NEUROMUSCULAR ADAPTATIONS TO THREE AND SIX WEEKS OF HIGH- VERSUS LOW-LOAD RESISTANCE TRAINING

By

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Adviser: Joel T. Cramer

The purpose of this study was to examine the neuromuscular adaptations following 3 and 6 weeks of 80% versus 30% one repetition maximum (1RM) resistance training to failure in the leg extensors. 26 men (mean ± SD; age = 23.1 ± 4.7 yrs) were randomly assigned to a high- (80% of 1RM; n = 13) or low-load (30% of 1RM; n = 13) resistance training group and completed leg extension resistance training to failure 3 times per week for 6 weeks. Testing was completed at baseline, 3, and 6 weeks of training. During each testing session, ultrasound muscle thickness (MT) and echo intensity (EI), 1RM strength, and maximal voluntary isometric contraction (MVIC) strength were measured. Percent voluntary activation (VA) and electromyographic (EMG) and mechanomyographic (MMG) amplitude (AMP) and mean power frequency (MPF) were measured during MVIC, and during randomly ordered isometric step muscle actions at 10 - 100% of the baseline MVIC. The results indicated that MT increased (2.8 – 3.0% and 6.0 – 6.6%) and EI (-3.8% and -6.8%) decreased similarly from Baseline to Week 3 and Baseline to Week 6, respectively, in the 80% and 30% 1RM groups. However, in the 80% 1RM group, 1RM strength increased by 14.7% and 27.7% and MVIC strength increased 11.8% and 28.0% from Baseline to Week 3 and Week 6, respectively. In the 30% 1RM group, 1RM strength did not change (-3.5%) and increased by 9.5% and MVIC strength did not change (-4.3%) and increased by 13.4% from

Baseline to Week 3 and Week 6, respectively. There were similar changes in VA, EMG AMP, and MMG AMP in the 80% and 30% 1RM groups during MVIC. However, there were greater neuromuscular adaptations at submaximal torques in the 80% versus 30% 1RM group, which were evident in the VA, EMG, and MMG responses. Therefore, despite causing similar muscle hypertrophy, 80% 1RM enhanced muscle strength to a greater degree than 30% 1RM and resulted in an increased efficiency of activation that was especially apparent at high contraction intensities (i.e.,~60 – 100% MVIC). These results suggest differences in the neuromuscular adaptations to high- versus low-load resistance training that may explain the disparate increases in muscle strength despite similar muscle hypertrophy in response to these two training modes.

DEDICATION

This dissertation is dedicated first, to my grandparents, David O. Moyer and Miriam J. Moyer; and second, to Brant C. Seal.

I was blessed with two very loving, supportive grandparents who have been integral in every part and time in my life. Everything in me wishes that you could've been here to see me complete my dissertation and degree, but I know that you would've been proud. Thank you for all that you have done, and for all that you have meant and continue to mean to me. I love you!

I was also fortunate to have had a friend who became a part of my family. Brant, I could not of asked for a better friend over the past 15 years of life. Thank you for remaining steadfast, loyal, and true to me to the end.

In Loving Memory

David O. Moyer
December 10, 1933 – September 19, 2009

Miriam J. Moyer
October 29, 1939 – February 6, 2016

Brant C. Seal
January 26, 1988 – January 29, 2016

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"It is not the critic who counts; not the man who points out how the strong man stumbles, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly; who errs, who comes short again and again, because there is no effort without error and shortcoming; but who does actually strive to do the deeds; who knows great enthusiasms, the great devotions; who spends himself in a worthy cause; who at the best knows in the end the triumph of high achievement, and who at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who neither know victory nor defeat."

