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DOES THE SEQUENCE OF EXERCISE IN A RESISTANCE TRAINING SESSION AFFECT STRENGTH GAINS AND MUSCULAR HYPERTROPHY? A CRITICAL EXAMINATION OF THE EVIDENCE

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Abstract

In a recent review of resistance training, the authors claimed that the sequence of performing resistance exercises in a training session is an important variable that can influence the efficiency, safety and effectiveness of a resistance training program. This Critical Examination challenges those claims and reveals that the sequence of performing resistance exercise has very little meaningful neuromuscular implication for an acute response (the ability to perform a specific number of repetitions) or any clinical application for chronic adaptations such as strength gains or muscular hypertrophy.

Key words: *order of exercise, strength gains, muscular hypertrophy*

Introduction

Skeletal muscle adaptations are often assumed to be intricately connected to specific resistance training variables. Some authors have suggested that the sequence of exercises in a training session is fundamental for optimal strength gains and muscular hypertrophy. The purpose of this Critical Examination is to challenge the claims and recommendations in a review of exercise sequence by Simão and colleagues [1]. The primary inclusion and exclusion criteria for this Critical Examination are the references cited by Simão and colleagues.

Simão and colleagues [1] stated that one of the main methodological variables in resistance training prescription is the order or sequence of exercises in a training session. In an attempt to support that claim, they cited the 2002 and 2009 American College of Sports Medicine (ACSM) position stands on resistance training [2-3]. The ACSM's 2002 position stand [2] was challenged [4] and subsequently removed from the ACSM website. In the 2009 position stand [3], the ACSM claimed that maximizing performance of multiple joint exercises such as the bench press, squat, leg press, and shoulder press by placing them early in a training session may be necessary for optimal strength gains. The only reference they cited was a study by Spreuwenberg and colleagues [5] that reported the acute responses—not chronic adaptations such as strength gains—as a result of a different sequence of exercises. That study is discussed in the next section on *Acute Responses* in this Critical Examination. Because there were no published studies on

the chronic effects relative to the sequence of exercise in resistance training prior to 2010, the ACSM's claim was based entirely on opinion.

Acute Responses

Many strength training enthusiasts believe that the number of repetitions in each set of resistance exercise is an important variable. Simão and colleagues [1] cited several studies [5-15] that reported how the sequence of resistance exercises acutely affected the number of completed repetitions either in subsequent exercises or subsequent sets of a specific exercise. Contrary to the claim by Simão and colleagues that there has never been a review article synthesizing the current literature relevant to the sequence of exercise, most of these studies [5,7,9-12,14-15] were discussed in a review by Carpinelli [16]. Perhaps because the studies by Bellezza and colleagues [6] and Farinatti and colleagues [8] were not specifically focused on the number of completed repetitions with a different sequence of exercise but on blood lactate and perceived exertion [6] or oxygen uptake [8], Carpinelli did not cite these studies in his review. Therefore, those studies will be discussed in this section.

Although Simão and colleagues [1] claimed that studies not published in the English language were excluded from their review, the study they cited in their narrative and Table IV (p. 260) by Silva and colleagues [13] was published in the Portuguese language, with only the title and abstract available in English.

Repetition duration is the time to complete an individual repetition in a set and can significantly affect

the number of completed repetitions. A subsequent sub-section in this Critical Examination entitled *Repetition Duration* discusses this concept in great detail. The pre-exhaustion method of training refers to the performance of a single joint exercise (e.g., lateral raise) for a large muscle group such as the deltoids prior to a multiple joint exercise (e.g., military press) for that muscle group. This concept is described in detail in a section entitled Pre-Exhaustion.

Sforzo and Touey [12]

The first study [12] discussed by Simão and colleagues [1] was one of the first published studies that manipulated the sequence of resistance exercise. Sforzo and Touey [12] assessed the amount of resistance used to complete eight repetitions with the eighth repetition requiring a maximal effort (8RM) for three upper body and three lower body exercises in 17 young males (age ~ 20 years) with approximately five years of resistance training experience. The trainees performed four sets of each exercise with their 8RM resistance in two counterbalanced sequence of exercises: squat, knee extension, knee flexion, bench press, seated military press, and triceps pushdown in session A; knee flexion, knee extension, squat, triceps pushdown, seated military press, and bench press in session B. There were two minutes rest between sets and three minutes between exercises. They recorded the total mass (resistance x number of repetitions) for each set of each exercise but incorrectly reported it as total force.

There was a significantly greater total mass (kg) lifted in some exercises for each of the four sets in session A compared with session B [12]. Understandably, total mass lifted in the bench press was significantly greater when the exercise was executed first in session A and total mass lifted in the triceps exercise was significantly greater when it was executed first in session B. Although the effects of exercise sequence were less pronounced for the lower body exercises, the total mass lifted across the four sets was significantly greater in the squat during session A and significantly greater for knee extension in session B.

Sforzo and Touey [12] concluded that performing larger muscle mass exercises prior to smaller muscle mass exercises resulted in a greater total resistance lifted during the session and that this difference in the volume of exercise would be an important stimulus for strength development. They noted that Goldberg and colleagues [17] concluded in their review of compensatory hypertrophy in frogs, chickens, rabbits, mice and rats that tension was the critical stimulus for muscular hypertrophy. However, Goldberg and colleagues did not discuss the amount of resistance or the number of sets and repetitions (the volume of exercise) that were required to produce an optimal stimulus for muscular strength gains in humans or any other animals.

Sforzo and Touey [12] also claimed that studies using a maximal or near maximal amount of resistance were most effective for improving strength and those studies supported the conclusions of Goldberg and colleagues [17]. The one reference they cited for that claim was a review by Atha [18] who cited only two resistance training studies [19-20]. Berger [19] compared strength gains in the free weight bench press in groups of young males who used a 2RM, 6RM or 10RM training protocol. O'Shea [20] compared a 2-3RM, 5-6RM or 9-10RM free weight squat protocol. The effort (RM) was similar for all the sets in each of the training protocols in both studies—maximal. Both studies reported no significant difference in strength gains as a result of using a very heavy, moderately heavy or a moderate resistance. Atha concluded: "*From these studies, one begins to believe that the importance of load and magnitude may have been exaggerated*" (p. 13). Therefore, neither the review by Goldberg and colleagues nor the review by Atha supported the claim by Sforzo and Touey. Simão and colleagues [1] did not place Sforzo and Touey's study in any of their five tables and they did not cite any references to support their own recommendation to maximize the total training volume in a training session. Sforzo and Touey did not attempt to justify prescribing four sets of every exercise for any demographic of trainees.

