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REVIEW ARTICLE

A Review of the Acute Effects and Long-Term Adaptations of Single- and Multi-Joint Exercises during Resistance Training

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Abstract Resistance exercises can be considered to be multi-joint (MJ) or single-joint (SJ) in nature. Many strength coaches, trainers, and trainees believe that adding SJ exercises to a resistance training (RT) program may be required to optimize muscular size and strength. However, given that lack of time is a frequently cited barrier to exercise adoption, the time commitment resulting from these recommendations may not be convenient for many people. Therefore, it is important to find strategies that reduce the time commitment without negatively affecting results. The aim of this review was to analyze and discuss the present body of literature considering the acute responses to and long-term adaptations resulting from SJ and MJ exercise selection. Studies were deemed eligible for inclusion if they were experimental studies comparing the effects of MJ, SJ, or MJ + SJ on dependent variables; studies were excluded if they were reviews or abstracts only, if they involved clinical populations or persons with articular or musculoskeletal problems, or if the RT intervention was confounded by other factors. Taking these factors into account, a total of 23 studies were included. For the upper and lower limbs, analysis of surface electromyographic (sEMG) activation suggests that there are no differences between SJ and MJ exercises when comparing the prime movers. However, evidence is contrasting when considering the trunk extensor musculature. Only one study directly compared the effects of MJ and SJ on muscle recovery and the results suggest that SJ exercises resulted in increased muscle fatigue and soreness. Long-term studies comparing increases in muscle size and strength in the upper limbs reported no difference between SJ and MJ exercises and no additional effects when SJ exercises were included in an MJ exercise program. For the lumbar extensors, the studies reviewed tend to support the view that this muscle group may benefit from SJ exercise. People performing RT may not need to include SJ exercises in their program to obtain equivalent results in terms of muscle activation and long-term adaptations such as hypertrophy and strength. SJ exercises may only be necessary to strengthen lumbar extensors and to correct muscular imbalances.

Key Points

- Single-joint (SJ) exercise does not increase motor unit activation more than multi-joint (MJ) exercise alone.
- The addition of SJ exercise to an MJ exercise program does not increase the gains in muscle size and strength in the upper limbs.
- SJ exercise results in increased gains in muscle strength of the lumbar extensors when compared with MJ exercises.

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1 Introduction

Resistance training (RT) has been shown to promote significant increases in muscular size and strength [1, 2] and, as a result, to improve health-related parameters as well as reduce the risk of all-cause mortality [3–10]. In order to optimize results, the prescription of RT programs should be based on scientific principles that consider the manipulation and combination of several variables, including exercise selection [11–14].

Resistance exercises can be considered to be multi-joint (MJ) or single-joint (SJ) in nature. SJ exercises are rotary in output and are performed at a single joint using a single muscle or muscle group, whereas MJ exercises are generally linear in output as a result of rotation occurring at multiple joints. As such, MJ exercises recruit multiple muscles or muscle groups synchronously, which are generally classified as prime movers or synergists [15]. For example, when performing a bench press exercise, the pectoralis major is often considered the prime mover (the muscle that dominantly performs the action), while the triceps and anterior deltoids would be considered to be synergist muscles for this movement (the muscles that assist in performing the desired movement). This definition suggests that some muscles have a primary role in performing the movement while the synergist muscles have a secondary role to perhaps stabilize or assist the prime mover. This has led to contrasting hypotheses that synergist muscles might either fatigue before prime movers (and thus that a prime mover might not receive sufficient stimulus from MJ exercises) or that synergist muscles might not be sufficiently activated during MJ exercises due to the dominance of the prime mover.

Furthermore, Rutherford and Jones [16] and Chilibeck et al. [17] have suggested that muscle hypertrophy occurs earlier when using SJ compared with MJ exercises due to prolonged neurological adaptations being required for MJ exercises. As a result, many strength coaches, trainers, and trainees believe that adding SJ exercises to an RT program is required to optimize muscular size and strength. Indeed, current recommendations by the American College of Sports Medicine (ACSM) suggest that RT sessions should involve eight to ten exercises using both SJ and MJ exercises [12, 18].

However, considering that lack of time is the most frequently cited barrier to exercise adoption and continued adherence [19–23], the time commitment resulting from these recommendations ($\sim$60 min of training) may not be convenient or practical for many people. Therefore, finding strategies that reduce the time commitment without negatively affecting results might be important in order to increase participation in RT programs. Furthermore, acute responses including muscle activation (measured by surface electromyography [sEMG] and magnetic resonance imaging [MRI]), muscle damage, and fatigue, as well as long-term adaptations (e.g., muscular strength and hypertrophy) observed when SJ and MJ exercises are compared appear to challenge this long-standing belief [24–32]. If the addition of SJ exercises is not necessary, it would be possible to design equally efficacious programs that are more time efficient. With this in mind, the purpose of the present review was to analyze and discuss the present body of literature considering the acute responses to, and long-term adaptations resulting from, SJ and MJ exercise selection in RT.

2 Literature Search Methodology

A narrative review was conducted after a literature search involving an emergent approach, detailed as follows. Studies that examined the effects of exercise selection in RT were accessed via the Scielo, Science Citation Index, National Library of Medicine, MEDLINE, Scopus, SPORTDiscus, LILACS, and CINAHL databases, utilizing the following keywords: ‘exercise selection’, ‘single joint’, ‘multi joint’, ‘isolation exercise’, ‘compound exercise’, ‘complex exercise’, ‘open kinetic chain’, ‘closed kinetic chain’ and their respective abbreviations and combinations along with ‘muscle strength’, ‘hypertrophy’, ‘motor unit activation’, ‘electromyography’, ‘muscle mass’, ‘muscle size’, ‘fiber recruitment’, and ‘muscle power’. A ‘snowballing’-style literature search [33] was used, involving an emergent approach as the search progressed, including searching references of references and using personal contact with authors and colleagues knowledgeable in the area. Names of the authors cited were also utilized in the search. Hand searches of relevant journals and reference lists obtained from articles were also conducted.

