International Journal of EXERCISE SCIENCE

Original Research

Pre-exhaustion Training, a Narrative Review of the Acute Responses and Chronic Adaptations

THIAGO BARBOSA TRINDADE†[1], RAGAMI CHAVES ALVES‡[2], BRUNO MAGALHÃES DE CASTRO†[1], MATHEUS ALCÂNTARA DE MEDEIROS†[3], JASON AZEVEDO DE MEDEIROS†[3], PAULO MOREIRA SILVA DANTAS‡[3], and JONATO PRESTES‡[1]

[1]Graduation Program in Physical Education, Catholic University of Brasilia, Brasilia, DF, BR; [2]Metabolism, Nutrition and Resistance Training Research Group, Federal University of Paraná, Curitiba, PR, BR; [3]Department of Physical Education, Federal University of Rio Grande do Norte, Natal, RN, BR

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 15(3): 507-525, 2022. Pre-exhaustion (PE) is a popular resistance training strategy that involves performing a single-joint exercise followed by a multi-joint exercise with minimal recovery between the transition. This approach is widely used by bodybuilding athletes and resistance training (RT) enthusiasts with the aim of enhancing muscle strength and hypertrophy. The present paper aimed to provide a narrative review as to the effects of the PE method on different acute and chronic outcomes, and discuss relevant practical applications. When considering the body of literature as a whole, we conclude that current evidence does not support a benefit to the PE method compared to traditional RT models regarding chronic improvements in strength, hypertrophy and body composition. However, the heterogeneous study designs confound the ability to draw strong conclusions on the topic. Further investigations are warranted with strict control of study variables to better elucidate what, if any, benefits may be obtained by the PE method.

KEY WORDS: Exercise order, resistance training systems, fatigue

INTRODUCTION

The success of a resistance training (RT) program depends on the appropriate manipulation of program variables - such as load, number of sets and repetitions (volume), rest interval between sets, exercise order, movement speed (cadence) and training frequency - whose combination must take into account individual objectives, physical capacity and training status (1,5,28). Various combinations of RT variables are used empirically by bodybuilders, coaches and sports enthusiasts to maximize gains in muscle strength and hypertrophy (18).

The pre-exhaustion (PE) method is among the manipulation strategies commonly employed by fitness enthusiasts to optimize muscular adaptations, as initially proposed by Arthur Jones (16) in the 1970s. The method is based on the hypothesis that the execution of compound exercises, in which more than one muscle group is required to carry out the movement, can be limited by the momentary failure of the weakest muscle involved in performance, resulting in the underutilization of some muscles (16). However, despite its widespread use among the general public, the efficacy of the PE method remains questionable (8).

Jones (16) claimed that to achieve desired results from PE, exercise order must be arranged so that a single-joint movement is carried out to muscular failure, immediately followed by the performance of a multi-joint exercise to muscular failure. Additionally, the load used in the isolated exercise should be light, so that "20, 30 or more repetitions" can be perform; and that the load usually used in the multi-joint exercise should be reduced by “approximately 50%”. Recently, it was suggest that individuals with experience in RT could obtain a previous exhaustion of the target muscle, using an isolated exercise as strategy to reduce the load frequently used in the next multi-joint exercise, reducing forces applied to the joints (27).

A number of acute studies have been conducted on various outcomes related to PE. However, the observed effects in such studies are not necessarily predictive of chronic adaptations relating to measures of strength and hypertrophy (33). This is particularly true of investigations that utilized surface electromyography (EMG) in the evaluation of agonist / synergist muscles after performing a pre-exhaustive exercise.

Another point that should be mention is that most studies about PE (both acute and chronic) deviate from the initial idea established by Jones (16). Reviews by Carpinelli (8,10) claim there is a lack of research-based support for PE given that studies on the topic did not apply the method in its intended form (16). Some of these deviations include a long transition in rest intervals between exercises and the use of isolated exercises only.