Miranda and colleagues [10]

Simão and colleagues [1] cited a study [10] in their Introduction that they did not place in any of their tables or discuss in their narrative. Miranda and colleagues [10] reported on the influence of the sequence of exercise and inter-set rest intervals in 16 young males (age ~25 years) with approximately six years of resistance training experience. All the participants performed three sets with their predetermined 8RM to voluntary exhaustion for each of six upper body machine and free weight exercises: wide grip lat pulldown, close grip lat pull-down, seated machine row, barbell row, dumbbell arm curl, and seated machine arm curl in sequence A. In sequence B the trainees followed the same exercise protocol in the reverse order. In four sessions separated by 48-72 hours (a randomized crossover design), the 16 trainees performed sequence A and sequence B with 1-minute rest between sets and exercises in two sessions and 3-minute rest intervals in another two sessions.

Based on the sequence of exercises, Miranda and colleagues [10] reported that the number of repetitions was significantly greater during sequence A compared with sequence B for the wide-grip lat pulldown; and was significantly greater during sequence B for the machine arm curl and barbell row. These results were similar for both 1-minute and 3-minute inter-set rest intervals. There was no significant difference in

the number of repetitions between sequence A and sequence B for the other three exercises when using either 1-minute or 3-minute inter-set rest intervals.

Perhaps an exercise sequence such as pulldown, bench press, rowing, military press, etc., which alternates each exercise with an antagonistic muscle group, would have less of an impact on the performance of subsequent sets and exercises than the 18 consecutive sets (3 sets of 6 exercises) for the biceps, which was a prime mover for the six exercises in the study by Miranda and colleagues [10]. The authors claimed that a greater number of repetitions and consequently a greater volume of exercise with a given load may provide a superior stimulus for strength gains. They failed to cite any resistance training studies to support that opinion.

Spreuwenberg and colleagues [5]

There are a couple of other acute response studies [5,11] that Simão and colleagues [1] cited as references but did not discuss in their narrative or incorrectly reported the results of those studies in their review. Spreuwenberg and colleagues [5] recruited nine young males (age ~24 years) with approximately seven years resistance training experience. The trainees performed four sets of free weight barbell squats with 85% 1RM for as many repetitions as possible with 2-minute inter-set rest intervals in session A. In session B, they performed three sets of 8-10RM bench press, lunge, rowing, biceps curl, deadlift, sit-up, and hang-pull exercises followed by the barbell squat (4 maximal effort sets with 85% 1RM, which was identical to the squat protocol in session A). The researchers randomized the two sessions, which were separated by 48-72 hours. The participants provided a rating of perceived exertion (RPE) immediately after completing each of the four sets of squats during both sessions.

Simão and colleagues [1] reported that the number of repetitions for the squat exercise was significantly greater in session A compared with session B [5]. However, what they failed to report was that the difference was significantly greater (2.6 repetitions) only in the 1st set of squats. There was no significant difference between session A and B in the number of completed repetitions for the 2nd, 3rd or 4th set of squats. Spreuwenberg and colleagues noted five times in their Discussion and Practical Applications sections that the number of repetitions was reduced when the squat was performed after the seven other exercises, but failed to note that this reduction was significant only in the 1st set of squats. One would hope that these omissions in data reporting by Spreuwenberg and colleagues [5] and Simão and colleagues [1] were unintentional errors rather than a deliberate attempt to mislead readers.

Although not mentioned in their Discussion or Practical Application sections, an important result of

the study by Spreuwenberg and colleagues [5] was that there was no significant difference between session A and B in the mean RPE (~8.4) immediately following each of the four sets of squats. The size principle unequivocally states that the recruitment of motor units is primarily dependent on the level of effort during the exercise [21]. Therefore, fewer completed repetitions when the exercise is performed later in a training session probably have no significant effect on the ability to recruit motor units. There is very little evidence to suggest that a different number of completed repetitions from session to session or between different training protocols (e.g., 4-6RM, 6-8RM, 8-10RM, 10-12RM, etc.) would significantly affect chronic adaptations such as muscular strength or hypertrophy. In a review by Jungblut [22], she reported that 82 out of 90 resistance training studies showed that training with a fewer number of repetitions (a heavier resistance) did not result in significantly greater strength gains compared with a greater number of repetitions (a lighter resistance).

Monteiro and colleagues [11]

Monteiro and colleagues [11] recruited 12 young females (age ~22 years) who were participating in a resistance training program three times a week for approximately six months prior to the investigation. Forty-eight hours after a 10RM assessment, the trainees performed three sets of 10RM bench press, military press and triceps pushdown exercises in session A. They performed the reverse sequence of exercises in session B. All sets were completed to voluntary exhaustion with 3-minute inter-set and inter-exercise rest intervals. There was no significant difference in the number of completed repetitions between the 1st, 2nd or 3rd sets for any of the exercises in session A. In session B there was a significant difference in repetitions between the 1st and 2nd sets (0.9 repetitions) and between the 1st and 3rd sets (1.5 repetitions) for the bench press, which was performed last in session B. There was no significant difference in the number of repetitions between the 1st, 2nd or 3rd sets for the other exercises in session B. The RPE was not significantly different between sessions.

Monteiro and colleagues [11] claimed that to maximize strength gains and muscular hypertrophy as a result of performing a specific exercise, that exercise should be placed first in a training session. They did not cite any reference to support that opinion. Their belief that this trivial difference of ~1.2 repetitions would have a significant impact on strength gains lacks scientific support and revealed their misinterpretation of the size principle [21-22]. Simão and colleagues [1] placed this study in their Table I (p. 255) and Table IV (p. 260) that showed the few trivial differences in the number of completed repetitions between the different

sequence of exercises and that there was no significant difference in the RPE. However, they did not discuss how the results of this study could have any practical application to resistance training and strength gains.

The two previously mentioned studies by Bellezza and colleagues [6] and Farinatti and colleagues [8] that were not reviewed by Carpinelli [16] are summarized below.

Bellezza and colleagues [6]

Bellezza and colleagues [6] recruited 11 young males and 18 females (age ~21 years) to perform one warm-up set (80% 10RM) and one 10RM set for each of nine exercises on Body Master machines: chest press, leg press, seated rowing, knee extension, overhead press, thigh curl, biceps curl, calf raise, and elbow extension (sequence A—large to small muscle groups). Most of the participants (79%) were already involved in a resistance training program 2-3 times a week. There was one minute rest between sets and exercises and the subjects were verbally encouraged to perform all the 10RM sets with a maximal effort. After a minimum of 48 hours, the subjects performed the same protocol in the reverse order (sequence B—small to large muscle groups). The researchers randomly assigned the order of sequence A and sequence B for each participant.

