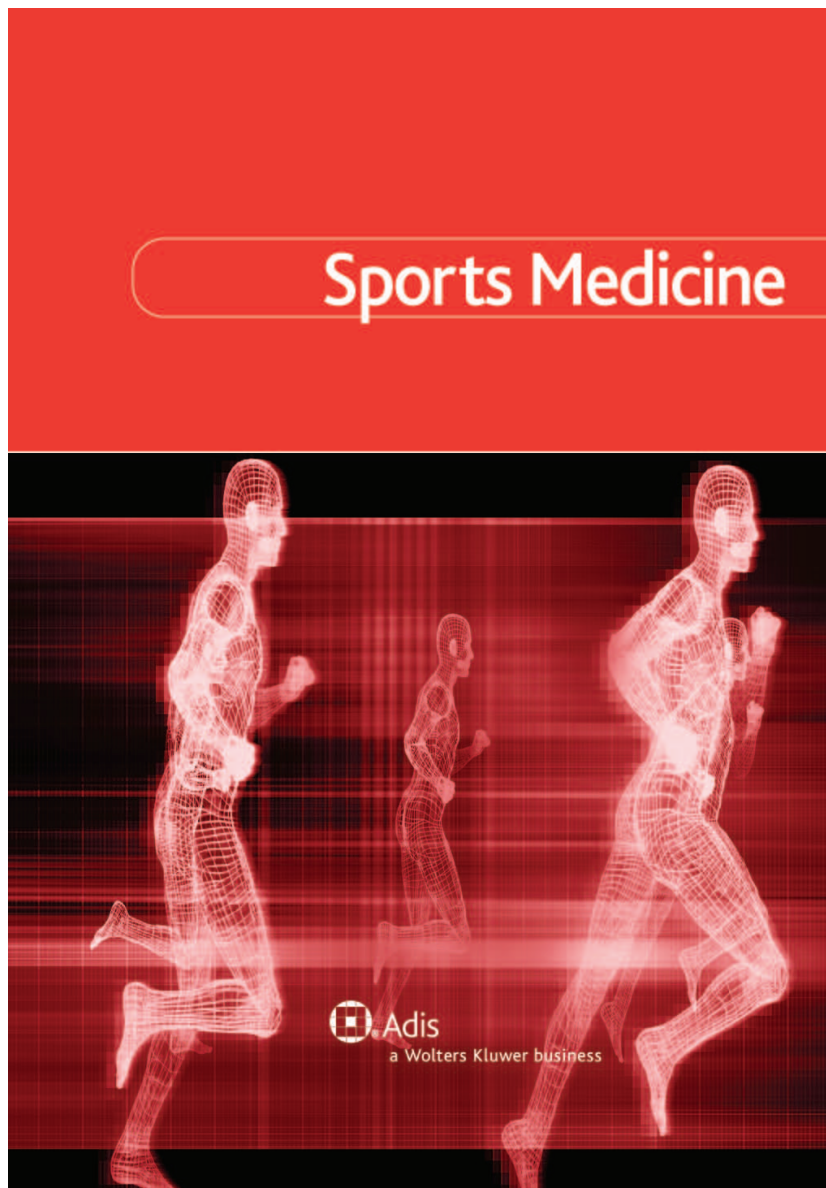


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Exercise Order in Resistance Training

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Abstract

Resistance training (RT) is now an integral component of a well rounded exercise programme. For a correct training prescription, it is of the utmost importance to understand the interaction among training variables, such as the load, volume, rest interval between sets and exercises, frequency of sessions, exercise modality, repetition velocity and, finally, exercise order. Sports medicine research has indicated that exercise order is an important variable that affects both acute responses and chronic adaptations to RT programmes. Therefore, the purpose of this review was to analyse and discuss exercise order with relevance to acute responses (e.g. repetition performance) and also the expression of chronic adaptable characteristics (e.g. maximal strength and hypertrophy). To accomplish this purpose, the Scielo, Science Citation Index, National Library of Medicine, MEDLINE, Scopus, SPORTDiscus™ and CINAHL® databases were accessed to locate previously conducted original scientific investigations. The studies reviewed examined both acute responses and chronic adaptations with exercise order as the experimental variable. Generally, with relevance to acute responses, a key finding was that exercise order affects repetition performance over multiple sets, indicating that the total repetitions, and thus the volume, is greater when an exercise is placed at the beginning of an RT session, regardless of the relative amount of muscle mass involved. The pre-exhaustion method might not be an effective technique to increase the extent of neuromuscular recruitment for larger

muscle groups (e.g. pectoralis major for the bench press) when preceded by a single-joint movement (e.g. pec-deck fly). With relevance to localized muscular endurance performance, oxygen consumption and ratings of perceived exertion, the limited amount of research conducted thus far indicates that exercise order does not appear to impact the acute expression of these variables. In terms of chronic adaptations, greater strength increases were evident by untrained subjects for the first exercise of a given sequence, while strength increases were inhibited for the last exercise of a given sequence. Additionally, based on strength and hypertrophy (i.e. muscle thickness and volume) effect-size data, the research suggests that exercises be ordered based on priority of importance as dictated by the training goal of a programme, irrespective of whether the exercise involves a relatively large or small muscle group. In summary, exercise order is an important variable that should receive greater attention in RT prescription. When prescribed appropriately with other key prescriptive variables (i.e. load, volume, rest interval between sets and exercises), the exercise order can influence the efficiency, safety and ultimate effectiveness of an RT programme.

1. Introduction

Resistance training (RT) has been heavily studied during the last 50 years and is now an integral component of a well rounded exercise programme. RT has been shown to contribute to improvements in sports performance, as well as treatment and prophylaxis of some illnesses.^[1-3] Additionally, RT has been proven to stimulate expression of chronic adaptable characteristics within the muscles, such as maximal strength, hypertrophy, power and localized muscular endurance.