Such combinations resulted in the inclusion of 23 original articles addressing exercise selection as an experimental variable in RT. The last search was performed on 5 May 2016. Only studies comparing the effects of MJ, SJ, or MJ + SJ on dependent variables such as neuromuscular activity, maximal strength, and hypertrophy were included. The review included articles in English, Spanish, Portuguese, German, or Italian. Studies were excluded if they were reviews or abstracts only, if they involved clinical populations or persons with articular or musculoskeletal problems, or if the RT intervention was confounded by other factors, such as other forms of exercise, diet, or pharmacological intervention.

3 Acute Effects

3.1 Surface Electromyography

Anecdotally, the recommendation of using SJ exercises is derived from the notion that SJ exercises recruit a higher number of motor units than MJ exercises, as commonly suggested [34] and employed by bodybuilders [35, 36]. While it seems logical that a higher degree of specific exertion and activation might occur when targeting a specific muscle through SJ exercises, it is important to consider the body of scientific literature (Table 1). A number of studies have sought to compare SJ and MJ exercises by examining sEMG variables such as amplitude and power spectrum characteristics, which are often used as proxy indicators of activation and fatigue, respectively.

The first known study to compare muscle activity between SJ and MJ exercises was published by Signorile et al. [37], who measured sEMG amplitude of the quadriceps muscles of trained males while performing 10 repetition maximum (RM) MJ (parallel squats) and SJ (knee extensions) exercises. Tests were performed in two sessions, 1 week apart. During the first session, participants performed one set of parallel squats followed, after a 15-min rest, by knee extensions, and the protocol was repeated in the reverse order in the second session. The results showed no differences between exercise order; however, significant differences were found between exercises. According to the results, the root mean square (RMS) sEMG amplitudes of the vastus lateralis and vastus medialis were higher during the squats than during the knee extensions. Additionally, the drop in mean power frequency in the vastus medialis was significantly greater for the squats than for the knee extensions. Although the same trend occurred for the vastus lateralis, the difference did not reach significance.

The studies by Wilk et al. [30] and Escamilla et al. [29] are presented together here as they report the same data. These studies analyzed sEMG in ten trained males with an average of 11 years' RT experience while performing knee extensions (SJ), leg press (MJ), and squats (MJ). sEMG of the quadriceps and hamstrings were measured while the participants performed four repetitions with a 12RM load and this was normalized into a percentage of the value obtained in a maximum voluntary isometric contraction. According to the results, the peak sEMG activity of the quadriceps was higher during the squat, with RMS reaching ~59 % of a maximal voluntary isometric contraction (MVC). The values for the leg press and knee extension were ~51 and ~52 % of MVC, respectively, and were not different to each other. When the quadriceps muscles were analyzed separately, knee extensions generated approximately 45 % more rectus femoris activity than squats, while squats generated approximately 20 % more vastus medialis activity and approximately 5 % more vastus lateralis activity than knee extensions. The sEMG for the hamstring muscle was also significantly higher during the squats than during leg press and knee extensions.

In the study by Alkner et al. [38], nine healthy men performed unilateral isometric leg press (MJ) and knee extensions (SJ) at a knee angle of 90 ° for 2–3 sec at 20, 40, 60, 80, and 100 % of MVC. sEMG was measured for the vastus lateralis, vastus medialis, rectus femoris, and biceps femoris. According to the results, there were no differences in the peak sEMG activity of individual muscles between knee extensions and leg press.

The study by Enocson et al. [28] assessed muscle activation in leg press and knee extensions using MRI in eight trained men. The participants performed five sets of eight to 12 repetitions in the leg press and the seated knee extension exercises at loads equivalent to 50, 75, and 100 % of the load used to perform five sets of 10RM. Analyses of the changes in signal intensity revealed that the quadriceps activation at 100 % load was greater after knee extensions (32 %) than after the leg press (22 %). However, separate analysis revealed no difference for vastus lateralis, intermedius, and medialis between exercises; therefore, the difference appeared to be due to the greater rectus femoris activation during the knee extensions (Table 2).

Subsequently, Ema et al. [39] examined whether sEMG amplitude of the quadriceps femoris muscles (rectus femoris and vastus lateralis and medialis) differs between knee extension (SJ) and leg press (MJ) exercises in 15 untrained men. The participants performed five repetitions of knee extension and leg press at intensities of 20, 40, 60, and 80 % of 1RM. Each quadriceps RMS was normalized to that during 1RM of the knee extension trial, and each biceps femoris RMS was normalized to that during 1RM of the leg press trial. RMS amplitude was averaged over the five repetitions. According to the results, no differences were observed in the vastus lateralis and medialis RMS between leg press and knee extension at any load. However, rectus femoris RMS was significantly higher during knee extensions than during leg press at all loads, whereas biceps femoris RMS was higher during the leg press at 40, 60, and 80 % of 1RM loads. The authors suggested that the differences in rectus femoris RMS amplitude are a product of being biaxial (e.g., crossing two joints). In this sense, we might consider that the rectus femoris appears to show greater amplitudes when it is shortened (e.g., during a SJ

