or no muscle protein synthesis (MPS) and minimizes hypertrophic gains (Peterson et al., 2005; Schoenfeld, 2012). To re-stimulate the hypertrophic response to resistance training (RT), strength and conditioning specialists may prescribe drop set training (DS), which maintains the structure of the typical HT design, but once the first set of 10-12 repetitions to momentary muscular failure is completed, includes the addition of one or several sets at progressively reduced loads also to failure before any recovery (see Figure 4 for examples). Increasing the volume of RT by completing more sets per muscle group typically has been shown to increase the magnitude and duration of MPS and muscle hypertrophy (Burd et al., 2010a; Krieger, 2010; S. M. Phillips, Tipton, Aarsland, Wolf, & Wolfe, 1997). Thus, DS protocols may provide the necessary physiological stimulus to reinitiate hypertrophic adaptations during a training plateau (Pearson & Hussain, 2014; Schoenfeld, 2011) by significantly increasing training volume-load (repetitions × load), time under tension (TUT), and stressing skeletal muscle metabolism compared to HT (Folland et al., 2002). This study aimed to determine if a DS leg extension protocol was superior to a typical HT leg extension protocol in acutely triggering the release of the potential anabolic mediators insulin-like growth factor (IGF)-1 and interleukin (IL)-6 post-exercise, which may contribute to the hypertrophic adaptations to RT.

The HT protocol was composed of 4 sets at 75% 1RM, with 3 minute rest intervals between sets (Figure 16). The DS protocol was composed of 4 sets, each with 3
progressive load reductions per set (load range: 75-30% 1RM, ~10% load reductions, ~10-12 repetitions per load), resulting in a total of 16 bouts to momentary muscular failure (Figure 17). There was no rest taken between load reductions, and 3 minute recovery intervals were taken between sets. DS generated over 2 times more volume-load (Figure 18A) and over 3 times more TUT (Figure 19) than HT. The mean volume-load data from our study showed similar, if not larger differences between DS and HT compared to other DS studies (Choi et al., 1998b; Goto et al., 2003; Melibeu Bentes et al., 2012) and was comparable to the volume generated by typical full body HT and lower body HT protocols employed in other studies (McKay et al., 2009; Mitchell et al., 2013; Nieman et al., 2004; M. D. Phillips et al., 2010). Burd et al. (2010a; 2012a) have suggested that significantly larger volume-load and TUT is crucial in promoting a more hypertrophic environment by upregulating MPS, enhancing local metabolic stress, and subsequently enhancing the formation of anabolic mediators. Physiologically, this significant increase in both volume-load and TUT observed in DS was matched by significantly higher heart rate responses (Figure 20), Borg rating of perceived exertion scores (RPE – Figure 21), and blood lactate (BLa) concentrations ([ ]) (Figure 22) than HT with each set. This indicates that the 4 DS loads lifted to failure without rest resulted in a higher exercise intensity and triggered a higher anaerobic glycolytic demand for adenosine triphosphate (ATP) production, and would maximize Type II muscle fiber activation (Burd et al., 2012a; Carpinelli, 2008). Given the single muscle group recruited and volume-load generated in our leg extension protocol, the higher [BLa] seen in DS appears comparable to other RT studies (Goto et al., 2005; Izquierdo et al., 2009) and
supports the results of previous DS research showing a higher anaerobic energy demand (de Paula Simola et al., 2015; Goto et al., 2003).

To determine if the differences in volume-load, TUT, RT protocol intensity (heart rate and RPE), and [BLa] collectively contributed to differences in acute muscle performance following DS and HT, we determined quadriceps maximum voluntary isometric contraction (MVIC) force output immediately following the completion of each set in both training protocols (Figure 23). After set 1, our HT data showed a small but significant 4.83% decline in MVIC force production, which we speculate may be a result of our initial warmup of 2 sets of 12 repetitions of leg extensions at 30% 1RM being too low to sufficiently increase the rate of quadriceps energy metabolism pre-exercise (Petrofsky, Laymon, & Lee, 2013). However, following a 3 minute recovery period and completion of each additional set, there was no decrease in MVIC force.
As Figure 26A depicts, the maintenance of MVIC force observed after each subsequent HT set of 75% 1RM to failure may be attributed to sufficient ATP availability and phosphocreatine (PCr) for ATP resynthesis (ATP → ADP + P_i + Mg^{2+}, PCr + ADP → ATP; see ① in Figure 26A), allowing for regular functioning of the ryanodine receptor (RyR), sarcoplasmic reticulum (SR) calcium (Ca^{2+}) release (⑥), actin-myosin interaction (⑦) and myosin ATPase activity (⑧) to generate isometric force during HT set of 75% IRM to failure.
skeletal muscle excitation/contraction coupling (ECC). Additionally, the maintenance of MVIC force indicates a minimal accumulation and/or sufficient removal of potential force-inhibiting metabolic by-products, such as adenosine diphosphate (ADP), inorganic phosphate (P_i), and magnesium ions (Mg^{2+}) generated from the hydrolysis of ATP by myosin ATPase, or hydrogen ions (H^+) from the formation of ATP and Lactate (La^- + H^+) during increased anaerobic glycolysis (Glycolysis \rightarrow ATP + (La^- + H^+), see ② in Figure 26A).