Studies have focused on manipulation of the different variables involved in RT prescription to gain a better understanding of how to best achieve different muscular characteristics.^[3] According to the American College of Sports Medicine (ACSM),^[1,2] the main methodological variables of prescription are the load, volume, rest interval between sets and exercises, frequency of sessions, exercise modality, repetition velocity and, finally, exercise order. Among such variables, the exercise order has been studied less frequently in scientifically controlled investigations.

The ACSM^[1,2] position stand on progression models in RT for healthy adults recommended that large muscle group exercises generally be performed first in a training session. However, in contrast to this recommendation, several studies^[4-14] indicated

that repetition performance was significantly greater for exercises that involve relatively large or small muscle mass when performed at the beginning of a session. With relevance to chronic adaptations, the few studies that analysed maximal strength in response to different exercise orders presented greater increases in maximal strength of exercises performed at the beginning of the training sessions.^[15-17] Both studies^[16,17] that analysed muscle-size responses to different exercise orders presented inconclusive statistical findings. However, effect-size analysis suggested that differences in muscle accretion were exhibited based on exercise order.^[16,17]

The current literature suggests that placement of exercises within a sequence should not be determined by the amount of muscle mass involved, but rather on individual needs or movement patterns in greatest need of improvement. To the authors' knowledge, there has never been a review article specifically synthesizing the current literature relevant to exercise order; although such a review is needed to establish a consensus within the scientific community concerning this variable. Therefore, the purpose of this review was to analyse and discuss exercise order with relevance to acute responses (e.g. repetition performance) and also chronic adaptable characteristics (e.g. maximal strength and hypertrophy).

2. Methods

2.1 Literature Search

Studies that examined the effects of exercise order in RT were accessed via Scielo, Science Citation Index, National Library of Medicine, MEDLINE, Scopus, SPORTDiscus™ and CINAHL® databases, utilizing the following keywords: ‘exercise order’, ‘order of exercise’, ‘exercise sequence’, ‘exercise selection’ and respective abbreviations combined with ‘training volume’, ‘repetitions’, ‘sets’, ‘resistance training’, ‘resistance exercise’, ‘resistive exercise’, ‘strength training’, ‘weight training’ and ‘weight lifting’. 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 at the Federal University of Rio de Janeiro library, Rio de Janeiro, Brazil. Such combinations resulted in the inclusion of 16 original articles addressing exercise order as the primary experimental variable in RT. The last search was performed on 5 February 2011.

2.2 Criteria for Inclusion and Exclusion

Only studies analysing the effects of exercise order as the experimental variable on dependent variables, such as repetition performance, neuromuscular activity, oxygen consumption ($\dot{V}O_2$), ratings of perceived exertion, maximal strength and hypertrophy were included. Studies were excluded if they were non-English language papers; if articles were reviews or abstracts; or if the RT intervention was confounded by other factors, such as aerobic exercise programmes, power training programmes, diet or pharmacological intervention.

3. Exercise Order on Acute Responses

3.1 Influence of Exercise Order on Repetition Performance Over Multiple Sets

Anecdotally, the recommendation regarding exercise order within RT workouts is to perform exercises involving large muscle groups prior to exercises involving small muscle groups (e.g. bench press prior to pec-deck fly or squat prior to leg extension). The reasoning behind this re-

commendation seems sound when considering that if smaller muscle groups (e.g. triceps brachii, anterior deltoids), considered to be secondary movers, are pre-fatigued via single-joint exercises (e.g. triceps extension, shoulder flexion), then the larger muscle groups (e.g. pectoralis major) might receive a less effective overload during performance of multi-joint exercises (e.g. bench press) due to less capacity to maintain the load and/or repetitions per set. Therefore, it has been recommended for several years that structural exercises, which involve multiple joints, precede accessory exercises, which often involve a single joint.^[18] However, relatively few studies have examined this recommendation under controlled scientific conditions.

The first study to verify the effect of exercise order on acute repetition performance was Sforzo and Touey.^[10] Trained men completed two sessions consisting of four sets for each of six exercises with an 8-repetition maximum (RM) load; 2-minutes rest were instituted between sets, 3-minutes rest between exercises, and 5-minutes rest between the lower and upper-body portions of each session. There was a recovery period of 48–72 hours between sessions conducted in randomized order; one session progressed from large muscle groups (e.g. multi-joint) to small muscle groups (e.g. single joint) [i.e. squat, leg extension, leg curl, bench press, shoulder press, triceps extension] and the other session progressed in the opposite order (i.e. leg curl, leg extension, squat, triceps extension, shoulder press, bench press), with the lower-body exercises being performed first in both sessions.

Additionally, the fatigue rate (FR) was expressed as the percentage difference in total volume (TV) [load × repetitions] between sets one and four for each exercise ($FR = \frac{TV_{[set 1]} - TV_{[set 4]}}{TV_{[set 1]}} \times 100\%$).^[10] The results indicated that when the triceps extension and shoulder press preceded the bench press, the bench press TV was significantly reduced resulting in a high FR. The TV for the squat was significantly greater when performed first. This study indicated that both multi-joint and single-joint exercise performance was negatively impacted when performed later in a sequence. Therefore, exercises should be programmed based

on priority of importance relative to individual needs and movement patterns. However, if the objective for the training session is to provide the greatest overload, then the multi-joint exercises should be performed first to maximize the total volume (load \times repetitions) during a training session.