Furthermore, most studies failed to use gold standard instruments to evaluate hypertrophy and body composition, while selecting less suitable evaluation parameters (9,25). In view of the diversity of approaches and variations used in the PE method, a critical review is warranted not only for drawing evidence-based conclusions, but also to provide insight for future investigations. The objective of this paper was to review the current literature as to the effects of the PE method on different acute and chronic outcomes, highlight current gaps in the literature, and discuss practical applications for program design.

METHODS

The search for articles was carried out in the following databases: Pubmed/MEDLINE, Scielo, EBSCO, LILACS, SportDiscus, Web of Science, and CINAHL, and Google Scholar which were searched from 20/01/2020 to 20/11/2020 without temporal delimitation for a broad spectrum of research. The descriptors used as search terms were: (“body composition” OR “muscular thickness” OR “cross-sectional area” OR “CSA” OR “muscle growth” OR “hypertrophy” OR “lean body mass” AND “resistance training” OR “pre- exhaustion” OR “strength training” AND "muscle activation" OR "electromyography" AND "RPE" OR "rate of perceived exertion"). The articles were identified and full-text was read.

Two specialists with expertise in strength and conditioning extracted the data. The following information was extracted from each study: subjects, training status, duration of the study, frequency of training, volume of training, repetitions range, load, rest interval, type of exercise, and the results of the variables hypertrophy, muscle thickness, body fat, muscular strength, muscle activation, and RPE.

The methods applied in this manuscript were in accordance with the standards proposed by Navalta et. al. (21).

RESULTS

The reviewed studies tested different protocols of PE, both for the lower and upper limbs. The lack of standardization in the application of the PE method was evident by the diversity of combinations of methodological variables observed in the analyzed studies; especially the transition rest interval between the pre-exhaustive exercise and the subsequent multi-joint exercise, that was excessively long as compared to the original proposal from Jones (16). Some studies used the same loads for both exercises, rather than a low load for the isolated pre-exhaustive exercise. These limitations were observed in both acute (Table 1) and chronic (Table 2) studies.

Table 1 presents eight acute studies; with subjects' characteristics, procedures, instruments, and main results obtained. The samples among studies varied from 9 to 19 subjects (trained or physically active), from both genders, aged between 22.5 ± 3.04 and 27.13±2.85 years old. In all studies samples were randomly assigned to different experimental protocols; six used upper limp exercises, while only two used lower limb exercises. Seven studies evaluated EMG activity.

The authors found three chronic studies that were included in the present review, see Table 2. The sample varied from 27 to 41 subjects (detrained or with some degree of experience in RT), from both genders, aged between 20.0 ± 1.8 e 49 ± 6 years old. In all studies the samples were randomly divided in to three groups (one control group), and training duration varied from eight to 12 weeks. Two studied used lower limb exercises, and one used upper and lower limb exercises. In all studies muscle strength was evaluated (1RM, or submaximal tests), while two studies evaluated muscle hypertrophy. Finally, two studied investigated modifications in body composition.

Table 1. Summarization of the acute effects of pre-exhaustion method.

Author(s)/Year	Sampling	Exercise protocol	Transition interval between isolated and multi-joint exercise	Evaluation	Results found
Augustsson et al. (2003)	16 M recreational trained (age: 26 ± 4 years; body mass: 77 ± 6 kg; height: 182 ± 6 cm).	PE - (Pre-exhaust): leg extension, load (10RM) + Leg Press, load for (10RM), up to FMM; WPE: Leg Press, charge for (10RM), until FMM.	"Immediately"	EMG muscles VL, RF and GM + n. of reps in the leg press.	With pre-exhaustion, there was a ↓ in the EMG activity of VL, RF, as well as of n. of reps on the Leg Press. There was no difference in the EMG activity of the GM.
Gentil et al. (2007)	13 M recreationally trained (age: 25.08 ± 2.58 years; body mass: 71.68 ± 8.65 kg; height: 172.50 ± 6.49 cm).	PE - (Pre-exhaustion): Peck-deck, load (10RM) + Bench press, load (10RM), both up to FMM; SP (priority system): Bench press, load to (10RM), up to FMM + Peck-deck, load (10RM), both up to FMM. Exercise execution speed: 2: 2 s concentric / eccentric	"Immediately –≤ 20s"	EMG muscles PM, DA and TB + n. of bench press reps, peck-deck and total training volume.	The EMG activity of TB was higher in the bench press, when performed after pre-exhaustion. The n. of reps. in the Peck-deck it was higher in the PE protocol and the n. of reps. the bench press was higher in SP. There was = in the total training volume.