In contrast to HT, DS MVIC force following set 1 showed a significant decline of 16.5% compared to pre-exercise, and, despite 3 minute recovery intervals between sets, MVIC force progressively decreased to 21%, 25.8%, and 28.8% of pre-exercise after set 2, 3, and 4, respectively. As Figure 26B depicts, the continuous loss in MVIC force with each set of repetitively fatiguing DS may be attributed to a significant decline in ATP from increased myosin ATPase activity and a subsequent increase in intramuscular force-inhibiting metabolic by-products (↓ATP \rightarrow ↑ADP + ↑P_i + ↑Mg^{2+}, see ⑨ Figure 26B), disrupting the skeletal muscle ECC process. Additionally, as limited PCr stores are depleted during DS, ADP continues to accumulate and ATP resynthesis slows, reducing overall ATP availability (↓PCr + ↑ADP \rightarrow ↓ATP, see ⑨ in Figure 26B). Decreased binding of ATP and increased binding of Mg^{2+} to RyR can reduce RyR activation and SR Ca^{2+} release during fatigue (⑩ in Figure 26B) (Lamb, 2000). To maintain ATP availability during repetitively fatiguing DS, the synthesis of ATP from anaerobic glycolysis increases, leading to an accumulation of lactate (La^- and H^+), which can reduce intramuscular pH (↑Glycolysis \rightarrow ↑ATP + (↑La^- + ↑H^+), ↓pH, see ⑪ in Figure 26B) (Lamb & Stephenson, 2006). The accumulated H^+ will compete with SR Ca^{2+} for Ca^{2+}
binding sites on troponin, competitively inhibiting actin-myosin interaction (\(^{12}\) in Figure 26B) (Debold, 2012). Furthermore, a reduction in myosin ATPase enzymatic activity with decreased [ATP] and decreased pH will further reduce actin-myosin interaction and reduce MVIC force generation following fatiguing DS (\(^{13}\) in Figure 26B) (MacIntosh, Holash, & Renaud, 2012).

There has been a long-standing belief in the literature that a well-designed HT program involving large volume, moderate intensity, and short rest intervals may potentially maximize acute spikes in circulating anabolic hormones (e.g. growth hormone, testosterone, and IGF-1), which may have both direct and permissive effects on the stimulation of MPS (Kraemer & Ratamess, 2005; Rønnestad, Nygaard, & Raastad, 2011; Spiering et al., 2008), and have been used as potential markers for muscle hypertrophy in HT research for decades (Kraemer et al., 1990).

Specifically, IGF-1 exogenously administered at physiological levels can stimulate MPS in skeletal muscle without muscle contraction (Philippou, Maridaki, Halapas, & Koutsilieris, 2007; Song et al., 2005), and is synthesized in the liver and in working muscle during RT (Goldspink, 2005). Recent RT research has also reported that overloaded skeletal muscle transiently produces and releases cytokines, with IL-6 specifically showing promise as an anabolic mediator in both \textit{in vivo} animal models (Serrano et al., 2008) and in humans (McKay et al., 2009). Further, multiple IGF-1 isoforms (e.g. IGF-1Ea, b, and c) and IL-6 synthesized and released by working skeletal muscle may contribute to the proliferation, differentiation, and fusion of satellite cells into muscle fibers (Philippou et al., 2007). These satellite cells, which are located between the skeletal muscle sarcolemma and basal lamina, become a part of the muscle...
fiber and donate their nuclei to increase the rate of muscle protein transcription, translation, and synthesis, which can lead to increased muscle hypertrophy (Goldspink, 2005; Serrano et al., 2008).