The ACSM in 2002 and 2009 *Position Stand on Progression Models in Resistance Training for Healthy Adults*^[1,2] recommended that generally, large muscle group exercises be performed first in a training session. Although the practice of performing large muscle group exercises first has been anecdotally accepted for several years, there is relatively little scientific examination of this recommendation with reference to acute responses and chronic adaptations. Simão et al.^[12] examined two resistance exercise sequences on the total repetitions performed in an upper-body session by recreationally trained men and women. The RT sessions were performed in random order and consisted of performing three sets of each exercise with 10-RM loads and 2-minute rest intervals between sets and exercises. One session began with exercises that involved large muscle groups and progressed to exercises that involved small muscle groups (i.e. bench press, lat pull down, shoulder press, biceps curl and triceps extension); while the other session utilized the opposite exercise order. The results indicated significantly fewer total repetitions for exercises performed later in the sequence; irrespective of whether the exercise involved relatively large or small muscle groups. Interestingly, the exercise that was always performed in the middle of each sequence (i.e. shoulder press) presented no significant changes in the total repetitions between sequences (see table I).

In a follow-up study, Simão et al.^[13] examined two resistance exercise sequences on the total repetitions performed by trained women. The RT sessions were performed in random order and consisted of three sets of each exercise with 80% of 1-RM, with 2-minute rest intervals between sets and exercises. One session began with exercises that involved large muscle groups and progressed to exercises that involved small muscle groups (i.e. bench press, shoulder press, triceps extension, leg press, leg extension and leg curl), while the other session utilized the opposite exercise order.

The results indicated significantly fewer total repetitions for exercises performed later in the sequence, irrespective of whether the exercise involved relatively large or small muscle groups (see table I). In both of the aforementioned studies,^[12,13] the results and implications were similar, irrespective of the size of muscle group involved for a given exercise; whenever an exercise was performed later in the sequence, repetition performance (and subsequently volume) decreased. Therefore, if an exercise is considered of primary importance to meet individual needs and movement patterns, then it should be performed early in a training session.

Other studies found similar results to Simão et al.^[12,13] in comparing opposing sequences on repetition performance by young trained (male and female) subjects (see table I). Conversely, Silva et al.^[11] did not find the same trend in older women who performed three sets of exercises in a sequence with 10-RM loads. One sequence (sequence A) was performed in the following order: bench press, shoulder press and triceps extension; the other sequence was performed in the opposite order (sequence B) [i.e. triceps extension, shoulder press and bench press]. Bench press total repetitions significantly decreased when performed last in the sequence (as could be expected); while, unexpectedly for the other exercises, there weren't any differences in total repetitions between sequences (see table I). However, a key limitation of this study^[11] was the relatively low number of subjects (i.e. eight) and the number of 10-RM assessments (i.e. only one test); both of these factors may have limited the validity and reliability of the findings. According to Ploutz-Snyder and Giamis,^[19] older subjects require greater practice and familiarization to obtain a valid estimate of maximum strength. A topic of future research might be to examine the number of testing sessions to achieve consistent 10-RM strength measurements by untrained older women.

Spreuwenberg et al.^[14] compared repetition performance and acute power production for the squat in four sets with 85% of 1-RM, when placed before (sequence A) or after (sequence B) a whole-body RT session by trained men. In addition to the squat, the other exercises included bench

Table 1. Influence of exercise order on repetition performance over multiple sets. Values are expressed as repetition maximum

Study	Load	Order	Exercises	Set 1	Set 2	Set 3	Set 4	Mean	Total
Simão et al. ^[12]	10-RM	S1: large to small muscle groups S2: small to large muscle groups	Bench press S1	9.9	9.7	8.5	-	a	-
			Bench press S2	8.3	6.9	6.7	-	-	-
			Lat pull down S1	10	9.5	7.8	-	a	-
			Lat pull down S2	9.8	8.3	7.1	-	-	-
			Shoulder press S1	9.4	8.1	5.6	-	-	-
			Shoulder press S2	9.8	8.6	7.1	-	-	-
Monteiro et al. ^[9]	10-RM	S1: large to small muscle groups S2: small to large muscle groups	Biceps curl S1	10	9	6.5 ^a	-	a	-
			Biceps curl S2	10	10	9.6	-	-	-
			Triceps extension S1	9.3	7.9	7.8	-	a	-
			Triceps extension S2	9.5	9.9	9.5	-	-	-
			Bench press S1	9.9	9.9 ^a	9.1 ^a	-	9.6 ^a	-
			Bench press S2	9.5	8.6	8.0	-	8.7	-
Spreuwenberg et al. ^[14]	85% 1-RM	S1: squat first S2: squat at the end of session	Shoulder press S1	8.9	8.8	8.5	-	8.7 ^a	-
			Shoulder press S2	9.9	9.6	9.3	-	9.7	-
			Triceps extension S1	9.3	9.7	9.3 ^a	-	9.4	-
			Triceps extension S2	9.9	9.9	9.9	-	9.9	-
			Squat S1	8.0 ^a	6.2	5.6	5.0	-	-
			Squat S2	5.4	5.0	4.7	4.5	-	-
Simão et al. ^[13]	80% 1-RM	S1: large to small muscle groups S2: small to large muscle groups	Bench press S1	10.2 ^a	8.2	6.7	-	8.4 ^a	-
			Bench press S2	6.7	6.0	5.3	-	6.0	-
			Shoulder press S1	9.4	7.9	7.3	-	8.2 ^a	-
			Shoulder press S2	7.9	6.7	5.7	-	6.8	-
			Triceps extension S1	8.8 ^a	8.5	8.4	-	8.6 ^a	-
			Triceps extension S2	12.4	10.3	9.6	-	10.8	-