Table 1 Acute responses to single- and multi-joint exercises

Study	Participants	Exercises	Protocol	Results
Muscle activity				
Torso and limbs				
Alkner et al. [38]	9 active men	Leg press (MJ) and knee extensions (SJ)	2–3 sec of isometric contractions at 90 ° at 20, 40, 60, 80, and 100 % of MVC	No difference between exercises for VM, VL, and RF
Campos and da Silva [43]	12 trained men	Bench press (MJ) and barbell pullovers (SJ)	12 repetitions at 70 % 1RM	Higher PM and AD for bench press. Higher TB and LD for pullovers
Ema et al. [39]	15 untrained men	Leg press (MJ) and knee extensions (SJ)	5 repetitions at 20, 40, 60, and 80 % 1RM	No difference between exercises for VM and VL, higher RF activation for knee extension
Enocson et al. [28]	8 trained men	Leg press (MJ) and knee extensions (SJ)	5 sets of repetitions, at 50, 75, and 100 % of the load used in 5 sets of 10RM	No difference between exercises for VI, VM, and VL, higher RF activation for knee extension
Franke et al. [44]	12 trained men	Inclined lat pull-down (MJ), seated row (MJ), and reverse pec deck (SJ)	10RM	Higher PD activation for the reverse pec deck, no difference for AD and lower MD activation for the inclined lat pull-down
Rocha Júnior et al. [31]	13 trained men	Bench press (MJ) and pec deck (SJ)	10RM	No difference between exercises for PM and DA, higher TB for bench press
Signorile et al. [37]	9 trained men	Squat (MJ) and knee extensions (SJ)	10RM	Higher VM and VL activity during the squat
Welsch et al. [32]	22 men and women with various training levels	Barbell bench press (MJ), dumbbell bench press (MJ), and dumbbell flies (SJ)	3 repetitions at 6RM load	No difference between exercises for PM and DA, lower activation time for dumbbell flies
Wilk et al. [30] and Escamilla et al. [29]	10 trained men	Squat (MJ), leg press (MJ), and knee extensions (SJ)	4 repetitions at 12RM load	Higher quadriceps and hamstrings activity for squat, no difference between leg press and knee extension
Lumbar extensors				
Da Silva et al. [49]	11 healthy men and 11 healthy women	Isolated lumbar extension (SJ) and trunk extension (MJ)	5 repetitions at 40 % of maximum voluntary isometric contraction	Higher activity for lumbar extensors in SJ exercise, higher activity for gluteus maximus and biceps femoris in MJ exercise
Lee [50]	9 healthy men	Isolated lumbar extension with (SJ) and without(MJ) use of restraints	20 repetitions at 50 % of maximum voluntary isometric contraction	Higher activity for the lumbar extensors in SJ exercise
San Juan et al. [48]	8 healthy men and 7 healthy women	Isolated lumbar extension with (SJ) and without(MJ) use of restraints	20 repetitions (or to momentary failure) at 50 % of maximum voluntary isometric contraction	Higher activity for lumbar extensors in SJ exercise, no difference between exercises for biceps femoris
Udermann et al. [46]	12 healthy men	Isolated lumbar extension with (SJ) and without (MJ) use of restraints	12 repetitions at 80 % of body mass	No difference between exercises for lumbar extensors, gluteals, or hamstrings
Walsworth [47]	9 healthy men	Isolated lumbar extension with use of restraints (SJ) and trunk extension (MJ)	8–15 repetitions to momentary failure	No difference between exercises for the lumbar extensors
Muscle fatigue and recovery				
Edinborough et al. [53]	8 active men	Isolated lumbar extension (SJ) and kettlebell swings (MJ)	SJ: a set of repetitions to momentary failure at 80 % of maximum voluntary isometric contraction MJ: a set of repetitions for 60 s using a 16 kg load	Higher lumbar extensor fatigue after SJ exercise
Korak et al. [52]	10 trained men	MJ (flat barbell bench press, seated dumbbell military press, barbell dead lift, and machine leg press) and SJ (knee extension, machine triceps extension, dumbbell side raises, machine chest fly, and seated machine hip abduction/ adduction)	1 set with 10 repetitions at 85 % of 10RM + 1 set to failure at 10RM	Faster recovery and increased RPE after SJ

Table 1 continued

Study	Participants	Exercises	Protocol	Results
Mendiguchia et al. [54]	11 trained men	Lunges (MJ) and leg curls (SJ)	3 sets of 6 repetitions (body weight for lunge and 120 % of 1RM for leg curls with only eccentric phase)	Similar load in SM and short head of BF; SJ loaded all regions of the ST, while MJ did not. Only MJ loaded the proximal regions AM and the long head of the BF
Soares et al. [51]	16 trained men	Biceps curl (SJ) and seated row (MJ)	8 sets of 10RM	Higher DOMS and lower recovery after SJ

AD anterior deltoid, *AM* adductor magnus, *BF* biceps femoris, *DOMS* delayed-onset muscle soreness, *LD* latissimus dorsi, *MD* medial deltoid, *MJ* multi-joint, *MVC* maximum voluntary contraction, *PD* posterior deltoid, *PM* pectoralis major, *RF* rectus femoris, *RM* repetition maximum, *RPE* rate of perceived exertion, *SJ* single-joint, *SM* semimembranosus, *ST* semitendinosus, *TB* triceps brachialis, *VI* vastus intermedius, *VL* vastus lateralis, *VM* vastus medialis