Bellezza and colleagues [6] claimed that there was a significant difference in the average number of repetitions between sequence A (9.8 repetitions) and sequence B (9.9 repetitions) and suggested that this greater training volume in sequence A (0.1 repetition) would result in greater health and fitness benefits. Bellezza and colleagues failed to cite any reference to support that opinion. The authors advised strength coaches to inform athletes of the possible decrement in performance if a small-to-large order of exercise (sequence B) is used in their training program. However, their conclusion and recommendation were based on an average difference between sequence A and sequence B of only one tenth of a repetition. They reported no significant difference in the session RPE between sequence A and sequence B. In their review, Simão and colleagues [1] noted only that the order of exercises produced no significant difference in RPE. They failed to report the trivial 0.1 repetition difference between protocols.

Farinatti and colleagues [8]

In the study by Farinatti and colleagues [8], 10 young females (age ~22 years) with approximately two years of resistance training experience performed three sets of 10RM bench press, shoulder press, and triceps pushdown on Life Fitness machines in sequence A. The subjects performed the same protocol 48 hours later but in the reverse order of exercises (sequence

B). The researchers randomly assigned the order of performing sequence A and B. All the sets were performed to concentric failure with 3-minute rest intervals between sets and exercises. In their review, Simão and colleagues [1] incorrectly reported 2-minute rest intervals even though Simão was the secondary author with Farinatti and colleagues.

There was no significant difference in the completed number of repetitions between sets for any of the exercises during sequence A [8]. When the bench press was performed last in sequence B, the number of repetitions in the 1st set was significantly greater than the 2nd and 3rd sets. When the bench press was performed first in sequence A, the number of repetitions in the 2nd and 3rd set was significantly greater than the 2nd and 3rd set in sequence B. However, the difference between sequence A and B was only 1.3 repetitions in the 2nd set and 1.1 repetitions in the 3rd set. Simão and colleagues [1] reported only that there was no significant difference between sequence A and B for total work, oxygen consumption or energy expenditure. They failed to report the number of completed repetitions or the trivial difference between sequence A and B. The authors did not speculate on any clinical relevance to chronic adaptations such as strength gains as a result of a difference of approximately one repetition between sequence A and sequence B.

There are a few studies [23-25] that were published since the review by Carpinelli [16] and the completion of the literature search by Simão and colleagues [1]. Those studies are discussed below.

Balsamo and colleagues [23]

Balsamo and colleagues [23] reported the acute effects of the sequence of performing three sets of 10RM for each of two lower body resistance exercises: seated knee flexion (KF) and knee extension (KE). There was no rest between these two exercises (the authors described this protocol as the *super set method*) and 90 seconds rest between these so-called *super sets*. Twelve young males (age ~23 years) with approximately six months of resistance training experience were randomly assigned to perform a *super set* of KF followed by KE during one session and reverse the order of exercises in another session 48-72 hours later. The KF-KE sequence resulted in a significantly greater volume of exercise for the second and third *super sets* and a greater total volume (the 3 *super sets* for both exercises) than the KE-KF sequence.

Balsamo and colleagues [23] stated: “Kraemer and Ratamess indicated that total training volume is an important variable in muscle hypertrophy” (p. 126). That review by Kraemer and Ratamess [26] was the only reference cited by Balsamo and colleagues in an attempt to show any practical application for a greater volume of exercise. In fact, Kraemer and Ratamess did

not cite any resistance training studies to suggest that a different sequence of exercise, which may result in a greater volume of training for a specific exercise, has a significant effect on muscle hypertrophy or strength gains.

If Balsamo and colleagues [23] believed that the results of their study had any practical application to resistance training, they should have cited references to substantiate that opinion. However, they failed to cite any resistance training studies that support their belief.

Figueiredo and colleagues [24]

Figueiredo and colleagues [24] recruited 19 females (age ~28 years) who they claimed were resistance training for approximately two years. In a counterbalanced crossover design, the subjects performed four maximal effort sets (verbally encouraged to concentric failure) with 60% 1RM for each of five free weight and machine exercises: bench press, lat pulldown, shoulder press, biceps curl, and triceps pushdown in sequence A. The subjects reversed the order of exercises in sequence B. There were 2-minute rest intervals between sets and exercises. They reported the RPE immediately after performing the 4th set of each exercise and at the completion of each exercise sequence.

The average number of completed repetitions was significantly greater for the four sets of bench press in sequence A (the 1st exercise in that sequence) compared with sequence B and significantly greater for the four sets of triceps pushdown in sequence B (the 1st exercise in that sequence) compared with sequence A [24]. There was no significant difference between sequences for the other three exercises. Within each sequence, there was a significant decrease in the total number of repetitions for each of the exercises as the sets progressed from the 1st set to the 4th set. For example, the number of repetitions for the bench press decreased from 22.0 to 10.5 in sequence A and from 15.5 to 8.6 in sequence B. In a similar pattern, the triceps pushdown decreased from 23.0 to 14.7 in sequence B and from 16.2 to 10.8 in sequence A.

The authors noted that as an exercise sequence progressed, there was a decrease in the total number of repetitions performed to failure [24]. However, different muscle groups were involved in each successive exercise and there were two minutes rest between sets and exercises. Therefore, fatigue should not have been a limiting factor in resistance trained subjects. The average number of completed repetitions for the 1st set of all the exercises was 17.8 in sequence A and 18.3 in sequence B; that is, approximately 18 repetitions for both sequences (Table 1, p. 240). The average number of repetitions for the 4th set of all the exercises was 10.7 in sequence A and 11.1 in sequence B; that is, approximately 11 repetitions for both sequences

(Table 1, p. 240). This was a decrease in repetitions of ~39% from the 1st to the 4th set, which was another indicator that suggested relatively poor training status. Figueiredo and colleagues claimed that the decrease in the number of repetitions in successive sets of an exercise appears to be the result of increasing fatigue as the session progressed. However, the significant decrease in the bench press repetitions from the 1st to the 4th set (~52% and ~45% in sequence A and B, respectively) with 2-minute inter-set rest intervals again questions the authors' claim that the subjects were resistance trained for approximately two years. In addition, the authors did not cite any evidence to justify the necessity of a 4-set per exercise protocol in any resistance training program for any demographic.