- Theodore Roosevelt

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CHAPTER I: INTRODUCTION

To maximize muscle hypertrophy and strength in response to a resistance training program, heavy loads are often recommended. For example, the National Strength and Conditioning Association (NSCA) recommends using loads of 67 – 85% 1RM if the objective is muscular hypertrophy (86). The current American College of Sports Medicine's (ACSM) position stand addressing the appropriate intensity to improve muscular fitness (52) states "…robust gains in both hypertrophy and strength result from using a resistance equivalent to 60 – 80% of the individual's one repetition maximum (1RM)…" (pg. 1343). However, recent experimental results (21, 68, 81, 87, 113, 114, 118) have called these recommendations in to question. For example, Wernbom et al. (118) demonstrated that acute resistance exercise at 30% 1RM to failure increased protein signaling and satellite cell numbers. Burd et al. (21) demonstrated that resistance exercise performed to failure at 30% 1RM is as effective as resistance exercise at 90% 1RM for the acute stimulation of muscle protein synthesis and anabolic signaling. In a follow-up to the acute study by Burd et al. (21), Mitchell et al. (81) demonstrated that 10 weeks of leg extension resistance training to failure at 30% 1RM increased muscle size similar to training at 80% 1RM. Similarly, Ogasawara et al. (87) showed that 6 weeks of bench press resistance training to failure at 30% 1RM caused muscle hypertrophy equivalent to that observed following training to failure at 80% 1RM. As a result, there is currently a debate (20, 104) regarding the most effective resistance exercise loads to prescribe for muscle hypertrophy.

Although high- and low-load training to failure cause similar muscle hypertrophy, high-load training may be superior for enhancing muscle strength (81, 87). For example,

Mitchell et al. (81) demonstrated that 80% 1RM leg extension training was superior to 30% 1RM for increasing 1RM, while Ogasawara et al. (87) demonstrated that 75% 1RM bench press training was superior for increasing maximal voluntary isometric contraction (MVIC) and 1RM strength. Therefore, these data may suggest that there are neural or peripheral adaptations that facilitate improvements in strength during high-load training that do not occur with low-load training. However, it has also been hypothesized that low-load resistance exercise may exhibit a reverse pattern of adaptations in comparison to high-load resistance training (79). That is, perhaps hypertrophy occurs first in response to low-load resistance training, with neural adaptations occurring later in the training program. Therefore, a direct comparison of the time course of neural and peripheral adaptations to the development of muscle strength in response to high- versus low-load resistance training to failure is needed.

Electromyographic amplitude (EMG AMP) has commonly been used to examine neural adaptations to resistance training (42, 56, 72, 82, 83, 111). For example, Moritani and DeVries (82) and Narici et al. (83) interpreted training-induced increases in EMG AMP as neural adaptations and Moritani and DeVries (82) stated that the EMG "…activation level is necessarily the result of the interaction of both facilitatory and inhibitory phenomena which may act at various levels of the nervous system" (pg. 116). Similarly, Komi et al. (72) and Thepaut-Mathieu et al. (111) reported training-induced increases in EMG AMP and suggested that these increases reflected greater motor unit activation following training. Therefore, quantification of EMG AMP from the surface EMG signal may provide qualitative information regarding neural adaptations that occur with resistance training.

Mechanomyography (MMG) involves the recording and quantification of the low-frequency, lateral oscillations of active skeletal muscle fibers (13, 90) and is thought to reflect the mechanical counterpart of the motor unit electrical activity that is detected by EMG (13). Specifically, it has been suggested (13) that the amplitude and frequency of the MMG signal are related to the number of active motor units and the global motor unit firing rate of the active motor units, respectively. For example, it has been shown that MMG amplitude (MMG AMP) increases linearly as torque increases with the recruitment of additional motor units (90). However, after maximal motor unit recruitment has been achieved (typically at approx. 80% of MVIC), the muscle primarily relies on rate coding to increase force and, consequently, MMG AMP plateaus (90) while MMG mean power frequency (MMG MPF) may be expected to increase. Therefore, the MMG signal may provide information regarding the motor unit activation strategies used to produce torque (or force) and may reflect neuromuscular adaptations following resistance training (36).