Table 2 Influence of exercise selection on long-term adaptations to resistance training

Study	Participants	Exercises	Duration (weeks)	Results
Torso and limbs				
França et al. [26]	20 trained men	Incline bench press, flat bench press, decline bench press, weighted push-ups, shoulder press, V bar lat pull-down, seated row (machine), supinated grip lat pull-down, seated row (pulley), and upright row (MJ) vs. the same as MJ plus pulley elbow extensions with a pronated grip, pulley elbow extensions with neutral grip, standing dumbbell biceps curls, and seated dumbbell unilateral biceps curls (MJ + SJ)	8	Similar increases in muscle size and strength
Gentil et al. [24]	29 untrained men	Lat pull-down (MJ) vs. lat pull-down + biceps curls (MJ + SJ)	10	Similar increases in muscle size and strength
Gentil et al. [25]	29 untrained men	Lat pull-down (MJ) vs. biceps curls (MJ + SJ)	10	Similar increases in muscle size and strength
Giannakopoulos et al. [27]	39 active men	Internal and external rotation to the right and left (SJ) vs. pull-up, overhead press, reverse pull-ups, and push-ups (MJ)	6	Greater increases in elbow internal and external rotations strength with MJ
Lumbar extensors				
Fisher et al. [59]	36 trained men	Isolated lumbar extension (SJ) vs. Romanian deadlift (MJ)	10	Only SJ exercise increased isolated lumbar extension strength
Graves et al. [57]	47 healthy men and 30 healthy women	Isolated lumbar extension (SJ) vs. trunk extension (MJ)	12	Only SJ exercise increased isolated lumbar extension strength
Mayer et al. [58]	14 healthy men and 4 healthy women	Isolated lumbar extension with (SJ) vs. without (MJ) use of restraints	12	Similar increases in isolated lumbar extension strength

MJ multi-joint, *SJ* single-joint

exercise) than when the net length does not change[1] (e.g., during MJ exercises). However, it is important to note that the use of a given percentage of 1RM may have led to differences in the relative loading of the exercises, since previous studies reported that the number of repetitions performed at a given percentage of 1RM is higher during leg press than during knee extensions [40–42]. Thus, it is possible that the higher sEMG values for the quadriceps femoris during knee extensions were a result of the relatively higher loads, in contrast to relatively lower loads during the leg press.

With regard to upper-body exercises, four studies were found. Welsch et al. [32] compared the activation levels for

[1] Lombard's paradox suggests that the biaxial nature of the rectus femoris means that the net length does not change in hip and knee extension (e.g., MJ) exercises because just as the muscle shortens as a result of knee extension, it lengthens proportionally as a result of hip extension.

the pectoralis major and anterior deltoid on the barbell bench press (MJ), dumbbell bench press (MJ), and dumbbell fly (SJ). The participants performed three repetitions at a 6RM load, during which the concentric phase of the exercises were analyzed. The results showed that peak sEMG values for both muscles were not significantly different during the exercises. However, dumbbell flies had significantly less relative time of activation than did the barbell and dumbbell bench presses. These results led the authors to suggest that the SJ exercise may be better suited as an auxiliary lift.

Rocha Júnior et al. [31] evaluated sEMG activity of the pectoralis major, anterior deltoids and triceps brachii muscles during 10RM of the barbell bench press (MJ) and the pec deck (SJ) exercises in 13 trained men with a mean of 7 years' RT experience. sEMG was normalized by the maximum values obtained during the tests. As expected, the results showed that triceps brachii RMS amplitude was higher during the bench press as the pec deck does not involve elbow extension. However, the results did not show any differences between exercises for pectoralis major and anterior deltoid RMS.

Subsequently, Campos and da Silva [43] compared the sEMG activity of the pectoralis major, triceps brachii, anterior deltoid, posterior deltoid, and latissimus dorsi between flat horizontal bench press (MJ) and barbell pullover (SJ) exercises. In the study, 12 young men experienced in RT performed 12 repetitions at 70 % of 1RM of the selected exercises. The results showed higher RMS for the pectoralis major and anterior deltoid muscles in the flat horizontal bench press than in the barbell pullover. RMS for triceps brachii and latissimus dorsi muscles were higher in the barbell pullover. However, it is important to note that the movement at the shoulder joint is very different between the exercises: the horizontal bench press involves horizontal adduction and abduction of the shoulder, while the barbell pullover involves flexion and extension.

Franke et al. [44] recently examined sEMG of the anterior, middle, and posterior deltoid during SJ and MJ exercises for the upper body including inclined lat pull-down (MJ), reverse pec fly (SJ), and seated row (MJ). Twelve healthy men with at least 6 months of RT experience participated in the study. Absolute loads differed between the exercises performed, but relative load was controlled by participants performing 10RM for each exercise. RMS sEMG amplitude was normalized to a maximum voluntary contraction using shoulder flexion at 90° for the anterior portion and shoulder horizontal abduction with the shoulder at 90° for the middle and anterior portions. RMS sEMG amplitudes for the second, fourth, sixth, and eight repetitions were used and an average of these four amplitudes was calculated. There were no differences between the exercises for RMS sEMG amplitudes for the anterior portion of the deltoid. For the middle portion there were significantly greater amplitudes during both the reverse pec deck (SJ; ∼47 %) and seated row (MJ; ∼38 %), with no differences between them, than for the inclined lat pull-down (MJ; ∼17 %). For the posterior portion there were significantly greater amplitudes during the reverse pec deck (∼91 %) than for both seated row (∼51 %) and inclined lat pull-down (∼56 %), between which there was no difference.