The average RPE (rating = 9) was not significantly different between sequence A and B [24]. Figueiredo and colleagues noted that the RPE was probably not affected by the sequence of exercise because all the sets were performed to concentric failure. The average number of repetitions for the four sets of the triceps exercise was significantly different between sequence A and B but the average level of RPE was identical (rating = 9). As previously discussed, the similar RPE for the four sets of all the exercises in both sequence A and B suggests a maximal effort and therefore similar recruitment of motor units [21]. Therefore, despite the authors' claim that exercises most important to the objective of the resistance training should be performed at the beginning of the session, there is little scientific foundation—and no evidence from their study—that would suggest any advantage for a specific sequence of exercises over another for producing superior strength gains or muscular hypertrophy.

Simão and colleagues [25]

In a recent study by Simão and colleagues [25], 21 males (age ~28 years) with approximately two years of resistance training experience performed three sets of 20RM for each of five upper body and three lower body free weight and machine exercises. In a randomized crossover design, two exercise sessions (72 hours apart) consisted of sequence A (bench press, lat pulldown, shoulder press, biceps, triceps, leg press, knee extension, and knee flexion exercises) and sequence B (the reverse sequence), with the upper body exercises always performed before the lower body exercises. Subjects rested two minutes between sets and exercises.

There was a significantly greater number of completed repetitions during the 1st set compared with the 2nd set and during the 2nd set compared with the 3rd set for all the exercises in both sequence A and B [25]. In a comparison of sequence A and B, there was a significantly greater number of completed repetitions for the exercises performed early in both sessions. For

example, the number of repetitions was significantly greater for all three sets of bench press, lat pulldown and leg press in sequence A compared with sequence B. In contrast, the number of completed repetitions was significantly greater for the triceps, biceps, shoulder press, knee extensor and knee flexor exercises during sequence B. There was no significant difference in the subjects' RPE, which was 10 on a scale of 1-10, at the end of each sequence.

Simão and colleagues [25] claimed that it may be necessary to reduce the resistance for subsequent sets of each exercise performed toward the end of a session. They claimed that the reduced resistance would enhance specific neuromuscular adaptations that would enable greater fatigue resistance. They cited only one study [27] in an attempt to support that claim. In fact, Willardson & Burkett [27] reported the acute response (sustainability of repetitions) to five sets of 15RM free weight bench press and squat exercises as a result of 30-second, 1-minute and 2-minute inter-set rest intervals. Willardson and Burkett were not sure whether to recommend maintaining shorter inter-set rest intervals with a reduction in resistance for subsequent sets or to maintain the same resistance in subsequent sets with longer inter-set rest intervals; nor did they attempt to justify performing five sets of each exercise in any demographic of trainees. Because this study by Willardson and Burkett was not a training study, they only reported acute responses, and the authors tentatively speculated on how to enhance specific neuromuscular adaptations with training, the reference failed to support the aforementioned claim by Simão and colleagues. Simão and colleagues [25] concluded that resistance exercises should be prioritized to elicit a greater volume of training and potential for specific neuromuscular adaptations. They failed to cite any resistance training studies that support their opinion.

Simão and colleagues [25] stated that the identical RPE immediately following sequence A and B was probably because all the sets of each exercise were performed to repetition failure. They speculated that a heavier resistance (e.g., 10RM) might elicit a greater RPE and therefore greater motor unit recruitment. However, the effort and RPE (rating = 10) was maximal with the 20RM in both sessions. Interestingly, two previous studies by Simão and colleagues [14-15]—that used a heavier resistance—reported a lower RPE with no significant difference in RPE between sequences (10RM, RPE = 8.5 and 7.6 [14]; 80% 1RM to failure, RPE = 8.0 and 8.0 [15], sequences A and B, respectively). As previously noted in this Critical Examination, it is the degree of effort at the end of a set that primarily determines motor unit recruitment and not the amount of resistance or the number of repetitions [21-22].

Repetition Duration (Speed of Movement)

Repetition duration is the time that is required to complete both phases of a repetition (lifting and lowering the resistance). Only one [9] of the previously mentioned acute studies attempted to control for repetition duration (2s lifting, 2s lowering), six studies [5-7, 1-13] did not mention that variable, and seven studies [8,10,14-15,23-25] stated specifically that no attempt was made to control repetition duration for any of the multiple assessments of the 1RM or the number of repetitions performed to volitional exhaustion.

Several studies [28-33] have compared the number of completed repetitions performed with shorter repetition duration (faster speed of movement) and longer durations (slower speed of movement) using a specific resistance. All of these studies reported a significantly greater number of completed repetitions when the exercise was performed with shorter repetition durations (faster speed of movement). For example, Pereira and colleagues [30] instructed nine physically active males and females (age ~36 years) to perform a maximal number of unilateral knee extension repetitions with 60% and 80% 1RM at repetition durations of ~2 seconds (~1s lifting, 1s lowering the resistance) and ~5.4 seconds (~2.7s lifting, 2.7s lowering). The maximum number of completed repetitions was significantly greater for the shorter duration repetitions compared with the longer duration repetitions at both 60% 1RM (16.3 versus 8.8 repetitions) and 80% 1RM (9.4 versus 5.9 repetitions). Pereira and colleagues noted that these results were probably because once the inertia is overcome with the shorter duration repetitions (faster speed of movement), the momentum is greater than with longer durations (slower speed of movement). Therefore, the force required to move the resistance through the remainder of the range of motion is reduced with the shorter repetition duration. They concluded: "*Greater intentional movement speed [shorter repetition duration] allows [a] greater number of maximum repetitions for the same load...*" (p. 263e). In other words, it was harder to move the resistance slower.

It is worth mentioning that in the last sentence of their report, Pereira and colleagues [30] cited a previous resistance training study from their laboratory [31] that used a similar shorter repetition duration of ~1.8 seconds (~0.9s lifting, 0.9s lowering) and a longer duration of ~7.3 seconds (~3.6s lifting, 3.6s lowering) training protocol. The researchers used a metronome to control the repetition duration for all training sessions but the subjects were assessed for 1RM with no restriction on repetition duration (described as *free velocity*). Fourteen healthy females and males (age ~27 years) were randomly assigned to a shorter or longer repetition duration training group. They performed

one set of 8-10RM Smith machine squats and bench presses three times a week for 12 weeks. Four of the participants had prior resistance training experience. Both training groups significantly increased 1RM squat (~23% and 20%) and bench press (~14% and 16%), longer and shorter repetition duration groups, respectively. There were identical significant strength gains in both groups when expressed relative to body mass (0.3 and 0.1, squat and bench press, respectively). There was no significant difference in strength gains between groups (absolute or relative to body mass) for either exercise.