We investigated if a fatiguing 4 set DS leg extension protocol designed to exceed a typical HT protocol in volume-load, TUT, and metabolic stress was superior in acutely triggering the systemic release of the potential anabolic mediators IGF-1 and IL-6 post-exercise. The mean resting [IGF-1] for both HT and DS (Figure 24) fell within the normal range for recreationally active males 18-28 years of age (Hay & Wass, 2009), but were significantly different between training protocols. Given this was a randomized, counterbalanced, within-subjects design, and circulating IGF-1 does not follow circadian variation in healthy adults (Oscarsson et al., 1997; Skjaerbaek et al., 2000), we have no explanation for this difference in resting values. Additionally, plasma [IL-6] in resting healthy adults are typically less than 1 pg/mL (Fischer, 2006), which was seen in both the HT and DS groups (Figure 25), with no significant differences observed between training types.

As previous research has shown that the synthesis and release of IGF-1 and IL-6 is related to RT volume and exercise intensity (McKay et al., 2009; Mitchell et al., 2013; Nieman et al., 2004; M. D. Phillips et al., 2010; Rubin et al., 2005; West et al., 2010), we expected small and perhaps insignificant increases in these markers following HT, and a significantly larger release of both IGF-1 and IL-6 post-exercise in DS due to the significantly larger total volume-load (Figure 18), TUT (Figure 19), and metabolic stress ([BLa] – Figure 22) incurred. However, there was only a small 2% increase in plasma [IGF-1] post-exercise after both DS and HT, suggesting that our RT protocols had little
effect on IGF-1 synthesis. Our data also showed no significant changes in plasma [IL-6] from pre- to post-exercise between or within the DS and HT protocols.

These insignificant changes in IGF-1 and IL-6 suggest that our DS and HT protocols may not have recruited enough muscle mass or the duration of the RT bouts may not have lasted long enough to stimulate appreciable synthesis of IGF-1 and IL-6 (Fischer, 2006; Pedersen & Febbraio, 2008; Popov et al., 2015). Previous experimental designs have reported significant elevations in IGF-1 (Rubin et al., 2005; West et al., 2010) or IL-6 (Mitchell et al., 2013; Nieman et al., 2004; M. D. Phillips et al., 2010) by employing HT programs recruiting several large muscle groups capable of lifting heavy weights during full body or lower body programs. These HT programs recruited significantly more muscle than our leg extension protocol, which recruited only the quadriceps, potentially accounting for their elevated synthesis of IGF-1 and IL-6.

Additionally, our DS and HT protocols required 12 minutes or less to complete, while the majority of HT experimental designs triggering increases in IGF-1 lasted approximately 30 minutes (Rubin et al., 2005; West et al., 2010), and those triggering increases in IL-6 lasted 45 minutes or longer (Izquierdo et al., 2009; McKay et al., 2009; Mitchell et al., 2013; Nieman et al., 2004; M. D. Phillips et al., 2010). Since we saw no significant differences between DS and HT in triggering IGF-1 or IL-6 release, our data indicate that RT protocols generating high volume-load, requiring 12 minutes or less to complete, and recruiting a single large muscle group are less likely to stimulate the release of anabolic mediators, even when RT volume, metabolic stress, and exercise intensity are high. Thus, our data suggest that DS is effective for reducing RT bout duration, but may not be ideal for optimizing acute anabolic stimuli when isolated to a
single exercise. Future DS research should focus on protocol designs including additional exercises that recruit more muscle groups (e.g. a full body DS protocol), which would also increase RT bout duration. This DS design may theoretically recruit the required muscle mass and generate the increased RT duration and intensity required to produce a significant increase in IGF-1 and IL-6 synthesis, without sacrificing the volume, metabolic stress, or intensity that DS provides.

Interestingly, while we had expected a larger systemic increase in IGF-1 in our acute DS design, West et al. (2010) reported significant hypertrophy of the biceps brachii over 15 weeks of HT with no significant acute elevations in any anabolic hormones during each training session. Several investigators have reported that increasing the systemic concentrations of putative anabolic hormones during acute RT may not be necessary for upregulating MPS or promoting muscle hypertrophy with training (Morton et al., 2016; Schroeder, Villanueva, Phillips, & West, 2013; West et al., 2010; West & Phillips, 2010). Further, our DS protocol incorporated several RT factors suggested by others (Burd et al., 2012a; Burd et al., 2010a; Burd, Mitchell, Churchward-Venne, & Phillips, 2012b) to be more relevant for maximizing MPS, including high volume and TUT, and repetitively causing momentary muscular failure, which is thought to maximize muscle fiber recruitment irrespective of the size of the load being lifted (Burd et al., 2012b; Carpinelli, 2008). Thus, despite the observed small IGF-1 response, it is possible that our short DS program could still result in muscle hypertrophy by triggering activators of MPS not assessed in this study, especially with long-term training. Therefore, extension of this DS research should also focus on attempting to quantify changes in intramuscular levels of IGF-1 and IL-6 and their specific local effects on MPS in both acute and chronic RT
regiments, with a potential focus on Type II muscle fibers, which are more prone to hypertrophy (Carpinelli, 2008; Cormie et al., 2011).