Most research has focused predominantly on the lower and upper limbs. However, some studies have also compared MJ and SJ exercise for the trunk and specifically the lumbar extensor musculature (i.e., thoracic and lumbar erector spinae, including the iliocostalis lumborum and longissimus thoracis, the multifidus, and also the quadratus lumborum when contracted bilaterally). Isolated lumbar extension exercise requires a particular restraint system and without it any extension-based movements of the trunk involve both lumbar and hip extension movements. Thus, isolated lumbar extension could be considered a SJ exercise, whilst other trunk extension-based movements could be considered MJ exercises [45].

In this regard, we found studies comparing resistance machines with and without appropriate restraints to permit isolated lumbar extension. Udermann et al. [46] examined maximum voluntary contraction-normalized integrated sEMG in 12 healthy males completing sets of 12 repetitions with repetition duration controlled using a load equal to 80 % of their body mass. In one condition participants performed a set with the machine restraints applied (SJ) and in the other without them (MJ). No significant effects were found between condition interactions for any of the lumbar extensors, gluteal, or hamstrings muscle groups. However, though non-significant ($p = 0.06$), all muscle groups showed a slightly greater activation under the SJ condition.

Walsworth [47] compared the use of an isolated lumbar extension machine (MedX Lumbar Extension Machine, MedX Holdings, Inc., Ocala, FL, USA; SJ) with a machine utilizing less sophisticated restraints (Cybex Trunk Extension Machine, Cybex International, Inc., Medway, MA, USA; MJ). Nine healthy males and four healthy females performed a set to momentary concentric failure using a load permitting eight to 15 repetitions and the mean MVC-normalized RMS amplitude of the sEMG was examined for the fifth repetition of each set under each condition. Results (mean ± SD) indicated a similar level of amplitude between both SJ (155 ± 13 %) and MJ (147 ± 15 %).

San Juan et al. [48], similarly to Udermann et al. [46], compared the use of an isolated lumbar extension machine with (SJ) and without (MJ) the use of the restraints. They examined normalized RMS amplitude using sEMG while participants performed sets of 20 repetitions (or to momentary concentric failure if it occurred first) using 50 % of the participants' maximum voluntary isometric torque for the lumbar extensors and biceps femoris. Their results revealed significantly greater RMS amplitude (both when expressed as raw data and when normalized to maximum voluntary isometric contraction) for the lumbar extensors both during the first and last two repetitions for the SJ condition. There was no difference between conditions for the biceps femoris.

Da Silva et al. [49] examined different restraint set-ups designed to permit either isolated lumbar extension (SJ) or trunk extension (MJ) to be performed. They measured sEMG RMS amplitude normalized to maximum voluntary isometric contraction in 22 healthy participants (11 males and 11 females) whilst participants completed five repetitions using 40 % of their maximum voluntary isometric contraction with the repetition duration controlled under each condition. The mean normalized RMS amplitude for the lumbar extensors across the three middle repetitions was significantly higher under conditions permitting SJ isolated lumbar extension to be performed. In addition, gluteus maximus and biceps femoris RMS amplitudes were significantly lower during SJ than during MJ conditions.

Lee [50] recently examined an isolated lumbar extension device with (SJ) and without (MJ) use of its restraint system. Nine healthy males performed a set of 20 repetitions using 50 % of their maximum voluntary isometric torque whilst controlling repetition duration under each condition. Mean sEMG RMS amplitude normalized to maximum voluntary isometric contraction was examined for the lumbar extensors and at all electrode sites there was a significantly higher amplitude for the SJ condition.

3.2 Muscle Damage and Fatigue

We were able to find four studies comparing muscle recovery after SJ and MJ exercises. Soares et al. [51] compared the time course of elbow flexor recovery after seated row (MJ) and seated preacher curl (SJ) in 16 resistance-trained men. Participants performed eight sets of 10RM of each exercise in a contralateral design. The results showed that the peak torque (PT) decrease was greater after seated preacher curl (26.8 %) than after the seated row (15.1 %). Moreover, elbow flexor PT returned to baseline values after 24 h for seated row but not after seated preacher curl. Delayed-onset muscle soreness (DOMS) increased at 24, 48, and 72 h after seated preacher curl, but only at 24 and 48 h after seated row. Comparison between exercises revealed that DOMS was greater after the SJ exercise at 24, 48, and 72 h after training, suggesting that muscle damage was higher following an SJ than after an MJ exercise.

However, a study by Korak et al. [52] produced divergent results. In their study, ten trained males performed one session involving only MJ exercises (flat barbell bench press, seated dumbbell military press, barbell dead lift, and machine leg press) and another session with only SJ exercises (knee extension, machine triceps extension, dumbbell side raises, machine chest fly, and seated machine hip abduction/adduction). Each exercise was performed with two sets, the first involved ten repetitions at 85 % of the 10RM load and the second was completed to volitional failure with the 10RM load. The authors compared the recovery by repeating the same session after 24 or 48 h and reported that subjects recover faster after a session involving SJ exercises. Participants also estimated their perceived recovery status (PRS) after their first set of each exercise and rating of perceived exertion (RPE) following the second set of each exercise. Session RPE was recorded 15 min after completing the entire workout protocol. There were increased RPE and lower PRS ratings for SJ than for MJ exercises at 24 h. Session RPE ratings did not differ between 24 and 48 h.