Continued next page

Table I. Cont'd

Study	Load	Order	Exercises	Set 1	Set 2	Set 3	Set 4	Mean	Total	
Bellezza et al. ^[4]	10-RM	S1: large to small muscle groups S2: small to large muscle groups	Leg press S1	23.9 ^a	20.3 ^a	19.3 ^a	-	21.1 ^a	-	
			Leg press S2	20	16.3	16.2	-	17.5	-	
			Leg extension S1	9.4 ^a	9.9 ^a	9.8	-	9.7 ^a	-	
			Leg extension S2	12.7	13.0	12.0	-	12.5	-	
			Leg curl S1	15.7 ^a	14.3 ^a	13.4 ^a	-	14.5 ^a	-	
			Leg curl S2	18.4	16.6	16.1	-	17.0	-	
Silva et al. ^[11]	10-RM	S1: large to small muscle groups S2: small to large muscle groups	Bench press	-	-	-	-	S1: 9.8 ^a	-	
			Leg press	-	-	-	-	S2: 9.9	-	
			Rows	-	-	-	-	-	-	
			Leg extension	-	-	-	-	-	-	
			Shoulder press	-	-	-	-	-	-	
			Leg curl	-	-	-	-	-	-	
			Biceps curl	-	-	-	-	-	-	
			Calve raise	-	-	-	-	-	-	
			Triceps extension	-	-	-	-	-	-	
			Bench press S1 YW	-	-	-	-	-	-	27.8 ^a
			Bench press S2 YW	-	-	-	-	-	-	20.4
Shoulder press S1 YW	-	-	-	-	-	-	27.5			
Shoulder press S2 YW	-	-	-	-	-	-	28.8			
Triceps extension S1 YW	-	-	-	-	-	-	23.9 ^a			
Triceps extension S2 YW	-	-	-	-	-	-	29.9			
Bench press S1 OW	-	-	-	-	-	-	26.8 ^a			
Bench press S2 OW	-	-	-	-	-	-	21.0			
Shoulder press S1 OW	-	-	-	-	-	-	26.4			
Shoulder press S2 OW	-	-	-	-	-	-	27.3			
Triceps extension S1 OW	-	-	-	-	-	-	27.2			
Triceps extension S2 OW	-	-	-	-	-	-	27.7			

^a Significant difference to S2.

OW = older women; RM = repetition maximum; S1 = sequence 1; S2 = sequence 2; YW = young women; - indicates non-reported data.

press, lunge, row, biceps curl, stiff leg, dead lift, sit up and the hang pull. The subjects performed significantly greater squat repetitions during sequence A (8.0 ± 1.9 when the squat was performed first) versus sequence B (5.4 ± 2.7 when the squat was performed last). The authors concluded that performing the squat first in an RT session allowed for the completion of greater total repetitions. However, the average power for each set of the squat was higher when performed last in the sequence. The authors suggested that this phenomenon could be accounted for as a result of postactivation potentiation, in which the previous exercises in a sequence (e.g. hang clean) enhanced the neurological drive and acute expression of muscular power. Regarding this finding, Spreuwenberg et al.^[14] recommended that athletes aiming for maximal strength gains should perform multi-joint, large muscle group exercises first; albeit, this recommendation was based solely on the squat exercise, which necessitates further research on this issue.

Gentil et al.^[7] examined different exercise sequences when applying the popular bodybuilding pre-exhaustion (PRE) technique. Traditionally, this technique involves performing a single-joint exercise first for a large muscle group, such as the pec-deck fly (i.e. horizontal adduction) for the pectoralis major, immediately followed by a multi-joint exercise that also emphasizes the same prime mover in addition to other secondary movers (i.e. anterior portion of the deltoid and triceps brachii), such as the bench press. The total repetitions completed were compared when utilizing the PRE (i.e. pec-deck fly followed by bench press) or priority system (PS) [i.e. bench press followed by pec-deck fly] by recreationally trained men; one set with 10-RM loads for each exercise was performed in opposing RT sequences. The results indicated that the total repetitions (from both exercises added together) were not significantly different between the PRE and PS sequences. However, when the exercises were analysed separately, the repetitions performed during the pec-deck fly were significantly greater for the PRE sequence (pec-deck fly was performed first), while the repetitions performed during the bench press were significantly greater for the PS sequence (bench press was performed first).

In summary, the studies that analysed the effect of exercise order on repetition performance indicated that the total repetitions and thus the volume, was greater when an exercise was placed at the beginning of an RT session, irrespective of the relative amount of muscle mass involved. However, these results must be considered with respect to other factors involved in an RT prescription. Although the research has demonstrated large and small muscle group exercises respond similarly to manipulation of exercise order in terms of repetition performance, large muscle group exercises are generally considered more transferable to functional performance and therefore should be performed at the beginning of RT sessions in the majority of the training protocols and prescriptions. Additionally, safety is a key issue, and the greater absolute loads utilized for large muscle group exercises may necessitate that they be performed first when the muscles are in a non-fatigued condition.

3.2 Influence of Exercise Order on Neuromuscular Activity

Data obtained via electromyography provides important information concerning the intensity and pattern of neuromuscular activity. Anecdotally, it has been assumed and promoted in the lay bodybuilding literature that the PRE technique is effective for stimulating greater muscle activation in the larger prime movers. This assumption is based on the premise that muscle size is positively correlated to fatigue resistance; therefore, a larger muscle group might be capable of performing greater work at a given relative intensity. For example, a common PRE technique for the pectoralis major initially involves performing a set of the pec-deck fly to produce a certain level of neuromuscular activation and subsequent fatigue. A pec-deck fly set is then immediately followed by a set of the bench press; this exercise order supposedly elicits a greater level of neuromuscular recruitment for the pectoralis major as the non-fatigued anterior fibres of the deltoid and triceps brachii may allow for additional repetitions and/or volume. However, the limited studies that have examined the PRE technique do not support the theory of enhanced neuromuscular activation when a single-joint exercise

Table II. Influence of exercise order on neuromuscular activity (pre-exhaustion method)

Study	Load	Exercises	Order	Measurements	Results
Augustsson et al. ^[20]	10-RM	Leg press Leg extension	S1: leg press S2: leg extension → leg press	10-RM; muscle activation (EMG); maximal voluntary isometric activation; number of repetitions	Significant lower EMG activity for rectus femoris and vastus lateralis during the leg press for S2. No significant difference of gluteus maximus in both conditions. Significant less repetitions of leg press for S2
Gentil et al. ^[7]	10-RM	Bench press Pec-deck fly	S1: bench press → pec-deck fly S2: pec-deck fly → bench press	10-RM; muscle activation (EMG); total work	No significant differences in muscle activation of pectoralis major and anterior deltoid between S1 and S2. Triceps brachii activation was higher during bench press for S2. Total work was similar
Brennecke et al. ^[5]	10-RM	Bench press Pec-deck fly	S1: bench press S2: pec-deck fly → bench press	10-RM; EMG of pectoralis major, anterior deltoid and triceps brachii	No significant differences in muscle activation of pectoralis major and anterior deltoid between S1 and S2. EMG of triceps brachii was significantly higher during bench press for S2

EMG = electromyography; **RM** = repetition maximum; **S1** = sequence 1; **S2** = sequence 2; → indicates exercise sequence was presented from before after the horizontal arrow.