It is reported that intramuscular IL-6 is produced under a positive feedback loop, with concentrations increasing exponentially until exercise is terminated, peaking immediately post-exercise, and returning to baseline concentrations several hours post-exercise (Fischer, 2006; Nieman et al., 2004; Peake, Nosaka, Muthalib, & Suzuki, 2006; M. D. Phillips et al., 2010). Since we chose to measure plasma [IL-6 and IGF-1] 15 minutes post-exercise, as others have (Mitchell et al., 2013; West et al., 2010), it is possible that our single sampling time point may have missed the peak for [IL-6] (McKay et al., 2009; Peake et al., 2006). Nonetheless, it is more likely that the design of our DS protocol, which recruited a single muscle group and minimized RT duration, triggered no significant IL-6 response (Buford, Cooke, & Willoughby, 2009; Fischer, 2006; Pedersen & Febbraio, 2008; M. D. Phillips et al., 2010; Uchida et al., 2009).

In a practical setting, the DS technique is thought to enhance muscle fiber recruitment, metabolic stress, and production of anabolic markers during standard HT workouts within a similar workout duration, potentially helping to overcome RT plateaus and reinitiate gains in muscle hypertrophy (Schoenfeld, 2011). We provide evidence showing that DS can be designed to provide significantly more volume-load and TUT, and trigger significantly higher heart rate, RPE, [BLa], and MVIC force decrement compared to a standard HT protocol. However, our results have also indicated that, when isolated to a single muscle group, the short duration of DS protocols may not elevate the acute systemic circulation of IGF-1 or IL-6. Nonetheless, the effect of DS on enhancing muscle hypertrophy is unclear and will require implementation into long-term DS studies.
with designs that recruit more muscle groups and last at least 45 minutes in length. It also remains unclear whether systemic measurements of [IGF-1 and IL-6] serve as accurate indicators of muscle anabolism, which may be better determined by investigating the effects of our DS protocol on muscle hypertrophy by measuring changes in acute MPS rates via examining radiolabeled amino acid incorporation into muscle protein and/or decreases in protein catabolism. Future work should also recruit both females and elderly participants in order to extend these findings beyond the young male cohorts recruited in DS research to date.

In summary, our study has shown that DS can be designed to maximize volume-load, TUT, and anaerobic metabolic stress placed on working muscle, which are all well established as important factors driving muscle hypertrophy during HT. Thus, this thesis may serve as a sufficient base for future research investigating how repetitively fatiguing DS can be used to reinitiate hypertrophic mechanisms, potential neurological adaptations, and overcome strength plateaus during RT.


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APPENDICES

Appendix A

Weightlifting study

MALE VOLUNTEERS NEEDED:

To investigate the acute effects of leg extension resistance training comparing two weightlifting techniques on different physiological markers that might increase muscle size and strength.

Sign up for a University of Windsor Kinesiology graduate thesis study:

“The acute physiological responses of leg extension resistance training using drop sets versus standard hypertrophy training in the quadriceps femoris”

You are eligible to participate if:
- You are 18-25 years old
- You have no history of knee pain, injury, or surgery
- You have been lifting weights at least twice a week for the last 3 months

Your participation will involve 3 sessions each no longer than 70 minutes. You will receive a Kinesiology Research t-shirt and entries into a draw for a $50 Sport Chek gift card for participating!

This study has been reviewed by, and received ethics clearance through the University of Windsor Research Ethics Board (REB#...).

If interested, contact Alex Waugh at waugh5@uwindsor.ca for more information about the study, or to schedule your first session!
Appendix B

To: HK-Kinesiology and University of Windsor Student Body

From: Masters Thesis Student – Alex Waugh, and Advisor – Dr. Kenji Kenno

Subject: Male volunteers needed for a weightlifting study using drop sets

I am currently recruiting participants for my graduate master’s thesis project investigating the acute responses of a leg extension RT protocol comparing two weightlifting techniques on different physiological markers that might potentially increase muscle size and strength. The study will involve 3 sessions including a familiarization and baseline measurement session, and two training sessions, which will be scheduled around your availability. The sessions will be scheduled no less than 1 week apart, with each session lasting approximately 60-70 minutes.