It is thought that resistance training causes small adaptive changes at multiple sites within the nervous system that, together, enhance muscle strength (51, 77, 101). One such adaptation may be an increase in voluntary activation via an enhanced ability to recruit agonist motor units and drive them to their maximal firing rates (51, 71, 77). Therefore, voluntary activation has been used to assess neural adaptations following resistance training (57, 71, 77, 112), although the effects of resistance training on voluntary activation in healthy adults are equivocal (57, 71, 77, 112). Curiously, few studies have examined alterations in percent voluntary activation (VA) across the entire torque spectrum following resistance training (68). However, VA may provide additional,

complimentary information to the EMG and MMG signals regarding training-induced changes in motor unit activation strategies during torque production.

In the only study to our knowledge that has examined neuromuscular adaptations to high- versus low-load resistance training, we (68) demonstrated that 4 weeks of resistance training to failure at 80% and 30% 1RM caused similar muscle hypertrophy in the forearm flexors, although training at 80% 1RM caused greater strength adaptations. Furthermore, when compared at adapting relative torque levels, the neuromuscular adaptations to 80% and 30% 1RM training were similar. Given the increase in strength observed for the 80% 1RM group, however, these results may suggest possibly greater, although subtle, neuromuscular adaptations following training at 80% versus 30% 1RM. Consequently, studies are needed to further examine the neuromuscular adaptations to high- versus low-load resistance training by studying the EMG, MMG, and VA responses at the same absolute torque levels from pre- to post-training. Therefore, the purpose of this study was to examine the neuromuscular adaptations following 3 and 6 weeks of 80% versus 30% 1RM resistance training to failure in the leg extensors.

Hypotheses

Based on previous studies (68, 81, 87), we hypothesized that resistance training at 80% and 30% 1RM to failure would elicit similar muscle hypertrophy, but that muscle strength would increase to a greater extent following training at 80% 1RM. We also hypothesized that the neuromuscular adaptations, reflected in EMG AMP, EMG mean power frequency (EMG MPF), MMG AMP, MMG MPF, and/or VA at the same absolute torque levels, would be more pronounced following training at 80% than 30% 1RM.

CHAPTER II: REVIEW OF LITERATURE

2.1. Time Course of Adaptations to Resistance Training

2.1.1. Moritani and Devries (82)

The purpose of this investigation was to determine the relative contributions of neural versus hypertrophic factors to the time course of strength adaptations in response to resistance training utilizing the efficiency of electrical activity (EAA) technique. Seven healthy men (mean age = 22.0 yrs) and 8 healthy women (mean age = 18.2 yrs) completed 8 weeks of forearm flexion resistance training that consisted of completing 10 repetitions at 66% of 1 repetition maximum (1RM) twice per day, three times per week. To measure changes in strength, the participants completed 3 maximal voluntary isometric (MVIC) forearm flexion muscle actions at baseline, and after 2, 4, 6, and 8 weeks of training. Based on the best MVIC, each subject then completed consecutive submaximal isometric muscle actions in 5 or 10 lb (for men or women, respectively) increments up to the 5 or 10 lb increment nearest the MVIC. EMG amplitude was recorded as the integrated EMG value (iEMG) during each of the isometric muscle actions, which provided an iEMG:force relationship for each subject. The results of the present study indicated that muscle strength increased after 8 weeks of training due to both neural and hypertrophic factors, as indicated by an increase in muscle activation (mean increase = 223 μV) and a decrease in the slope of the iEMG:force relationship (mean decrease of -6.36), respectively. In addition, the increases in strength during the first 2 weeks of training were due almost entirely to an increase in muscle activation. However, as the training continued, the slope of the iEMG:force relationship began to

decrease, indicating a progressively larger contribution of muscular hypertrophy to the observed increases in strength. By 8 weeks, hypertrophy was responsible for nearly all (~97%) of the strength increases. In summary, neural factors account for the large proportion of strength gains prior to approximately 4 weeks of training, while hypertrophy is the dominant factor following the first 4 weeks of training.