Although the researchers did not report a statistical comparison, another important result from this study [31] was that the increase in 1RM was similar to the increase in 8-10RM at both repetition durations in both groups for both exercises. For example, the 1RM bench press increased ~14% and the 8-10RM increased ~14% (at 0.44 rad·s⁻¹ and 1.75 rad·s⁻¹) in the longer repetition group. The 1RM bench press increased ~16% and the 8-10RM increased ~18% (at 0.44 rad·s⁻¹ and 1.75 rad·s⁻¹) in the shorter duration group. These results strongly suggest that researchers, trainers and trainees should question the necessity of ever assessing the 1RM for anyone other than competitive weightlifters and powerlifters [34].

The previously mentioned acute studies on the sequence of exercise [5-15,23-25] involved exercises that used mass for the resistance (free weights, plate loading or selectorized weight machines). Consequently, when there is no control or consideration for the speed of movement throughout the entire range of concentric and eccentric muscle actions for the full duration of the repetition, any change in repetition duration for any repetition within a set, from one set to subsequent sets, or from one sequence of exercise to another sequence of exercise could significantly affect the number of completed repetitions performed to volitional exhaustion. Therefore, all the aforementioned studies [5-8,10-15,23-25] that reported the maximal number of completed repetitions from one set to another or from one exercise sequence to another – and did not control for repetition duration – have very little clinical application to resistance training.

Summary of Acute Responses

Some of the studies cited by Simão and colleagues [1] reported significantly fewer repetitions during the performance of subsequent sets of a specific exercise or some exercises when they were performed later in a session compared with when they were performed early in a session. However, the previously discussed correct understanding of the size principle–motor unit recruitment based primarily on effort rather than a specific number of repetitions–applies to all of the studies that investigated acute responses to different

sequences of exercises. Therefore, the difference in only a couple of repetitions between sequences, or between sessions with a similar sequence of exercise, would have very little–if any–effect on motor unit recruitment. Because most studies did not control for repetition duration when reporting the maximal number of repetitions for different sequence of exercises, those data are questionable at best.

Many of the studies on acute responses that were cited by Simão and colleagues [1], in addition to studies by Balsamo and colleagues [23] and Figueiredo and colleagues [24], suggested that future research should focus on the effect of different exercise order on strength gains and muscular hypertrophy. That suggestion appears to be based on an unsubstantiated belief rather than a hypothesis with some scientific foundation (see later section entitled *Overwhelmed by Belief*).

Pre-Exhaustion

Simão and colleagues [1] listed three studies [7,9,35] in their Table II (p. 258) and labeled them as studies that used the *pre-exhaustion method*. None of those studies actually tested the pre-exhaustion method as originally described by Jones [36]. Simão and colleagues stated incorrectly that the purpose of the pre-exhaustion, for example the peck-deck fly immediately followed by the bench press, was to allow additional repetitions and a greater volume of exercise. In fact, the goal is to minimize the hypothetical weak link (the triceps) between the pectoral muscles and the resistance used in the bench press. Hypothetically, the pre-exhaustion of the pectoral muscles would create a greater stimulus in those muscles–not necessarily a greater volume of exercise.

A detailed description of the genesis of the pre-exhaust hypothesis and its misinterpretation in the three aforementioned studies [7,9,35] can be found in the previously mentioned review by Carpinelli [16]. Therefore, only one example from that review is briefly discussed in this Critical Examination. Simão and colleagues [1] described the protocol that Augustsson and colleagues [35] used in their investigation and noted that the electromyographic (EMG) activity in the rectus femoris and vastus lateralis was significantly lower when the leg press was performed immediately after the single joint knee extension exercise. They also reported that the number of repetitions in the leg press was significantly less with that protocol. However, Simão and colleagues failed to note either in their Table II (p. 258) or the narrative that the difference in EMG activity was only 5%–well within the margin of error for surface EMG–and most importantly that there was only one repetition difference between the protocols (9 versus 8 repetitions). In addition, because Augustsson and colleagues did not control for repetition duration,

any change in momentum could have significantly impacted the number of repetitions.

Augustsson and colleagues [35] noted that testing the pre-exhaustion hypothesis for the leg press should involve pre-exhausting the hip extensors with a single joint hip extension exercise. Unfortunately, because they selected knee extension as the pre-exhaustion exercise, they actually pre-exhausted the hypothetical weak link (the quadriceps) between the hip extensors and the resistance.

Most importantly, the so-called pre-exhaustion studies [7,9,35] cited by Simão and colleagues [1] reported only the acute responses to performing two exercises (e.g., peck-deck fly and bench press) for a similar muscle group (e.g., pectoralis major). However, no study has tested the effect of the original pre-exhaustion hypothesis [36] on chronic adaptations such as strength gains or muscular hypertrophy.

Chronic Adaptations

There is a lack of credible evidence to suggest that any difference in the number of completed repetitions in a set as a result of a specific exercise sequence has any significant affect on strength gains or muscular hypertrophy. There are only three studies that reported the effects of the sequence of exercises on strength gains [37-39]. One of those studies additionally reported on muscle thickness [38] and one on muscle volume [39].

Dias and colleagues [37]

Dias and colleagues [37] randomly assigned 48 physically active young males (age ~19 years) to one of two training groups or a control group. Subjects had not participated in a resistance training program for at least six months prior to the investigation. The training groups performed three sets of 8-12RM for each of five upper body exercises three times a week for eight weeks. Group 1 progressed from the larger to the smaller muscle group exercises: barbell bench press, lat pulldown, seated military press, barbell biceps curl, and elbow extension machine for the triceps. Group 2 performed the five exercises in the reverse sequence. Trainees were encouraged to perform all sets to concentric failure with two minutes rest between sets and exercises. The authors stated that there was no attempt to control for repetition duration during the training or the 1RM assessments. Dias and colleagues did not state if the 1RM assessors were blinded to the different training protocols.

Both training groups significantly increased 1RM strength in the five exercises [37]. The only significant difference between groups was that group 2 showed a significantly greater strength gain in the biceps curl and elbow extension exercises. Dias and colleagues stated: "*The current results revealed no significant*

difference in strength gains in large muscle group exercises" (p. 67). In their Practical Implications section, they recommended: "*If an exercise is important for the training goals of a program, then it should be placed at the beginning of the training session, whether or not it is a large or a small muscle group exercise*" (p. 69). Because the strength gains were not significantly different between groups for the larger muscle group exercises, the results of their study did not accurately support their recommendation.