This would be a great opportunity for you to learn about some of the applied research that takes place here in Kinesiology as well as discover a new weightlifting technique to incorporate into your own training. We are looking for 18-30-year-old, recreationally active males who have exercised at least 2 times per week for the past 3 months, that will be able to schedule these training sessions over approximately 3-4 weeks. These sessions will consist of leg extension exercise performance testing, RT, and taking a small amount of blood for analysis, which shouldn’t affect your regular activity.

This study has been reviewed by, and received ethics clearance through the University of Windsor Research Ethics Board (REB# 16-031).

If interested or for more information, contact:

Alex Waugh at waugh5@uwindsor.ca (phone: (226) 345-8888)
Appendix C

Emergency Action Plan (EAP)

for Medical Emergencies during Exercise Testing

STEP 1: REMAIN CALM.
CONTROL and ASSESS the situation.
DESIGNATE a person to CALL and meet EMERGENCY PERSONNEL:

911 OR Campus Police EXT. 4444
(they will dispatch required authorities)

OUR ADDRESS/DIRECTIONS:
The University of Windsor
Human Kinetics Building
2555 College Ave.
Main Entrance off College Ave.
Room 202 (uppermost floor)

Directions: Enter the HK building at the North entrance and
head up the staircase on the left. Take your first right and
Room 202 is immediately on the right.

Multi-Purpose Research Lab: (519) 253-3000 ext. 4280

Alex Waugh: [number]
Dr. Kenji Kenno: [number]

STEP 2: PERFORM all measures (CPR/First Aid) to ensure safety of subject.
ATTEND to subject until replaced by emergency personnel.

STEP 3: CREATE a Department of Kinesiology Incident Report.
Appendix D

2015 PAR-Q+
The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

<table>
<thead>
<tr>
<th>Please read the 7 questions below carefully and answer each one honestly: check YES or NO.</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2) Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3) Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? PLEASE LIST CONDITION(S) HERE:</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5) Are you currently taking prescribed medications for a chronic medical condition? PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past, but it does not limit your current ability to be physically active. PLEASE LIST CONDITION(S) HERE:</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7) Has your doctor ever said that you should only do medically supervised physical activity?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

- If you answered NO to all of the questions above, you are cleared for physical activity. Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.
  - Start becoming much more physically active – start slowly and build up gradually.
  - Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
  - You may take part in a health and fitness appraisal.
  - If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
  - If you have any further questions, contact a qualified exercise professional.

- If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

- Delay becoming more active if:
  - You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
  - You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X at www.eparmedx.com before becoming more physically active.
  - Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.
## 2015 PAR-Q+
**FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)**

1. **Do you have Arthritis, Osteoporosis, or Back Problems?**
   - If the above condition(s) is/are present, answer questions 1a-1c
   - If NO ☐ go to question 2

1a. **Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?**
   - Answer NO ☐ if you are not currently taking medications or other treatments

1b. **Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebrae (e.g., spondylolisthesis), and/or spondylolysis/ pars defect (a crack in the bony ring on the back of the spinal column)?**

1c. **Have you had steroid injections or taken steroid tablets regularly for more than 3 months?**

2. **Do you have Cancer of any kind?**
   - If the above condition(s) is/are present, answer questions 2a-2b
   - If NO ☐ go to question 3

2a. **Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?**

2b. **Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?**

3. **Do you have a Heart or Cardiovascular Condition?**
   - This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm
   - If the above condition(s) is/are present, answer questions 3a-3d
   - If NO ☐ go to question 4

3a. **Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?**
   - Answer NO ☐ if you are not currently taking medications or other treatments

3b. **Do you have an irregular heart beat that requires medical management?**
   - (e.g., atrial fibrillation, premature ventricular contraction)

3c. **Do you have chronic heart failure?**

3d. **Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?**

4. **Do you have High Blood Pressure?**
   - If the above condition(s) is/are present, answer questions 4a-4b
   - If NO ☐ go to question 5

4a. **Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?**
   - Answer NO ☐ if you are not currently taking medications or other treatments

4b. **Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication?**
   - Answer YES ☐ if you do not know your resting blood pressure

5. **Do you have any Metabolic Conditions?**
   - This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes
   - If the above condition(s) is/are present, answer questions 5a-5e
   - If NO ☐ go to question 6

5a. **Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?**

5b. **Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.**

5c. **Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet?**

5d. **Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?**

5e. **Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?**

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6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer’s, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome
   If the above condition(s) is/are present, answer questions 6a-6b
   If NO go to question 7

   6a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)
       YES ☐ NO ☐

   6b. Do you ALSO have back problems affecting nerves or muscles?
       YES ☐ NO ☐

7. Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure
   If the above condition(s) is/are present, answer questions 7a-7d
   If NO go to question 8