2.1.2. DeFreitas, Beck, Stock, Dillon, and Kasishke (37)

The authors investigated the time course of skeletal muscle hypertrophy of the thigh in response to resistance training. Twenty-five sedentary men (mean ± SD; age = 21.5 ± 3.6 yrs) completed 8 weeks of high-load (i.e., 80% 1RM) resistance training consisting of incline leg press, leg extension, and bench press exercise. Three sets of each exercise were performed to failure 3 times per week. At the end of every week, peripheral quantitative computed tomography scans were used to determine whole muscle cross-sectional area (mCSA) of the right thigh. Maximal voluntary isometric muscle actions were performed to determine maximal isometric strength of the dominant leg extensors (MVIC). The results of this study demonstrated that significant muscle hypertrophy occurred after just 2 resistance exercise sessions. However, the technique utilized in this study was not able to distinguish between intramuscular fluid and muscle tissue. Therefore, it is possible that training-induced muscle damage and inflammation were partly responsible for these increases in mCSA. However, even after adjusting the comparisons to account for the possible influence of muscle damage and edema during the first week of training, there were still significant increases in mCSA at week 3 and in MVIC at week 4. Furthermore, mCSA continued to increase weekly throughout the

study. Collectively these results suggest that skeletal muscle hypertrophy may occur much earlier in a training program than had been previously reported.

2.1.3. Ogasawara, Thiebaud, Loenneke, Loftin, and Abe (88)

The purpose of this study was to determine the time course of skeletal muscle hypertrophy of the arms and chest during 24 weeks of free-weight bench press training. Seven untrained young men (mean ± SD; age = 25 ± 3 yrs) completed 3 sets of 10 repetitions of bench press training 3 times per week at 75% of 1RM. 1RM was assessed every 3 weeks, and the resistance training load was adjusted based on the new 1RM. Muscle thickness (MT) of the pectoralis major (PM), and biceps (BB) and triceps brachii (TB) were measured pre- and post-training, and prior to the first exercise session of each week throughout training using B-mode ultrasound. The results indicated that PM MT increased after week 1, while TB MT increased after week 5. 1RM increased after week 3, and all three of these dependent variables (i.e., PM MT, TB MT, and 1RM) continued increasing throughout the study. There were no changes in BB MT during the 24 weeks of training. Thus, skeletal muscle hypertrophy may occur as early as 1 week after beginning a resistance training program in untrained participants.

2.1.4. DeFreitas, Beck, and Stock (36)

The purpose of this study was to determine if the mechanomyographic amplitude (MMG AMP)-force relationships would change with 8 weeks of strength training. Twenty-two healthy men (mean ± SD; age = 21.7 ± 3.7 yrs) completed 8 weeks of strength training that consisted of 3 sets of bench press, bilateral leg extension, and bilateral incline press exercise performed at 80% of 1RM, 3 times per week. Maximal voluntary isometric (MVIC) strength was determined and submaximal isometric muscle

actions at 10 – 90% of MVIC were performed at baseline, week 4, and week 8 of training. During all isometric muscle actions, the MMG signal was collected from the vastus lateralis muscle and MMG AMP was calculated as the root mean square during a 1 s, steady force epoch. At baseline, the MMG AMP increased until 66% MVIC on average and then plateaued. However, at week 4 and week 8, MMG AMP increased until 85% MVIC on average before plateauing. In addition, there were significant decreases in MMG AMP at 30 – 60% and 80 – 100% MVIC from baseline to week 8, decreasing the slope of the MMG AMP-force relationship. The authors interpreted the decreases in MMG AMP at submaximal force levels as a byproduct of hypertrophy, since "fewer motor units would be required to produce the same amount of force when compared to before training" if each fiber experienced an increase in contractile protein content. Furthermore, the decrease in MMG AMP at 100% MVIC were interpreted as a result of increased muscular stiffness, which may have also been a byproduct of skeletal muscle hypertrophy. The authors suggested future research to simultaneously track changes in MMG AMP, muscle size, and musculotendinous stiffness in order to confirm this hypothesis.