(e.g. pec-deck fly) is succeeded by a multi-joint exercise (e.g. bench press).

Augustsson et al.^[20] analysed neuromuscular activation of the lower extremity musculature for the leg press when performed alone versus the PRE technique (leg extension immediately before the leg press). Trained men performed two RT sessions during which one set with a 10-RM load for the leg press was performed alone or in traditional PRE order. The total number of repetitions and electromyographical data were collected for the rectus femoris, vastus lateralis and gluteus maximus. The results indicated that the traditional PRE order, as promoted in the lay bodybuilding literature (i.e. leg extension followed by leg press), was associated with decreased leg press total repetitions and decreased quadriceps muscle activation (i.e. rectus femoris, vastus lateralis) versus the performance of leg press alone (see table II).

Gentil et al.^[7] corroborated the aforementioned findings in analysing neuromuscular activation of the upper extremity musculature when the pec-deck fly and bench press exercises were performed successively and in opposite sequences. Trained men performed two RT sessions during which one set with 10-RM loads for each exercise was performed; the traditional PRE order being the RT session during which the pec-deck fly was immediately

followed by the bench press. The total number of repetitions for each exercise and electromyographical data were collected for the pectoralis major, anterior fibres of the deltoid and triceps brachii. The results indicated that repetition performance increased when an exercise was performed first (both bench press and pec-deck fly) and that the traditional PRE order, as promoted in the lay bodybuilding literature (i.e. pec-deck fly followed by bench press), was associated with increased triceps brachii activation during the bench press versus the alternative method of performing the bench press first followed by the pec-deck fly (see table II). These results indicate the importance of prioritizing exercises based on individual weaknesses to maximize neuromuscular activity and avoid the negative consequences associated with neuromuscular fatigue.

Recently, Brennecke et al.^[5] analysed the effects of PRE on pectoralis major, anterior deltoid and triceps brachii activation for the bench press when performed alone versus the PRE technique (pec-deck fly immediately before the bench press) by trained men. The results were very similar to Gentil et al.^[7] and the authors concluded that the PRE technique did not increase pectoralis major and anterior deltoid activation, but was more effective for increasing triceps brachii activation

(see table II). So we can conclude that if an exercise is important to the training goal, then it should be placed at the beginning of a sequence and that the PRE method might not be an effective technique to increase the extent of neuromuscular recruitment for larger muscle groups (e.g. pectoralis major for the bench press) when preceded by a single-joint movement (e.g. pec-deck fly). However, more studies are necessary to validate this conclusion in more muscle groups other than the quadriceps and pectoralis major.

3.3 Influence of Exercise Order on Oxygen Consumption

RT has become a key strategy to improve physical functioning^[2] as a result of favourable modifications in body composition from the repeated sessions that acutely increase $\dot{V}O_2$ and energy expenditure. However, only two studies have examined the influence of exercise order on $\dot{V}O_2$ during or after an RT session.^[6,21] Farinatti et al.^[6] examined the influence of exercise order on $\dot{V}O_2$ in recreationally trained women, when performing two exercise sequences that consisted of three sets with a 10-RM load and 2-minute rest intervals between sets. One exercise sequence was performed in the following order: bench press, shoulder press and triceps extension; the other exercise sequence was performed in the opposite order with 48-hours rest between sessions. The results indicated that

exercise order had no effect on the total work, $\dot{V}O_2$ or total energy expenditure (see table III); albeit, the last exercise in each sequence (i.e. triceps extension or bench press) was associated with greater $\dot{V}O_2$ during the rest interval between sets. In this study, given the load and rest interval between sets, the accumulation of H⁺ ions would stimulate chemoreceptors with subsequent feedback to the central respiratory control centre, to initiate an increase in the depth and frequency of breathing to offset the ensuing metabolic acidosis. However, the exercise order did not affect the magnitude of the excess $\dot{V}O_2$.

Similarly, da Silva et al.^[21] examined the effect of two different training methods (circuit vs PRE) that involved the same exercises on post-exercise energy expenditure and $\dot{V}O_2$ of untrained women. The RT sessions consisted of one set of seven exercises, without rest between exercises for the circuit session (bench press, leg press, high row, leg extension, pec-deck fly, leg curl and back fly [horizontal abduction]), and for the PRE session (bench press, pec-deck fly, leg press, leg extension, leg curl, high row, back fly with 50% of 1-RM for single-joint exercises and 55% of 1RM for multi-joint exercises). Interestingly, the authors utilized PRE to designate one of the studied protocols that did not represent the traditional PRE order as promoted in the lay bodybuilding literature (i.e. leg extension followed by leg press). $\dot{V}O_2$ and energy expenditure were measured for 30 minutes before and following each RT session. The results indicated

Table III. Influence of exercise order on $\dot{V}O_2$

Study	Load	Exercises	Order	Measurements ^a	Results (mean \pm SD)
Farinatti et al. ^[6]	10-RM	Bench press	S1: large to small muscle groups	Total $\dot{V}O_2$ S1	24.41 \pm 6.51
		Shoulder press	S2: small to large muscle groups	Total $\dot{V}O_2$ S2	24.81 \pm 4.08
		Triceps extension		Net EE S1	60.01 \pm 29.26
				Net EE S2	57.02 \pm 15.25
da Silva et al. ^[21]	50–55% of 1-RM	Bench press	S1: circuit	EPOC S1	7.19 \pm 6.17
		Pec-deck fly	S2: PRE	EPOC S2	7.22 \pm 5.84
		Leg press		Post-exercise EE S1	34.67 \pm 29.76
		Leg extension		Post-exercise EE S2	34.77 \pm 28.15
		Leg curl			
		High row			
		Back fly			

a Values of total $\dot{V}O_2$ and EPOC are expressed in litres; values of net EE and post-exercise EE are expressed in Kcal.