   7a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)
       YES ☐ NO ☐

   7b. Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?
       YES ☐ NO ☐

   7c. If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?
       YES ☐ NO ☐

   7d. Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?
       YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? This Includes Tetraplegia and Paraplegia
   If the above condition(s) is/are present, answer questions 8a-8c
   If NO go to question 9

   8a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?
       YES ☐ NO ☐

   8b. Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?
       YES ☐ NO ☐

   8c. Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?
       YES ☐ NO ☐

9. Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event
   If the above condition(s) is/are present, answer questions 9a-9c
   If NO go to question 10

   9a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)
       YES ☐ NO ☐

   9b. Do you have any impairment in walking or mobility?
       YES ☐ NO ☐

   9c. Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?
       YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?
    If you have other medical conditions, answer questions 10a-10c
    If NO read the Page 4 recommendations

   10a. Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?
       YES ☐ NO ☐

   10b. Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?
       YES ☐ NO ☐

   10c. Do you currently live with two or more medical conditions?
       YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE:

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.
2015 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:
- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should consult the specially designed online screening and exercise recommendations program - the ePARmed-X+ at www.eparmedx.com and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

- Delay becoming more active if:
  - You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
  - You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
  - Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.

- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME ___________________________ DATE ___________________________
SIGNATURE ___________________________ WITNESS ___________________________
SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ___________________________

For more information, please contact

www.eparmedx.com
Email: eparmedx@gmail.com

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References:

Copyright © 2015 PAR-Q+ Collaboration 4 / 4
01-01-2015
LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: The acute physiological responses of leg extension resistance training using drop sets versus standard hypertrophy training in the quadriceps femoris

You are asked to participate in a research study conducted by Alex Waugh and Dr. Kenji Keno, from the Department of Kinesiology at the University of Windsor. The results of this study will contribute to a master's thesis.

If you have any questions or concerns about the research, please feel to contact:

Alex Waugh – phone: [redacted], e-mail: [redacted]
Dr. Kenji Keno – phone: [redacted], e-mail: [redacted]

PURPOSE OF THE STUDY

Resistance training (i.e. lifting weights) can be used for strength training, hypertrophy (muscle growth) training, and endurance training. Initial strength gains are due to neural adaptations, and further strength gains are primarily through muscle hypertrophy. However, as resistance training continues, the hypertrophy response slows resulting in a training plateau. To overcome training plateaus, trainers often use drop sets (DS), a specific technique which involves lifting a moderately heavy load to momentary muscular failure, then reducing the load and immediately performing additional sets at sequentially lighter loads without rest to promote hypertrophy. However, how DS protocols compare to hypertrophy training workouts in promoting hypertrophy is limited. The purpose of this study is to compare and contrast the acute physiological effects of leg extension resistance training using drop sets to a standard hypertrophy training protocol.

PROCEDURES

If you volunteer to participate in this study, you will be asked to:

- Session 1
  - Complete a pre-screening questionnaire and PAR-Q+ (Physical Activity Readiness Questionnaire Plus) (~5 minutes)
  - Read and sign a “Consent to Participate in Research” form (~5 minutes)
  - Complete a three repetition maximum test (3RM) and maximum voluntary contraction test (MVC) (~30 minutes)

- Session 2
  - Complete one leg extension workout using DS or HT (~30 minutes)

- Session 3
  - Complete one leg extension workout using DS or HT (~30 minutes)
  - Have a small amount of blood taken before and after each workout via the fingertips and antecubital vein (arm) by a certified Medical Lab Assistant (MLA) (~10 minutes/workout)
  - Wear electromyography (EMG) equipment to measure muscle activity and a heart rate monitor to measure heart rate

Total participation time is ~ 60-70 minutes per session for 3 sessions, totaling ~ 3-3.5 hours, each separated by 1 week. This study will take place in the Multi-Purpose Research Lab in the Human Kinetics Building at the University of Windsor.

POSSIBLE RISKS AND DISCOMFORTS

The inherent risks in weightlifting include potential injury due to improper technique or misuse of equipment. DS is a high-intensity weightlifting technique that presents a risk of local discomfort in the working muscles. There is also a risk that participants will experience general fatigue and exercise-induced muscle soreness post-exercise. The use of EMG provides a minimal risk of discomfort with application/removal of electrodes on skin surface. Lastly, routine blood collection presents few risks if performed by a trained person; however, there are inherent risks:

- Allergic reaction to latex (tourniquet) or adhesive material on bandage
- Injury from fainting typically due to fear of needles
- Hematoma (internal bleeding), bruising or nerve damage as a result of improper technique
- Pain or discomfort due to application of tourniquet, needle puncture or removal of either
- Infection at site of puncture