The difference between studies may lie in their methods: Soares et al. [51] performed standardized evaluations for both SJ and MJ exercises, while in the study by Korak et al. [52] participants were evaluated in two different situations (during SJ and MJ sessions). Therefore, the methods used by Korak et al. [52] provide information related to repeating SJ and MJ sessions, but did not provide direct comparison.

Lastly, Edinborough et al. [53] recently examined the fatigue response of the lumbar extensors as a result of either performing isolated lumbar extension (SJ) or kettlebell swing (MJ) training. Eight active healthy males underwent a series of fatigue response tests involving an MVC test for isolated lumbar extension at five angles throughout their range of motion, followed by an exercise condition and then another maximal test immediately thereafter. Participants performed either a set of isolated lumbar extension exercises to momentary concentric failure using 80 % of their maximum voluntary isometric torque or a set of kettlebell swings using a 16 kg load for a duration of 60 sec. Results revealed that both the SJ and MJ conditions significantly induced fatigue in the lumbar extensors, as indicated by a reduction in torque production, though the SJ condition produced a significantly greater fatigue response. The RPE (mean $\pm$ SD) using Borg's 15-point scale was also significantly greater under the SJ conditions (18.38 $\pm$ 1.6) than under the MJ condition (11.75 $\pm$ 2.5). A limitation with this design, however, relates to the fact that the two exercise conditions were not matched for load, repetitions, repetition duration, or indeed effort.

For the hamstring muscles, Mendiguchia et al. [54] compared the effects of eccentric leg curl and lunge exercises on the activation of the biceps femoris, semitendinosus, semimembranosus, and adductor magnus in 11 male professional soccer players. MRI was performed for 15 sites of the thigh before and 48 h after three sets of six repetitions of each exercise. One leg performed lunges and the other leg curls; lunges were performed with body weight and leg curls were at 120 % of 1RM. According to the results, there were no differences in absolute short tau inversion recovery values between exercises for the semimembranosus and the short head of the biceps femoris. However, the authors found a difference for the semitendinosus, such that leg curl loaded all regions of the semitendinosus muscles. In addition, only lunges loaded the proximal regions of the adductor magnus and the long head of the biceps femoris. However, it is important to note that the exercises had many differences that may have interfered in the results, such as speed (no control for lunges and 3 sec during the eccentric phase for the leg curls); action (there is no concentric component in leg curls, in contrast to lunges); and load (leg curls were performed at 120 % 1RM and lunges with bodyweight) [55, 56]. Therefore, it is not possible to confirm if the different alterations were due to the use of SJ versus MJ exercise or to other intervening factors.

4 Long-Term Effects

With regard to long-term adaptations, the study by Giannakopoulos et al. [27] compared the effects of performing SJ or MJ exercises on the shoulder cuff muscular performance of 39 active men. Participants were randomly assigned to one of three groups: the SJ group performed four SJ exercises for the internal and external shoulder rotators (internal and external rotation to the right and left) using dumbbells; the MJ group performed four MJ exercises (pull-ups, overhead press, reverse pull-ups, and push-ups); and the control group had no training. Training was performed 3 days a week for 6 weeks, with the same number of sets and repetitions for the SJ and the MJ groups. Before and after the training period, PT for internal and external shoulder rotation were evaluated on an isokinetic dynamometer. When comparing the SJ and the MJ groups, the results showed that the improvements were greater for the MJ group. Additionally, the MJ group showed significant improvements in external and internal rotation of both the 'strong' and 'weak' sides, while the SJ group only had significant improvements for the 'weak' side, in both internal and external rotation. According to the authors, SJ exercises are only effective when the training goal is to strengthen a weaker muscle group, but they must be replaced by more complex exercises in order to obtain increases in muscle strength.

Gentil et al. [25] compared the effects of performing MJ and SJ exercises on muscular size and strength increases in the elbow flexors in untrained men. In this study, 29 young men without prior RT experience were randomly divided into one group that trained the elbow flexors with lat pull-downs (MJ), while the other group trained with biceps curls (SJ). Lat pull-downs were performed with a pronated grip and no instructions were given to emphasize activation of the elbow flexors. Both groups trained twice a week, with three sets of 8–12RM for a period of 10 weeks. The results showed significant increases of 6.10 and 5.83 % in muscle thickness and 10.40 and 11.87 % for elbow flexors isokinetic PT for the MJ and SJ exercises, respectively, with no significant between-group differences for any variables considered.

Based on these findings, one may question if the addition of SJ exercises to an MJ exercise program would provide additional benefits. To address this issue, Gentil et al. [24] examined the effect of adding SJ exercises to an MJ (e.g., MJ + SJ) exercise program on the upper-body muscle size and strength of 29 untrained young men. The study lasted 10 weeks and the MJ group trained the elbow flexor only though the performance of lat pull-downs while the MJ + SJ group performed additional biceps curls in their sessions. Participants trained two times a week with three sets of 8–12RM in each exercise. Before and after the training period, the elbow flexors of the participants were evaluated for muscle thickness and isokinetic PT. The results revealed that both groups significantly increased muscle thickness (6.5 % for MJ and 7.04 % for MJ + SJ) and PT (10.40 % for MJ and 12.85 % for MJ + SJ), with no significant between-group differences. Based on the results, the authors suggest that the addition of an SJ exercise to an MJ training routine resulted in no additional benefits in terms of muscle size or strength gains in untrained young men.