EE = energy expenditure; EPOC = excess post exercise $\dot{V}O_2$; PRE = pre-exhaustion method; RM = repetition maximum; S1 = sequence 1; S2 = sequence 2; $\dot{V}O_2$ = oxygen consumption.

Table IV. Influence of exercise order on rating of perceived exertion

Study	Load	Exercises	Order	Measurement	Results (mean±SD or median)
Simão et al. ^[12]	10-RM	Bench press	S1: large to small muscle groups	Borg Cr-10 S1	8.5±1.6
		Lat pull down	S2: small to large muscle groups	Borg Cr-10 S2	7.6±1.8
Monteiro et al. ^[9]	10-RM	Shoulder press			
		Biceps curl			
		Triceps extension			
Simão et al. ^[13]	80% 1-RM	Bench press	S1: large to small muscle groups	Borg Cr-10 S1	8.0±1.0
		Shoulder press	S2: small to large muscle groups	Borg Cr-10 S2	8.0±1.0
Bellezza et al. ^[4]	10-RM	Triceps extension			
		Leg press			
		Leg extension			
		Leg curl			
		Biceps curl			
		Calve raise			
		Triceps extension			
Silva et al. ^[11]	10-RM	Bench press	S1: large to small muscle groups	Borg Cr-10 S1 YW	6.3
		Shoulder press	S2: small to large muscle groups	Borg Cr-10 S2 YW	6.3
		Triceps extension		Borg Cr-10 S1 OW	4.6 ^a
				Borg Cr-10 S2 OW	6.1

a Significant difference to S2.

OW = older women; **RM** = repetition maximum; **S1** = sequence 1; **S2** = sequence 2; **YW** = young women.

that both exercise sequences maintained post-exercise $\dot{V}O_2$ above resting levels. However, there was no significant difference between sequences (see table III). Therefore, the aforementioned studies^[6,21] indicate that exercise order may not be a key factor influencing the magnitude of $\dot{V}O_2$ or energy expenditure; more studies are still necessary to confirm or refute these data.

3.4 Influence of Exercise Order on the Rating of Perceived Exertion

The rating of perceived exertion (RPE) provides a conveniently subjective estimate of RT intensity.^[22] The Borg-10 category and Omni-Res scales have been validated objectively with measures of blood lactate concentration,^[23,24] neu-

romuscular activity^[25,26] and varying percentages of a 1-RM.^[25]

Five studies have examined the influence of exercise order on RPE scores following RT sessions with conflicting results.^[4,9,11-13] For example, four of five studies conducted to date did not demonstrate differences in RPE scores between opposing RT sequences,^[4,9,12,13] while only one study^[11] presented significant increases in RPE scores by older women following an RT sequence that was ordered from small to large muscle group exercises (vs large to small muscle group order). All studies utilized the Borg Cr-10 Scale and the RPE mean in these studies ranged from 4.6 in the Silva et al.^[11] study to 8.5 in the Simão et al.^[13] study (see table IV).

A key limitation of the methodology in validating the RPE scales (Borg Cr-10, Omni-Res

scale)^[22] was the performance of exclusively sub-maximal RM sets; whereas, the aforementioned studies involved performance of full RM sets to voluntary exhaustion. Therefore, it is possible that significant differences in RPE scores occur only when a submaximal number of repetitions are performed at a predetermined percentage of 1-RM; this might be the reason for the lack of significant differences in studies examining the influence of exercise order on RPE.

4. Chronic Adaptations and the Exercise Order

To our knowledge, Dias et al.^[15] was the first study to examine the chronic effects of exercise order as the independent variable. Dias et al.^[15] examined the influence of exercise order on strength in untrained men following an 8-week progressive RT programme. Subjects were randomly assigned into three groups as follows: (i) group 1 began with large and progressed toward small muscle group exercises; (ii) group 2 began with small and progressed toward large muscle group exercises; and (iii) group 3 served as a non-training control. The exercise order for group 1 was bench press, lat pull down, shoulder press, biceps curl and triceps extension. The exercise order for group 2 was triceps extension, biceps curl, shoulder press, lat pull down and bench press. Training sessions were conducted 3 times per week with at least 48 hours of rest between sessions and 2 minutes of rest between sets and exercises during training sessions. The resistance load for a given exercise was increased whenever an individual could perform more than the prescribed number of repetitions (8- to 12-RM) of a particular exercise. 1-RM was assessed for all exercises at baseline and after 8 weeks of training.

Both groups demonstrated significant strength increases of 16.3–77.8% for all exercises. There were no significant differences in strength increases between training groups for the large muscle group exercises (e.g. bench press, lat pull down, shoulder press). In contrast, greater strength increases were evident for the small muscle group exercises in group 2 (e.g. triceps

extension, biceps curl), suggesting that the exercise order could be particularly important during the initial stages of RT in untrained men, but primarily for small muscle group exercises. Another interesting point to observe was that strength gains in each exercise for both training groups was greater for the exercises performed earlier in a training session. The major limitation of this study was not assessing muscle size and hypertrophy to promote further understanding of the chronic adaptations consequent to different exercise sequences.