In order to minimize potential risks, individuals with prior knee conditions are not permitted to participate, as well as those individuals with allergies that would interfere with the blood collection procedure or application of any of the EMG equipment. There is a chance that the primary investigator may know you through previous GA responsibilities, but will not influence data collection or use. Risks associated with weightlifting equipment or technique will be minimized through constant supervision of exercise by following the guidelines for early termination (i.e. testing or sessions are discontinued if the researcher observes an inability of the participant to meet the demands of the testing protocol or exercises). A proper warmup will be performed to avoid injuries associated with use of cold or stiff muscles. You will be performing leg extensions using a leg extension machine, which minimizes required knowledge of proper form and reduces likelihood of injury. Load adjustments during testing will be made exclusively by the researchers, which minimizes chance of equipment misuse. In the unlikely event that muscle soreness is experienced, it will subside within 48 hours and is of no danger to you. Blood samples require minimal collection and should not interfere with your regular activity post-testing.

To minimize/manage risks to participant:
- Non-latex tourniquets and gloves will be used;
- Injury due to fainting will be minimized by proper monitoring of subject at all times during the testing procedures. Moreover, our participants will be on a seated leg extension machine and at any given time, there will be 3 members of the experimental team (MLA, principal investigator and/or advisor, data collection volunteer) present;
- Hematoma (internal bleeding), bruising or nerve damage will be minimized by using a trained professional to perform the blood draws as well as by the choice of puncture site (i.e. antecubital vein);
- Pain or discomfort due to application of tourniquet, needle puncture or removal of either will be minimized by straightforward discussion and informed consent with the participant. The possibility of slight pain (pin prick) cannot be eliminated, but more serious injury (jumping/jerking the participant) can be avoided by proper truthful communication with the participant;

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

You will have the opportunity to experience the collection of physiological biosignals and markers, including EMG, heart rate, and various blood markers, which may be useful in your studies and/or future careers. You may receive the results of your individual analyses upon request. You will be exposed to an understudied weightlifting technique, which you may use in your own training.

A better knowledge of the underlying physiological mechanisms of drop sets will help to address a gap in current strength and conditioning research regarding specialized resistance training techniques, and may validate their incorporation into resistance training programs both in the field (by strength and conditioning specialists, coaches, and personal trainers) and in research.

COMPENSATION FOR PARTICIPATION

A Kinesiology Research t-shirt as well as entries into a draw for a $50 gift card of your choice will be provided to express our gratitude for your role in the study. You will receive a t-shirt regardless of completion of the study. You will receive 1 entry into the draw for attending session 1, 2 entries for attending session 2, and 3 entries for attending session 3 (totaling 8 entries for all sessions).

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your data will be coded so it can only be identified by the researchers involved. Only the researchers involved will be present during testing to eliminate the risk of data exposure and allow for confidentiality. All of the data collected will be transcribed and stored electronically on a computer to which only the researchers involved have access. Any hardcopies of data files will be kept in a locked filing cabinet that only one researcher has access to. The data will be stored both physically and electronically for potential future outputs for a minimum of 5 years and a maximum of 10 years, after which it will be destroyed, with physical data being shredded and electronic data being permanently deleted.
PARTICIPATION AND WITHDRAWAL

You have the right to withdraw from the study and request that your data be removed from the study without consequences of any kind to you. You can contact any of the researchers via email or in person to withdraw. Upon completion of data collection and completion of the study, you are acknowledging that your data cannot be withdrawn due to initiation of data analysis. The investigator may withdraw you from if circumstances arise which warrant doing so. You will still be compensated for your participation regardless of withdrawal.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

Your email address: ____________________________
Date when results are available: June 1, 2016

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario N9B 3P4, Telephone: 519-253-3000, ext. 3846; e-mail: ethics@uwindsor.ca

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

__________________________________________  ____________________________
Signature of Investigator                     Date
Appendix F

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: The acute physiological responses of leg extension resistance training using drop sets versus standard hypertrophy training in the quadriceps femoris

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Alex Waugh – phone: [Redacted], e-mail: [Redacted]
Dr. Kenji Kenno – phone: [Redacted], e-mail: [Redacted]

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CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your data will be coded so it can only be identified by the researchers involved. Only the researchers involved will be present during testing to eliminate the risk of data exposure and allow for confidentiality. All of the data collected will be transcribed and stored electronically on a computer to which only the researchers involved have access. Any hardcopies of data files will be kept in a locked filing cabinet that only one researcher has access to. The data will be stored both physically and electronically for potential future outputs for a minimum of 5 years and a maximum of 10 years, after which it will be destroyed, with physical data being shredded and electronic data being permanently deleted.
PARTICIPATION AND WITHDRAWAL