Subsequently, França et al. [26] compared the changes in upper-body muscle strength and size in 22 trained men performing upper-body RT programs involving MJ + SJ or only MJ exercises. The study lasted 8 weeks and the RT was divided into two sessions per week and followed a linear periodization model. On Mondays and Thursdays the MJ group performed incline bench press, flat bench press, decline bench press, weighted push-ups, and shoulder press exercises. On Tuesdays and Fridays they performed V bar lat pull-down, seated row (machine), supinated grip lat pull-down, seated row (pulley), and upright row exercises. The MJ + SJ group followed the same routine but added pulley elbow extensions with a pronated grip and pulley elbow extensions with a neutral grip at the end of the Monday and Thursday sessions; they also added standing dumbbell biceps curls and seated dumbbell unilateral biceps curls at the end of the Tuesday and Friday sessions. The results revealed that the changes in flexed arm circumference (1.72 and 1.45 % for the MJ and MJ + SJ groups, respectively) and arm muscular circumference (1.33 and 3.17 % for the MJ and MJ + SJ groups, respectively) were not different between the groups. Similarly, both groups significantly increased 1RM for elbow flexion (4.99 and 6.42 % for the MJ and MJ + SJ groups, respectively) and extension (10.60 and 9.79 % for the MJ and MJ + SJ groups, respectively). Once again, there were no significant between-group differences.

For the lumbar extensors, Graves et al. [57] compared changes in isolated lumbar extension strength of 77 participants (47 males and 30 females) after 12 weeks of RT using either an isolated lumbar extension machine (MedX Lumbar Extension Machine; SJ) or machines[2] without restraints (Nautilus Lower Back Machine [Nautilus, Vancouver, WA, USA] or Cybex Eagle Back Machine [Cybex International, Inc.]; MJ) and a non-training control. All participants trained once a week, performing a single set of full range of motion repetitions using a load that would permit them to reach momentary concentric failure between eight and 12 repetitions. Significant increases in isolated lumbar extension strength occurred only in the SJ group. Neither the control group nor the MJ group had an increase in isolated lumbar extension strength. However, both the MJ and SJ group had an increase in the load used during training without significant between-group differences (~28 and ~39 % for MJ and SJ, respectively). This suggests that the MJ group, although they did not increase their isolated lumbar extension strength, may have increased their hip extension strength.

In order to avoid issues of specificity of training and testing as in the study of Graves et al. [57], Mayer et al. [58] compared the use of an isolated lumbar extension machine with (SJ) and without (MJ) the use of the restraints. In their study, 18 healthy participants (four females and 14 males) trained once a week, performing a single set of full range of motion repetitions using a load equal to 50 % of their maximum voluntary isometric torque to momentary concentric failure. Peak isometric lumbar extension strength increased significantly in both groups with no between-group differences (15.8 and 20.6 % for SJ and MJ, respectively).

Lastly, Fisher et al. [59] compared the use of an isolated lumbar extension machine (SJ) against a Romanian deadlift exercise (MJ). Thirty-six trained male participants completed a 10-week intervention in either an SJ, MJ, or a non-training control group. The SJ and MJ training groups performed a single set of repetitions to momentary concentric failure using a load equal to 80 % of maximum voluntary isometric torque or 1RM, respectively. All groups were examined for changes in isolated lumbar extension strength and also deadlift 1RM. Only the SJ group significantly increased in isolated lumbar extension strength, whereas both the SJ and MJ groups increased significantly in deadlift 1RM, though this was slightly greater for the MJ group (7.5 and 16.0 % for SJ and MJ, respectively).

No study was found for the lower limbs. Based on previous findings, it is possible to conclude that using SJ exercises does not provide additional benefits in terms of upper-limb muscle size and strength in comparison with performing MJ exercises. However, the results of the studies that compared SJ and MJ exercises for the conditioning of the lumbar extensors were generally in favor of SJ exercises.

5 Discussion

With regard to the acute effects of SJ and MJ exercises for the upper and lower limbs, analysis of sEMG activation suggests that there are no differences between SJ and MJ exercises when comparing the prime movers of both exercises. However, it is important to be careful in extrapolating this conclusion to biaxial muscles, especially when the muscle shortening in one joint is accompanied by its lengthening in the other joint. In such cases, muscle activity during MJ exercises seems to be compromised. This phenomenon appears to be well-established for the rectus femoris during lower-body MJ exercises such as squats and leg press. However, it may also apply to the gastrocnemius and hamstrings in the same exercises. When considering the trunk extensor musculature, evidence is contrasting as to whether or not there are differences in sEMG measures for either the lumbar or hip extensors during SJ or MJ exercises.

Only one study directly compared the effects of MJ and SJ on muscle recovery and the results suggest that SJ exercises result in increased muscle fatigue and soreness in trained subjects. The difference in muscle recovery may seem controversial, since most studies found no difference in muscle activation between SJ and MJ exercises. However, this supports previous research that has reported no correlation between muscle activation and muscle damage [60, 61]. When analyzing knee extension, Prior et al. [60] reported that the four quadriceps muscles were recruited similarly, but the rectus femoris showed disproportionate muscle damage. Similarly, Takahashi et al. [61] found greater muscle damage in the rectus femoris after squats, although there were no differences in the activation of the quadriceps muscles. In addition, the findings of Edinborough et al. [53] showed considerably greater fatigue responses after SJ exercise for the lumbar extensors despite

[2] The two groups using these machines did not differ significantly and so were pooled to create a single group that trained without restraints, thus performing MJ trunk extension.

the equivocal sEMG findings relating to this musculature. Taken together, these studies suggest that muscle activation is not a unique determinant of muscle damage or fatigue.