Subsequently, Simão et al.^[16] examined the influence of exercise order on strength and muscle thickness (MT) in untrained men following 12 weeks of linear periodized RT. Subjects were randomly assigned into three groups; one group began with large and progressed toward small muscle group exercises (group 1) while another started with small and progressed toward large muscle group exercises (group 2). The exercise order for group 1 was bench press, lat pull-down, triceps extension and biceps curl. The order for group 2 was biceps curl, triceps extension, lat pull down and bench press. The third group served as a control group. Training frequency was two sessions per week with at least 72 hours between sessions. Maximal strength for all exercises and biceps and triceps MT (assessed by ultrasound techniques) were collected at baseline and following 12 weeks.

The results indicated significant strength increases in all exercises for the training groups versus the control group, with the exception of the biceps curl in group 1 and the bench press in group 2. Triceps MT for both training groups was significantly greater versus the control group, but with no significant differences between the training groups. Significant differences in triceps MT from pre- to post-training were evident only for group 2, while the biceps MT presented significant differences only for group 1 versus the control group. Another key finding was that exercises placed at the end of the sequences for both training groups (e.g. bench press in group 2 and biceps curl in group 1) did not present significant strength increases between baseline and 12 weeks, suggesting the potential negative outcome of placing a given exercise at the end of a sequence (table V).

Table V. Chronic adaptations and the exercise order

Study	Duration (wk)	Order	Measurements ^a	Results		
				Baseline (mean±SD)	After (mean±SD)	Effect size ^b (mean)
Dias et al. ^[15]	8	G1: large to small muscle groups (n=16) G2: Small to large muscle groups (n=17) CG: (n=15)	Bench press 1-RM G1	59.7±12.4	83.1±10.9 ^{c,d}	1.89
			Bench press 1-RM G2	61.7±9.1	73.2±8.3 ^{c,d}	1.26
			Bench press 1-RM CG	56.5±7.5	57.8±7.1	0.17
			Lat pulldown 1-RM G1	48.8±9.4	72.0±11.6 ^{c,d}	2.47
			Lat pulldown 1-RM G2	54.3±8.6	65.5±7.8 ^{c,d}	1.30
			Lat pulldown 1-RM CG	46.6±6.9	47.8±7.5	0.17
			Shoulder press 1-RM G1	32.0±5.1	50.7±7.3 ^{c,d}	3.67
			Shoulder press 1-RM G2	35.0±5.0	49.6±5.6 ^{c,d}	2.92
			Shoulder press 1-RM CG	32.1±3.5	31.0±2.1	-0.31
			Biceps curl 1-RM G1	27.5±3.1	32.0±2.4 ^{c,d,e}	1.45
			Biceps curl 1-RM G2	29.5±3.3	39.2±3.7 ^{c,d}	2.94
			Biceps curl 1-RM CG	27.7±3.1	26.6±2.9	-0.35
			Triceps extension 1-RM G1	21.8±5.1	29.9±4.4 ^{c,d,e}	1.59
			Triceps extension 1-RM G2	25.0±5.0	44.1±6.6 ^{c,d}	3.82
			Triceps extension 1-RM CG	22.3±5.6	21.0±3.8	-0.23
Simão et al. ^[16]	12	G1: large to small muscle groups (n=9) G2: small to large muscle groups (n=13) CG: (n=9)	Bench press 1-RM G1	79.25±13.31	86.38±12.12 ^{c,d}	0.54
			Bench press 1-RM G2	70.33±13.66	78.00±14.92 ^d	0.56
			Bench press 1-RM CG	71.6±8.9	69.5±7.2	-0.23
			Lat pulldown 1-RM G1	88.68±16.02	99.38±10.84 ^{c,d}	0.78
			Lat pulldown 1-RM G2	86.67±9.37	92.08±10.33 ^{c,d}	0.58
			Lat pulldown 1-RM CG	86.6±10.4	85.2±8.7	-0.13
			Triceps extension 1-RM G1	75.63±18.60	90.94±13.82 ^{c,d}	0.75
			Triceps extension 1-RM G2	73.33±13.03	92.29±14.00 ^{c,d}	2.07
			Triceps extension 1-RM CG	34.0±4.1	32.1±3.0	-0.17
			Biceps curl 1-RM G1	33.25±6.30	38.25±6.27	0.82
			Biceps curl 1-RM G2	32.58±4.94	38.08±4.48 ^{c,d}	1.11
			Biceps curl 1-RM CG	34.7±2.9	34.2±3.1	-0.46
			Triceps MT G1	3.88±0.45	3.88±0.42 ^d	0.00
			Triceps MT G2	3.47±0.59	3.75±0.45 ^{c,d}	0.47
			Triceps MT CG	3.25±0.48	3.19±0.39	-0.12
Biceps MT G1	3.66±0.64	3.88±0.42 ^d	0.34			
Biceps MT G2	3.67±0.50	3.80±0.40	0.26			
Biceps MT CG	3.66±0.46	3.65±0.37	0.07			
Spinetti et al. ^[17]	12	G1: large to small muscle groups (n=11) G2: small to large muscle groups (n=10) CG: (n=9)	Bench press 1-RM G1	76.1±9.7	93.1±10.4 ^{c,d}	1.74
			Bench press 1-RM G2	70.0±16.1	84.6±14.8 ^{c,d}	0.90
			Bench press 1-RM CG	71.6±9.4	68.2±8.4	-0.36
			Lat pulldown 1-RM G1	92.0±15.5	102.0±15.5 ^{c,d}	0.67
			Lat pulldown 1-RM G2	82.5±13.0	96.6±9.8 ^{c,d}	1.25
			Lat pulldown 1-RM CG	86.6±11	84.8±9.5	-0.16
			Triceps extension 1-RM G1	38.5±5.7	49.0±7.0 ^{c,d}	1.83
			Triceps extension 1-RM G2	32.7±4.4	49.0±7.0 ^{c,d}	2.99
			Triceps extension 1-RM CG	34.7±3.1	34.2±3.1	-0.44