You have the right to withdraw from the study and request that your data be removed from the study without consequences of any kind to you. You can contact any of the researchers via email or in person to withdraw. Upon completion of data collection and completion of the study, you are acknowledging that your data cannot be withdrawn due to initiation of data analysis. The investigator may withdraw you from if circumstances arise which warrant doing so. You will still be compensated for your participation regardless of withdrawal.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

Your email: 
Date when results are available: June 1, 2016

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario N9B 3P4, Telephone: 519-253-3000, ext. 3948, e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study, “The acute physiological effects of leg extension drop set resistance training versus traditional hypertrophy training,” as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Name of Participant

Signature of Participant ___________________________ Date __________

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

Signature of Investigator ___________________________ Date __________
Appendix G

Participant Information Sheet

Participant ID: _______

Date: ________________________

Group: 1 2

Name: ____________________________________________

Date of birth: (mm/yy) _____/____

Height (feet, inches): _____ Weight (pounds): _____ BMI: ______

Contact Information:

Phone (cell)#: ( ) __________-__________

Phone (home) #: ( ) __________-__________

E-mail: ____________________________________________@_________________________________________

Emergency Contact (Optional)

Name: __________________________________________

Phone #: ( ) __________-__________

Physical Activity Background:

How many months have you been regularly resistance training?

1 2 3+ 6+ 12+

How many times do you resistance train per week?

1 2-3 3-4 4+

Have you ever used the drop set technique before? YES or NO

If yes, how often do you use it? ___________

Recent or past injuries (N/A if not applicable):

Alergies/current medications (N/A if not applicable):
# Appendix H

**Borg rating of perceived exertion**

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<tr>
<th>Rating</th>
<th>Description</th>
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<tbody>
<tr>
<td>6</td>
<td>No exertion at all</td>
</tr>
<tr>
<td>7</td>
<td>Extremely light</td>
</tr>
<tr>
<td>8</td>
<td>Very light</td>
</tr>
<tr>
<td>9</td>
<td>Light</td>
</tr>
<tr>
<td>10</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>11</td>
<td>Hard (heavy)</td>
</tr>
<tr>
<td>12</td>
<td>Very hard</td>
</tr>
<tr>
<td>13</td>
<td>Extremely hard</td>
</tr>
<tr>
<td>14</td>
<td>Maximal exertion</td>
</tr>
</tbody>
</table>

Borg RPE Scale
Instructions to the Borg-RPE-Scale®

During the work we want you to rate your perception of exertion, i.e. how heavy and strenuous the exercise feels to you and how tired you are. The perception of exertion is mainly felt as strain and fatigue in your muscles and as breathlessness or aches in the chest.

Use this scale from 6 to 20, where 6 means "No exertion at all" and 20 means "Maximal exertion."

9 Very light. As for a healthy person taking a short walk at his or her own pace.

13 Somewhat hard. It still feels OK to continue.

15 It is hard and tiring, but continuing is not terribly difficult.

17 Very hard. It is very strenuous. You can still go on, but you really have to push yourself and you are very tired.

19 An extremely strenuous level. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling of exertion and fatigue as spontaneously and as honestly as possible, without thinking about what the actual physical load is. Try not to underestimate, nor to overestimate. It is your own feeling of effort and exertion that is important, not how it compares to other people's. Look at the scale and the expressions and then give a number. You can equally well use even as odd numbers.

Any questions?
Appendix I

Participant Motivation Dialogue

The following statements may be made during training, in no particular order:

“Come on, man!”
“You got this!”
“Dig deep!”
“One more rep!”
“Awesome job!”
“Good work!”
“You’re doing great!”
“Keep going!”
## Hypertrophy training data collection sheet

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<tbody>
<tr>
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**Comments:**
# Drop set training data collection sheet

**SESSION** 2 3

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Date: _______________ Belt Notches: _______

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**Comments:**

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**Appendix K**
Appendix L
## Appendix M

### Hypertrophy Training Data Collection Sheet

**Participant ID:** __________  
**Back Pad:** __________

**Date:** ______________

**Belt Notches:** __________

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</tbody>
</table>

**TOTAL**

**Comments:**

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**START**

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**STOP**

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**START**

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Appendix N

Certificate of Completion

This document certifies that

Alex Waugh

has completed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics (TCPS 2: CORE)

Date of Issue: 9 January, 2014
Certificate of Completion

This document certifies that

Kenji Kenno

has completed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics (TCPS 2: CORE)

Date of Issue: 8 May, 2012
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