However, we should acknowledge the significant limitations presented by the biomechanical differences between SJ and MJ exercises and free-weight or machine-based exercises. A free-weight dumbbell or barbell maintains a constant load but provides varying torque to the muscular system as lever lengths change throughout a range of motion [62]. With this in mind, studies where free-weight exercises were considered might be hindered by a lack of tension at specific points in the exercises (e.g., internal and external rotation from a supine position [20] and supine dumbbell flies [25]). In contrast a selectorized resistance machine varies the load using cams, cables, and pulleys and should provide tension throughout the entire range of motion. It should also be considered that many MJ exercises can be performed with differing hand positions that might further affect acute responses or long-term adaptations. For example, a narrow, pronated grip bench press has been shown to be associated with greater triceps sEMG amplitude than wider and supinated grip variations [63]. Furthermore, exercises such as press-ups, shoulder press, lat pull-down, and seated row might present differences in response. For example, for these exercises a narrow hand position produces shoulder flexion and extension, whereas, in contrast, a wider hand position results in shoulder abduction and adduction. These results might be particularly pertinent in consideration of rotator cuff response. In this sense, it is important to consider that there might not be parity in the torque applied at differing joints and thus to different muscles when comparing exercises. However, in considering the long-term adaptations, the studies reviewed here represent ecologically valid training protocols and thus realistic comparisons of muscular adaptive responses.

Studies comparing increases in muscle size and strength for the upper limbs reported no difference between SJ and MJ exercises and no additional effects for the inclusion of SJ exercises in an MJ exercise program. One limitation in the current literature is that the methods used to measure muscle size (ultrasound and circumference) do not consider non-uniform muscle hypertrophy. Since previous studies have suggested that SJ and MJ exercises result in different patterns of muscle hypertrophy [64, 65], it is possible to suggest that the results of the comparison are limited to the region analyzed and not necessarily representative of the response of the whole muscle. Based on this, one may argue that performing SJ exercise would be necessary for complete development of a muscle. However, it is debatable if this would be achieved only with the inclusion of a SJ exercise, or if simply varying between MJ exercises would bring the same adaptations. For example, Fonseca et al. [66] found that performing a variety of MJ exercises (squat, deadlift, and leg press) compared with a single MJ exercise (squat) produced a similar increase in overall quadriceps cross-sectional area. However, the use of variation in MJ exercises produced hypertrophy in all quadriceps muscles, whereas use of only a single MJ exercise hypertrophied the vastus medialis and rectus femoris.

Another interesting point is that the time course of hypertrophic adaptations in both the upper arm and trunk muscles seems to differ following bench press training. According to the results of Ogasawara et al. [67], pectoralis major muscle thickness significantly increased after 1 week, while triceps muscle thickness increases took 5 weeks to reach significance. The results indicate that the time course of the muscle hypertrophic response differs between the arm and trunk muscles in response to MJ exercises. If this is true, SJ exercise may be useful for beginners training for aesthetic reasons, since changes might take less time to occur. Nevertheless, this extrapolation is limited because the study did not compare the effects of SJ and MJ training; therefore, it is not possible to confirm that the delayed response was due to the use of MJ exercises or is a characteristic inherent to the triceps muscle.

When analyzing the current literature, it seems that the inclusion of SJ exercises in an RT program appears only to be justifiable in order to correct imbalances between different muscle groups. This could be the case during the preparation of bodybuilders, since they are evaluated for symmetry and equilibrated muscle development. Another possible utilization would be in a rehabilitation program, when a muscle or muscle group presents an imbalance that represents a risk of increased injury or pain, such as for the rotator cuff [27], hamstrings [68, 69], and the hip posterolateral musculature [70, 71].

Another case in which SJ exercise may be needed is for the lumbar extensors. The studies reviewed on long-term adaptations tend to support the view that this muscle group may benefit from SJ exercise and it has been argued that this is due to the recruitment patterns that occur during MJ trunk extension-based exercises; in essence, the lumbar extensors de-recruit while the hip extensors increase in their contributions [72, 73]. A recent review article has examined the role of exercise selection in conditioning the lumbar extensors and concluded that, while it may be possible to condition them through MJ exercises and this musculature is indeed recruited during such movements, improvements are optimal when performing specific isolated lumbar extension-based SJ exercise [45].

It is important to note that the lack of necessity of SJ exercises is specific for the muscles that are directly involved in the movement. In this regard, both short- and long-term studies show that the activation [29, 30] and muscle hypertrophy of the hamstrings [74] in lower-body

MJ exercises are limited. This is understandable because, although they participate in hip extension, this movement is accompanied by knee extension during lower-body MJ exercise. However, it should be noted that there is a distinct lack of studies examining SJ and MJ exercise for the lower-body musculature that have employed long-term interventions. Thus, this is an area that future research should examine further.

6 Conclusion

The results of this review suggest that performing SJ exercises may not bring additional benefits to MJ exercises when comparing both short- and long-term responses, in either trained or untrained individuals, for exercise involving the upper limbs. Moreover, the addition of SJ exercise to an MJ exercise program does not seem to increase gains in muscle size and strength. Fatigue responses, perceived effort, and soreness seem to be greater for SJ exercise; however, as this does not seem to be accompanied by greater adaptations, the indiscriminate use of SJ exercise may be detrimental since it induces higher discomfort without bringing superior results. The only presently proven instance in which SJ exercises might be recommended is for individuals wishing to condition their lumbar extensor musculature. Based on these findings, we suggest that persons performing RT may not need to include SJ exercises in their program to obtain equivalent results in terms of muscle activation and long-term adaptations such as hypertrophy and strength.

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