Continued next page

Table V. Contd

Study	Duration (wk)	Order	Measurements ^a	Results		
				Baseline (mean±SD)	After (mean±SD)	Effect size ^b (mean)
			Biceps curl 1-RM G1	35.1±5.4	40.5±5.9 ^{c,d}	0.98
			Biceps curl 1-RM G2	35.1±5.4	46.1±5.0 ^{c,d}	1.95
			Biceps curl 1-RM CG	34.0±4.1	34.7±3.1	-0.16
			Triceps MV G1	398.4±105.6	457.7±78.1 ^{c,d}	0.40
			Triceps MV G2	408.6±69.3	459.3±78.3 ^{c,d}	1.08
			Triceps MV CG	347.1±63.7	339.1±54.1	-0.13
			Biceps MV G1	416.6±103.1	457.4±108.7 ^{c,d}	0.56
			Biceps MV G2	368.7±41.8	416.2±59.0 ^{c,d}	0.69
			Biceps MV CG	299.3±59.2	283.0±61.3	-0.28

a Values of 1-RM tests are expressed in kg; values of MV are expressed cm³; values of MT are expressed cm.

b Effect-size classifications for recreationally trained subjects:^[26] trivial = <0.35; small = 0.35–0.80; moderate = 0.80–1.5; large = >1.5.

c Significant difference from baseline.

d Significant difference from CG.

e Significant difference from G2.

CG = control group; G1 = group 1; G2 = group 2; MT = muscle thickness; MV = muscle volume; RM = repetition maximum.

It is important to examine treatment effects independent of statistical probability, especially in the case of small sample sizes, because probability values are highly affected by sample size and variance. In this context, the effect size for determining the magnitude of the treatment effect has been used to assist in the interpretation of RT studies.^[27] Therefore, calculation of increases by the effect size in 1-RM strength and MT (the difference between pre-test and post-test scores divided by the pre-test standard deviation) and the scale proposed by Rhea^[27] were used by Simão et al.^[16] The effect-size analysis demonstrated greater magnitude for strength increases in triceps extension and biceps curl exercises, and for triceps MT in group 2, suggesting that RT sessions should be prioritized based on the training goal or movement patterns in greatest need of improvement, irrespective of whether or not it is a large or a small muscle group exercise.

A similar study^[17] examined the influence of exercise order on strength and muscle volume (MV) following 12 weeks of nonlinear periodized RT. Group 1 of 3 groups performed a large to small muscle group exercise order; group 2 performed a small to large muscle group exercise order; and the third group did not exercise and

served as a control group. The exercise order for group 1 was bench press, lat pull-down, triceps extension, and biceps curl. The order for group 2 was biceps curl, triceps extension, lat pull down and bench press. The training frequency was two sessions per week with at least 72 hours of rest between sessions. MV for the triceps and biceps was assessed at baseline, at week 6, and following 12 weeks using ultrasound techniques; 1-RM for all exercises was assessed at baseline and following 12 weeks of training.

The results indicated no statistically significant differences in strength gains or muscle accretion between the different exercise order for training groups. Similarly to Simão et al.,^[16] Spinetti et al.^[17] also included the calculation of increases by the effect size in 1-RM strength and MV and the scale proposed by Rhea.^[27] Effect-size data demonstrated that differences in strength and MV were evident based on the exercise order. Overall, both training groups demonstrated greater effect sizes versus the CG. Bench press strength increased with greater magnitude in group 1. In all other strength measures (lat pull down, triceps extension and biceps curl), group 2 showed greater strength increases. Triceps MV increased to a greater extent in group 2; however, the increases in biceps MV did not differ

between the training groups. This research bolsters the aforementioned conclusion that exercise order should not always progress from large to small muscle group exercises; perhaps the more important determinant should be on individual needs and movement patterns most in need of improvement.

5. Conclusions and Recommendations

From an acute standpoint, exercise order affects repetition performance over multiple sets, indicating that the total repetitions, and thus the volume, is greater when an exercise is placed at the beginning of an RT session, regardless of the relative amount of muscle mass involved. Exercises performed at the end of an RT session were associated with less repetitions and/or volume, irrespective of whether the movement involved a small muscle group, as in single-joint exercises; or a large muscle group, as in multi-joint exercises. The PRE method might not be an effective technique to increase the extent of neuromuscular recruitment for larger muscle groups (e.g. pectoralis major for the bench press) when preceded by a single-joint movement (e.g. pec-deck fly). With relevance to localized muscular endurance performance, $\dot{V}O_2$ and RPE, the limited amount of research conducted thus far indicates that exercise order does not appear to impact the acute expression of these variables. In terms of chronic adaptations, greater strength increases were evident by untrained subjects for the first exercise of a given sequence, while strength increases were inhibited for the last exercise of a given sequence. Additionally, based on strength and hypertrophy (i.e. muscle thickness and volume) effect-size data, the research suggests that exercises be ordered based on priority of importance as dictated by the training goal of a programme, and irrespective of whether the exercise involves a relatively large or small muscle group. The overall conclusion from the literature, whether considering acute responses or chronic adaptations, is that exercises should be prioritized so that those exercises that best address individual needs and training objectives are performed first. When prescribed appropriately with other important prescriptive variables (i.e. load, volume, and rest interval between sets and

exercises), the exercise order can influence the efficiency, safety and ultimate effectiveness of an RT programme.

Because of the lack of studies concerning chronic adaptations and exercise order, this review should provide some direction for future studies investigating aspects related to strength, power, hypertrophy, $\dot{V}O_2$ and muscular-endurance development. Additional investigations concerning acute responses are also necessary, involving women or individuals with different levels of physical conditioning and potential interactions between the exercise order, other RT variables and physiological responses. Furthermore, comparison between different exercise orders for exercises that involve relatively large versus small muscle groups would be useful from a practical standpoint. Overall, there is still much research to be done on this topic.

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