2.2. Chronic Adaptations to High- Versus Low-Load Resistance Training

2.2.1. Mitchell, Churchward-Venne, West, Burd, Breen, Baker, and Phillips (81)

The primary purpose of this study was to determine the chronic effect of resistance training load on skeletal muscle hypertrophy and strength. A secondary purpose was to examine the acute effects of resistance training load on anabolic signaling and to determine if this signaling was related to hypertrophy. Eighteen men (mean ± SD; 21 ± 4 yrs) had each of their legs randomly assigned to one of three leg extension

resistance training conditions: [1] 3 sets of 30% of one repetition maximum (1RM) performed to failure (3xLL), [2] 3 sets of 80% 1RM performed to failure (3xHL), or [3] 1 set of 80% 1RM performed to (1xHL). Participants trained each leg with their assigned condition 3 times per week for 10 weeks. Before and after the training program, maximal voluntary isometric strength (MVIC), rate of force development (RFD), 1RM, quadriceps femoris muscle volume (MV), and fiber-type specific hypertrophy via vastus lateralis biopsies were measured. In addition, a single biopsy of the VL was taken 1 h after the first resistance exercise session to measure anabolic signaling. The primary results of this study indicated that there were significant 6.8 ± 1.8%, 7.2 ± 1.9%, and 3.2 ± 0.8% increases in MV for 3x30%, 3x80%, and 1x80%, respectively, with no differences among groups. Similarly, there were 30 ± 12%, 17 ± 4%, and 16 ± 7% increases in type I fiber area and 18 ± 8%, 16 ± 5%, 20 ± 5% increases in type II fiber area for 3xLL, 3xHL, and 1xHL, respectively, with no differences among groups. MVIC and RFD also increased equally in all conditions. In contrast, 1RM strength increased for all conditions, but was greater for the 3xHL and 1xHL conditions than for 3xLL. There was no relationship observed between acute anabolic signaling and the degree of hypertrophy observed in this study. This study demonstrated that low-load resistance training to failure resulted in similar muscle hypertrophy, increases in isometric strength, and RFD, but smaller increases in 1RM, compared to high-load resistance training to failure.

2.2.2. Ogasawara, Loenneke, Theibaud, and Abe (87)

This study investigated the effects of high- versus low-load bench press training on skeletal muscle hypertrophy and strength. Nine untrained men (mean ± SD; age = 25 ± 3 yrs) completed 2 different 6-week resistance training programs separated by 12 months.

In the first training program, all participants performed 3 sets of 10 repetitions of bench press exercise at 75% of 1RM (HL), 3 times per week. In the second training program, all participants performed 4 sets of the free bench press exercise to failure at 30% of 1RM (LL). In both training programs, the resistance training loads were adjusted based on the new 1RM established after 3 weeks of training. Magnetic resonance imaging was used to measure muscle cross sectional area (mCSA) of the pectoralis major (PM) and triceps brachii (TB) at baseline and after each 6-week training program. Maximal voluntary isometric forearm extension strength (MVIC) and 1RM were measured at baseline, after 3 weeks, and after 6 weeks of training. The results indicated that MVIC and 1RM strength increased from baseline to 6 weeks in both the HL and LL training groups. However, the percent increases in MVIC and 1RM strength from baseline to 6 weeks were greater in the HL (21.0% and 13.9%, respectively) than the LL (6.5% and 8.6%, respectively) group. Furthermore, MVIC and 1RM strength increased from baseline to 3 weeks and from 3 to 6 weeks of training in the HL group; however, MVIC and 1RM did not change from baseline to 3 weeks, but did increase from 3 weeks to 6 weeks in the LL group. mCSA in the PM and TB increased equally following HL and LL training. Thus, LL resistance training is capable of causing muscle hypertrophy equivalent to that seen with HL training. However, the increases in muscular strength observed following HL training were greater than for LL training. Therefore, the authors suggested that "focus on percentage of external load as the important deciding factor on muscle hypertrophy is too simplistic", but that the "consistent practice of lifting a heavy load is necessary to maximize gains in muscular strength".