In the review by Simão and colleagues [1], the authors listed effect sizes (Table V, p. 262-3) for all the exercises in both training groups and the control group in the aforementioned study by Dias and colleagues [37]. However, Dias and colleagues did not report effect sizes. Simão and colleagues did not discuss the effect sizes in their narrative or note who generated these effect sizes in their table. Most importantly, Simão and colleagues did not report confidence intervals and they failed to indicate whether there was a significant difference between any of the effect sizes in their Table V.

Simão and colleagues [38]

Simão and colleagues [38] recruited 31 physically active males (age ~28 years) who had not performed regular resistance training for at least six months prior to the study. Participants were randomly assigned to one of two training groups or a control group. The training groups performed four sets of 12-15RM with 1-minute inter-set rest intervals (weeks 1-4), three sets of 8-10RM with 2-minute inter-set rest intervals (weeks 5-8), and two sets of 3-5RM with 3-minute inter-set rest intervals (weeks 9-12). They were encouraged to perform all sets to concentric failure in each of their twice-weekly training sessions. There was no attempt to control for repetition duration during the training or the 1RM assessments.

One group (LG-SM) performed the four exercises in a sequence from the larger to smaller muscle group exercises: barbell bench press, machine lat pulldown, machine triceps exercise (elbow extension), and standing barbell curl [38]. The other group (SM-LG) performed the four exercises in the reverse sequence. Muscle thickness for the biceps and triceps was assessed with ultrasound at baseline and after the 12 weeks training (24 sessions). Simão and colleagues did not state whether those who assessed the 1RM or muscle thickness were blinded to the different training protocols.

Both training groups showed significant 1RM strength gains in the four exercises [38]. There was no significant difference in strength gains between the training groups for any of the four exercises. Regardless of the sequence of exercises, Simão and colleagues specifically noted that both groups showed

very similar strength gains with only a 2% difference between groups for all the exercises. Triceps muscle thickness significantly increased in the SM-LG group but there was no significant increase in biceps muscle thickness in either group. The authors stated: “*The absolute strength gains and muscle accretion do not present statistical differences between training groups*” (p. 4).

Despite the reported miniscule non-significant 2% difference in strength gains between training groups, Simão and colleagues [38] estimated effect sizes. They reported that the increase in triceps strength showed a greater effect size in the SM-LG group compared with the LG-SM group but there was a similar effect on bench press strength gains for both groups. However, Simão and colleagues did not state if this difference in effect size was statistically significant, nor did they report confidence intervals. In the Results section they claimed that the effect size for lat pulldown strength gain was greater in the SM-LG group. In contrast to their claim, the data in their Table 4 (p. 4) showed that they labeled the effect size for both the LG-SM (0.78) and SM-LG (0.58) groups as *moderate*. Simão and colleagues [38] also claimed: “*The opposite occurred in BC [biceps curl], where modest strength increases was observed in SM-LG*” (p. 4). Table 4 (p. 4) actually showed an effect size labeled as *large* for both training groups. Consequently, the data in their Table 4 did not support their claims and revealed discrepancies between their narrative and Table 4.

It is commonly recommended that confidence intervals should be reported with effect sizes because they indicate the range of values that includes a population value within a specific probability [40]. A confidence interval is the expected range for the value of a given statistic (e.g., effect size) if the study were repeated with a very large sample; that is, it is the range of the population value for the statistic drawn from a small sample [41]. Even those statisticians who favor the inclusion of effect size in research studies have stated that the reporting of confidence intervals with an effect size is required to provide two important components of statistical information: the estimated magnitude of the specific effect and the precision of that estimate [42]. Simão and colleagues did not report confidence intervals in their study [38] or their review [1].

In their Statistical Analysis section, Simão and colleagues [38] stated that they used Cohen’s scale for classification of effect size magnitude [43], which is designated as *small* (0.2), *medium* (0.5), and *large* (0.8). They also noted that they were applying an alpha level of $P < 0.05$ to calculate statistically significant comparisons. However, Simão and colleagues [1] claimed that Simão and colleagues [38] used a scale proposed by Rhea [44] to determine the magnitude of effect sizes. Because Simão was the lead author and de Salles

a coauthor in both the study [38] and the review [1], their antithetical statements raise additional questions about the credibility of their review.

In the previously mentioned article by Rhea [44], he criticized Cohen [43] because Cohen arbitrarily assigned the magnitudes of effect size to a specific scale of small, medium and large effect. However, Rhea arbitrarily assigned the magnitude of effect size in three categories of previously untrained, recreationally trained, and highly trained subjects as trivial, small, moderate and large among the three training categories and four magnitude classifications. Rhea’s proposed complex changes in the scale were based solely on his opinion that Cohen’s scale should be revised to evaluate the magnitude of effect sizes in resistance training research. However, it has been standard practice for researchers to interpret effect size using Cohen’s scale of magnitudes.

Simão and colleagues [38] reported that their effect size calculation indicated an increase only in triceps muscle thickness for the SM-LG group. That increase was 0.28 cm and designated as *small* in their Table 4 (p. 4). Interestingly, had they actually used the classification of effect size magnitude suggested by Rhea [44] (he designated an effect size < 0.50 as *trivial*)—as incorrectly claimed by Simão and colleagues [1] in their review—the effect (0.47) would have been classified as *trivial* for these previously untrained subjects.

In their Discussion section, Simão and colleagues [38] concluded: “*The fact that the different exercise orders did not increase strength and MT [muscle thickness] significantly different between the training groups, throughout the course of the study, was unexpected*” (p. 5). In contrast to their own statement, they claimed in their Conclusion section that “*...it appears exercises that are particularly important for the training goals of a program should be placed at the beginning of the training session, whether or not it is a large or small muscle group exercise*” (p. 5). From these antithetical statements by Simão and colleagues, it appears that this group of researchers strongly believe that the sequence of exercises has a significant affect on chronic adaptations such as strength gains and muscular hypertrophy—despite the results of their own study.