2.2.3. Van Roie, Delecluse, Coudyzer, Boonen, and Bautmans (114)

The authors investigated the effects of 12 weeks of high- versus low-load resistance training on muscle volume, muscle strength, force-velocity characteristics, and functional performance in 56 older adults (mean ± SD; age = 68.0 ± 5.1 yrs). The participants were randomly assigned to one of three conditions: [1] a high-load (HL) group in which participants performed 2 sets at 80% of 1RM to failure in 10 – 15 repetitions; [2] a low-load (LL) group in which participants performed 1 set at 20% of 1RM to failure in 80 – 100 repetitions; or [3] a 'mixed' low-load (LL+) group in which participants completed 1 set of 60 repetitions at 20% 1RM immediately followed by one set at 40% 1RM to failure in 10 – 20 repetitions. Before and after the 12 weeks of resistance training, computed tomography estimates of thigh muscle volume (MV), leg press 1RM, leg extension 1RM, leg extension muscular endurance (ME), force-velocity characteristics of the leg extensors, and functional performance (as determined by 6 min walk test, maximal gait speed test, 30 s chair sit-to-stand test, 5 repetition char sit-to-stand test, and timed up-and-go test) were measured. 1RM was also measured at weeks 5 and 9. The results indicated that thigh MV increased over time with no differences between groups. All groups increased 1RM strength, however, 1RM increased more in the HL and LL+ groups than in LL, and these differences were apparent by week 5 of training. ME increased in LL and LL+, but did not increase in HL. Isometric peak torque increased in all groups. Peak torque at $180°\cdot s^{-1}$ increased in HL and LL, while peak torque at $240°\cdot s^{-1}$ increased in HL only. In general, the HL group also improved to a greater degree in functional performance than either LL or LL+. In conclusion, both HL and LL resistance training to failure were effective for muscle hypertrophy in older

adults. However, HL resistance training led to greater increases in 1RM strength than LL, but not than LL+.

2.2.4. Van Roie, Bautmans, Boonen, Coudyzer, Kennis, and Delecluse (113)

The purpose of this study was to compare the effects of low-load versus high-load resistance training on muscle strength and force-velocity characteristics in the leg extensors. Thirty-six men and women were randomized to one of three training conditions: [1] a high-load group that performed 1 set to failure at 80% 1RM (HL), [2] a low-load group that performed 1 set of 60 repetitions at 20 – 25% 1RM, immediately followed by 1 set to failure at 40% 1RM (LL+), and [3] a low-load group that performed 1 set of 10 – 12 repetitions at 40% 1RM (LL-). The participants completed their respective training protocols 3 days per week on non-consecutive days for 9 weeks on a bilateral leg extension machine. Repetition cadence was controlled by a metronome. Before (pre-) and after (post-) training, force-velocity characteristics of the leg extensors were determined on a calibrated Biodex isokinetic dynamometer. Specifically, participants completed 3 muscle actions during which they accelerated the dynamometer lever arm as quickly as possible at loads corresponding to 20%, 40%, and 60% of their maximal isometric force and 3 maximal concentric muscle actions of the leg extensors and flexors at $60°\cdot s^{-1}$ to determine increases in force-velocity characteristics and concentric peak torque, respectively. One repetition maximum was determined at pre- and post-training, and before the 7th, 13th, and 19th training sessions. The results indicated that leg extension 1RM increased similarly among groups from pre- to the 7th training session. However, from the 13th session on 1RM increased to a greater degree in HL than either LL group. For isometric peak torque, only HL increased from pre- to post-training.

For force-velocity, there was a general upward shift in the force-velocity curve for the LL+ group, with significant increases in leg velocity at 20% and 40% of maximal isometric force. The increase in leg velocity at 20% maximal isometric force was greater in LL+ than in HL or LL-. For concentric peak torque at $60°\cdot s^{-1}$, LL+ improved peak torque to a greater degree than HL and LL-. HL and LL- did not improve concentric peak torque. These results suggested that there are different adaptations to LL+ versus HL resistance training, such that HL may be more beneficial for improving maximum strength while LL+ may be effective for improving velocity-related characteristics, even when maximum velocity is not used in training.

2.3. Neuromuscular Factors that may Influence Adaptations to High- Versus Low-Load Resistance Training

2.3.1. Wernbom, Jarrebring, Andreasson, and Augustsson (119)

The objectives of this study were to determine if there were differences in electromyographic amplitude (EMG AMP) responses and the number of repetitions completed during low-load leg extension exercise performed to failure with or without blood flow restriction (BFR). Eleven resistance trained men (n = 8) and women (n = 3) (mean ± SD; age = 25 ± 5 yrs) completed this study. Prior to experimental testing, the participants were familiarized and unilateral leg extension 1RM was determined for each leg. Six to 10 days later, the participants returned and completed 3 sets of leg extension resistance exercise to failure at 30% 1RM with (LL) and without BFR (LLBFR). All repetitions were performed with no rest between repetitions. The design was such that one leg (dominant or non-dominant) experienced BFR, while the other was tested without BFR in a randomized fashion. During the resistance exercise sets, EMG signals were

recorded. EMG AMP was calculated as the root mean square value for each repetition and was normalized to the EMG AMP value collected during a preceding MVIC. The lowest and highest EMG AMP values during concentric and eccentric muscle actions for the vastus lateralis (VL) and vastus medialis (VM) were reported. Rating of perceived exertion (RPE) and delayed onset muscle soreness (DOMS; VAS pain scale) were recorded immediately following exercise, and at 24 h, 48 h, and 72 h post-exercise, respectively. There were a greater number of repetitions completed during LL than LLBFR during each set. There were no differences noted in minimum or maximum EMG AMP for LL and LLBFR, except for the maximum EMG AMP during the eccentric muscle actions of set 3, where EMG AMP was greater for LL than LLBFR. There were no differences in RPE following exercise; however, there were greater ratings of DOMS for LL than LLBFR at 24 h, 48 h, and 72 h post-exercise. These results suggested that continuous, low-load dynamic resistance exercise to failure is capable of eliciting similar (or greater) muscle activation to LLBFR. Furthermore, LL allowed for a greater total volume and was capable of eliciting greater muscle damage than LLBFR. Therefore the authors suggested future research examining the chronic hypertrophic and strength adaptations to LL resistance training. They hypothesized that LL may elicit greater chronic adaptations than LLBFR.

2.3.2. Akima and Salto (4)

The aim of this study was to investigate the neuromuscular activation patterns of the four quadriceps femoris muscles (i.e., vastus lateralis, rectus femoris, vastus medialis, vastus intermedius) during fatiguing dynamic leg extensions performed with 70% and 50% of one repetition maximum (1RM). Nine healthy men (mean ± SD; age = 24.7 ± 7.7

yrs) completed a familiarization session and a 1RM protocol prior to returning to the laboratory on two separate occasions to complete 1 set of leg extension resistance exercise to failure at 70% or 50% 1RM. During each condition, surface EMG signals were recorded from the 4 quadriceps femoris muscles. EMG amplitude (EMG AMP) was quantified as the root mean square value from the repetitions corresponding to the 1st, 25th, 50th, 75th, and 100th percentiles and normalized to the EMG AMP values obtained during 1RM. For 70% and 50% 1RM, normalized EMG AMP for the four quadriceps femoris muscles increased with fatigue. The change in normalized EMG AMP of the vastus medialis (VM) was greater at 50% than 70% 1RM. However, while the authors did not report statistical analyses of normalized EMG AMP at 50% vs 70% 1RM, a qualitative analysis based on the data they presented suggests that muscle activation was lower at 50% than 70% 1RM (their Figure 3). Therefore, single sets of resistance training exercise to failure at 50% and 70% 1RM resulted in increasing muscle activation; however, it does not appear that the fatigue-induced increases in EMG AMP at 50% 1RM are sufficient to achieve the level of muscle activation experienced during exercise with 70% 1RM.

2.3.3. Cook, Murphy, and Labarbera (29)

The purpose of this study was to compare maximal isometric torque decrements, voluntary activation, and evoked contractile function before and after acute bouts of low-load, low-load with blood flow restriction, and high-load resistance training. In addition, the authors investigated muscle activation during the resistance training bouts with each load. It was speculated that if all three resistance training loads were performed to volitional failure, there would be sufficient ‘muscular overload’ to cause an increase in