Spinetti and colleagues [39]

In a study from the same university (five of these authors contributed to the previously discussed study by Simão and colleagues [38]), Spinetti and colleagues [39] randomly assigned 30 previously untrained males (age ~29 years) to one of two sequences of resistance training, or a control group. The exercise sequence from the larger to smaller muscle groups was the barbell bench press, lat pulldown, machine elbow extension (triceps) and free weight biceps curl in one training group (LG-SM) and the reverse sequence of

the four exercises in the other training group (SM-LG). All the trainees performed four sets of 12-15RM with 1-minute inter-set rest intervals, three sets of 8-10RM with 2-minute inter-set rest intervals, and two sets of 3-5RM with 3-minute inter-set rest intervals for all the exercises during three successive training sessions (described as *nonlinear periodization* resistance training). There were two training sessions a week for 12 weeks (8 cycles of the 3 training sessions). The trainees were encouraged to perform all sets to concentric failure and were supervised by a strength and conditioning professional. There was no attempt to control for repetition duration during the training or the 1RM assessments. The researchers evaluated the 1RM for each exercise and used ultrasound to assess the muscle volume for the biceps and triceps at baseline and post-training. The authors did not specify if those who assessed the 1RM or muscle volume were blinded to the different training protocols.

Both training groups significantly increased 1RM strength for all the exercises and these increases were significantly greater than the control group [39]. Using an analysis of variance, the authors reported no significant difference between the LG-SM and SM-LG groups in strength gains (absolute and relative to body mass) for any of the four exercises. There was a significant increase in triceps and biceps volume in both training groups with no significant difference between groups for the increase in either muscle. Spinetti and colleagues stated: "*Despite the significant gains among both training groups, the present results revealed no statistically significant differences of strength gains or muscle accretion between the different exercise order training groups*" (p. 6).

When Spinetti and colleagues [39] calculated effect sizes, they reported that the magnitude of the 1RM bench press was significantly greater when that exercise was performed first in the LG-SM group compared with the SM-LG group where it was performed last in the training sessions (*moderate* and *small* effect sizes, respectively). However, the difference between groups was only about 1% (LG-SM ~22%, SM-LG ~21%) despite the significantly greater (~35%) total work performed (sessions x sets x resistance) in the LG-SM group. The authors incorrectly used a measure of mass (kg) to denote *work*.

Spinetti and colleagues [39] reported a significantly greater effect size in the SM-LG group for the lat pull-down (*moderate* versus *small*), elbow extension (*large* versus *moderate*), and biceps curl (*moderate* versus *small*). They stated that their effect size estimates suggested that the increase in biceps volume was not significantly different between groups but claimed that the increase in triceps volume was significantly greater in the SM-LG group compared with the LG-SM group (*small* versus *trivial*, respectively). In fact, the data

from their Table 3 (p. 5) showed a significant increase in triceps volume of 14.9% in the LG-SM group and 12.4% in the SM-LG group. The authors did not report confidence intervals with their effect sizes. Spinetti and colleagues concluded: "*Little can be drawn from these conflicting data with regard to muscle hypertrophy, and additional investigation would be needed for further evaluation of this variable*" (p. 6).

Spinetti and colleagues [39] claimed that the order of exercises in a resistance training session is an important consideration in program design. They cited only one reference to support that opinion, which was a book by Kraemer and Fleck [45]. Kraemer and Fleck claimed: "*The traditional exercise order—performing multijoint exercises early in a training session or before single-joint exercises involving the same muscle groups—does result in the ability to use a heavier resistance for the desired number of repetitions or performance of more repetitions at the training resistance when performing the multijoint exercises. So over time it may result in greater total-body physiological adaptations*" (p. 47). Kraemer and Fleck did not cite any evidence to support that opinion. Interestingly, almost three decades ago Kraemer claimed that training variables such as the order of exercise can affect strength gains [46]. The only reference he cited was his previous article in the same journal [47]. In that article, Kraemer made a similar claim about the order of exercise but failed to cite any references that would support his claim. Consequently, the claims by Kraemer [46-47] and Kraemer and Fleck [45] were based solely on their opinion—not resistance training studies.

Summary of Chronic Adaptations

Only three studies [37-39] reported the chronic effects of the sequence of exercise in resistance training. One study [37] showed a significantly greater strength gain in the smaller muscle groups when they were performed first in the training session. The researchers in that study did not assess muscular hypertrophy. The other two studies [38-39] showed no significant difference between groups in strength gains for any of the exercises or any significant difference in muscular hypertrophy. Questionable calculations and reporting of effect sizes indicated some differences in strength gains for a few exercises and some minor differences (e.g., *small* versus *trivial*) in muscular hypertrophy for the triceps. However, the authors of these two studies [38-39] failed to report confidence intervals and they categorized the practical application of those effect sizes by using different scales of magnitude that were arbitrarily created by Cohen [43] or Rhea [44].

None of these studies [37-39] controlled for repetition duration during the training or assessment of strength (1RM). Because of momentum, any change in repetition duration could significantly affect the 1RM

assessments [33]. There was no indication in any of these three studies that those who assessed strength gains or muscular hypertrophy were blinded to the different training protocols. Although it may be difficult to blind the trainees from the protocol, blinding the assessors could minimize any potential observer bias or conscious deception.

The evidence for any significant difference in strength gains or muscular hypertrophy as a result of performing a specific sequence of exercise is weak at best [37-39], with no practical application to resistance training—even in their very limited demographic of previously untrained young males (age ~19-29 years).

Overwhelmed by Belief

Beliefs come first and the explanations for those beliefs follow. The believers seek confirming evidence to support an already existing belief and they ignore or misinterpret disconfirming or contradictory evidence [48]. Simão was the lead author in one of the training studies [38] and a contributing author in the other two [37,39]. Simão and colleagues [1] apparently have a strong belief that the sequence of resistance exercises in a training session can have a significant effect on strength gains and muscular hypertrophy—despite the lack of evidence for support over the last quarter-century.

The belief by Simão and colleagues [1] that manipulation of specific training variables such as the sequence of exercise or inter-set rest intervals may result in a greater volume of training, which in turn results in greater strength gains, conflicts with previous resistance training studies [49-50] that were co-authored by Simão. The following studies [49-51] and a lengthy review [52] are specific examples of how belief can falsely overshadow the evidence.

de Souza and colleagues [49]

de Souza and colleagues [49] recruited 20 young males (age ~21 years) with approximately one year of resistance training experience. They randomly assigned the participants to train with a constant 2-minute inter-set rest interval (CI group) for the 8-week study or with a progressive decrease in inter-set rest intervals (DI group). The DI group began with two minutes during the first two weeks and decreased 15 seconds each of the following six weeks (from 120 seconds down to 30 seconds). All the trainees performed three sets of 10-12RM during the first two weeks and four sets of 8-10RM during the next six weeks. They used a 3-way split routine (6 training sessions/week) with ~12 upper and lower body free weight and machine exercises. The researchers assessed the 1RM and calculated the training volume for the free weight bench press and squat. These two exercises were performed first in each of their

respective training sessions. The resistance (load) was modified when necessary to stay within the designated range of repetitions.

Total training volume (sets x repetitions) for the eight weeks was significantly greater in the CI group compared with the DI group for the bench press (~10%) and squat (~16%) [49]. Both groups significantly increased 1RM bench press and squat, knee extension and flexion isokinetic peak torque, thigh and arm muscle cross-sectional area, which was assessed with magnetic resonance imaging. Despite the significantly greater volume of exercise in the CI group, there was no significant difference between groups in strength gains or muscular hypertrophy.

de Souza and colleagues [50]

In a similar study, de Souza and colleagues [50] randomly assigned 22 young males (age ~22 years), with approximately one year of resistance training experience (4x/week), to a constant inter-set rest interval (CI) or a decreasing inter-set rest interval (DI) training protocol. The CI group trained with 2-minute inter-set rest intervals for the duration of the study (8 weeks) and the DI group's inter-set rest intervals decreased 15 seconds each week for the eight weeks (from 2 minutes down to 30 seconds during the 8th week). All the trainees performed four sets of 8-10RM for each of 10 upper body and four lower body free weight and machine exercises in a 3-way split routine (6 days/week). Each session was supervised and the trainees were verbally encouraged to perform every set to voluntary exhaustion. The resistance was modified as necessary to maintain the 8-10RM. The researchers calculated the weekly volume of exercise for the free weight squat and bench press, which was the resistance lifted multiplied by the total number of repetitions. Both groups were supplemented with creatine: 20g/day for the first seven days and 5g/day for the next 35 days.

The total training volume (resistance x repetitions) for the bench press was significantly greater (~23%) in the CI group compared with the DI group [50]. Similarly, the volume of exercise for the squat was significantly greater (~15%) in the CI group. The resistance had to be reduced in the DI group to maintain the 8-10RM for each of the four sets of bench press and squats.

Both groups significantly increased 1RM bench press and squat, knee extension and flexion isokinetic peak torque, thigh and arm muscle cross-sectional area, which de Souza and colleagues assessed with magnetic resonance imaging [50]. There was no significant difference between groups for any of these outcomes. The calculation of effect sizes by de Souza and colleagues revealed a *moderate* effect size (1.11) in the CI group for arm muscle cross-sectional area

and a *large* effect size (2.53) in the DI group—the group that performed a significantly lower total volume of exercise.

Willardson and Burkett [51]

de Souza and colleagues [50] cited a study by Willardson and Burkett [51] in their discussion section. Willardson is a coauthor of the previously discussed study by de Souza and colleagues [50] and the review by Simão and colleagues [1]. Willardson and Burkett recruited 15 young males (age ~21 years) who were performing the free weight squat exercise for approximately four years prior to the study. The researchers randomly assigned the participants to a 2-minute or 4-minute inter-set rest interval training protocol. The trainees exercised two times a week; one *light* session consisting of five sets of eight repetitions with 60% 1RM and one *heavy* session consisting of eight sets of 11-15 repetitions with 70% 1RM, seven sets of 6-10 repetitions with 80% 1RM, and six sets of 3-5 repetitions with 90% 1RM in three consecutive weeks. This 3-week so-called *mesocycle* was repeated several times during the 13-week study. All the sets in the heavy session were performed to volitional exhaustion. The authors claimed that the purpose of the light training sessions was to produce a large volume of training but would not interfere with the recovery process.

The total volume of exercise (sets x resistance x repetitions) during the heavy sessions was significantly greater (~25%) in the 4-minute rest group [51]. Both groups showed a significant increase in 1RM squat. However, despite the significantly greater volume of training in the 4-minute group, there was no significant difference in strength gains between groups. Willardson and Burkett stated: “*The primary finding of this study was that the squat strength gains were not significantly different between groups that rested 2 minutes or 4 minutes between sets* (p. 147). In a non sequitor, the authors concluded: “*For continued gains in maximal strength, advanced lifters must perform increasingly higher volumes of training*” (p. 151). Their own data failed to support that conclusion.

de Salles and colleagues [52]

Interestingly, the training study by Willardson and Burkett [51] was also cited in an extensive review [52] on inter-set rest intervals by the same group of researchers including Simão and Willardson. de Salles and colleagues [52] claimed that longer inter-set rest intervals would result in a greater volume of exercise, which would produce superior strength gains. However, they failed to adequately support that opinion (see reference 16 for a critical analysis of their review), which again demonstrated that their belief took preference over the evidence.

Summary of Belief Studies

All these studies [49-51] included young males (age ~21-22 years) who were currently participating in a structured resistance training program for at approximately 1-4 years. The authors of the resistance training studies by de Souza and colleagues [49-50], in addition to the other study by one of de Souza's coauthors [51], and the lead author of the review by Simão and colleagues [1], apparently believe that a greater volume of resistance training will produce superior strength gains—despite the evidence that is contrary to their belief. In other words, their belief-based recommendations regarding training volume overshadowed the scientific evidence from their own resistance training studies.

Conclusions

Simão and colleagues [1] noted in the Abstract, and their Conclusions and Recommendations section that exercise order can influence the efficiency and safety of a resistance training program. However, neither Simão and colleagues nor any of the studies cited in their review addressed the issues of efficiency or safety.

Simão and colleagues [1] did not offer any physiological hypothesis to base their suggestion that a larger volume of exercise—because of a specific sequence of exercise—would produce greater strength gains and muscular hypertrophy. The absence of a working hypothesis and supporting evidence questions their suggestion for more research on the sequence of exercise.

One of the primary claims in their Conclusions and Recommendations section was that an exercise performed at the end of a training session is associated with fewer repetitions [1]. However, they also reported that the sequence of exercise did not significantly affect the rating of perceived exertion. Because the level of exertion (effort) and not the number of completed repetitions is the primary factor for recruiting motor units and strength gains [21-22], their rating of perceived exertion results nullify any physiological benefit or practical application of their former claim regarding the number of completed repetitions in any set.

There is very little evidence to suggest that any specific sequence of exercise affects strength gains or muscular hypertrophy. If researchers believe that the sequence of performing resistance exercise affects chronic adaptations such as strength gains and muscular hypertrophy, science dictates that the entire burden of proof is on them to support that belief with results from peer-reviewed resistance training studies. They have not fulfilled that requirement.

Declaration of interest

The author declares no conflicts of interest.

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