Brennecke et al. (2009)	12 M trained (age: 27.7 ± 6.2 years; body mass: 80.06 ± 11.0kg, height: 173 ± 05 cm	SEQ. A - (Pre-exhaustion): Crucifix with dumbbells, load (10RM) + Bench press, load (10RM), until FMM; SEQ. B: Bench press, charge for (10RM), until FMM.	11.29 ± 67 s between the crucifix and the bench press, in seq. A	EMG of the PM, DA and TB muscles.	The TB showed significantly ↑ EMG activity in the bench press after PE. There was = in the EMG activity of the PM and DA muscles between the protocols.
Júnior et al. (2010)	9 M trained (age: 23.33 ± 3.46 years, body mass: 75.68 ± 8.10 kg, height: 1.76 ± 0.66 m).	"Pre-activation routine (R30)": Leg extension, 15 reps. with load (30% 1RM) + Leg press, 15 reps. with load (60% of 1RM) "Pre-activation routine (R60)": Leg extension, 15 reps. with load (60% 1RM) + Leg press, 15 reps. with load (60% of 1RM) "Routine Control" (RC): Leg press, 15 reps. with load (60% of 1RM)	≤ 40 seconds, between the leg extension and the leg press, in the R30 and R60 routines.	VL muscle EMG	There was a significantly greater ↑in the recruitment of VL during the execution of leg press in routines R30 and R60, compared to RC.

Vilaça-Alves et al. (2014)	8 M (age: 27.13±2.85 years; body height: 180.63±6.65 cm; body mass: 82.05±8.92 kg; and body fat: 14.67±6.09%); and 11 W (age: 28.81±3.68 years; body height: 162.91±6.51 cm; body mass 59.63±6.47 kg; and body fat: 24.11±4.33%)	Sessions 3 and 4, the number of repetitions and RPE values in the front pull-down with a wide grip or with a normal grip positions were measured. In session 3 the choice of the exercise was randomly selected, and in session 4 the front pull-down was performed with a different grip than in the previous session. In sessions 5 and 6, the same variables and exercises of sessions 3 and 4 were measured and performed, respectively, after PE of the biceps brachii muscle. The PE was obtained by using the arm curl exercise with a barbell.	All exercises: 70%RM load with an up-down cadence of 60 beats/min (30 repetitions per minute). Three sets of 10 repetitions of the BB exercise were used to promote pre-exhaustion with a rest interval of 90 s between sets.	Number of repetitions and the RPE in the front pull-down exercise with different handgrip positions with and without PE of the BB.	PE of the BB ↓ the number of repetitions ($p<0.001$) and ↑ the RPE ($p<0.001$); the narrow handgrip width elicited a ↑ RPE ($p<0.001$) and women performed fewer repetitions than men in all front pull-down exercise variations ($p=0.023$). Significant interactions were also observed between PE or sex and the RPE ($p=0.024$); and PE or handgrip width and the number of repetitions ($p<0.001$). PE of the BB promotes ↓ performance in the front pull-down exercise along with a greater RPE, especially when using a narrow handgrip position.

Guarascio, Penn, Sparks (2016)	12 M (24, ± 1.5 years) weighed 88 ± 8 kg, were 183 ± 6.3 cm in height, and performed resistance training at least 3x per week during the previous 12 months, with lifting experience that spanned 9 ± 2 years	SEQ1 (PE of TB prior to performing the bench press); SEQ 2 (only bench press). Group AB performed protocol SEQ 1, rested 72 hours, and then preformed protocol SEQ 2. Group BA performed protocol SEQ 2, rested 72 hours, and then preformed protocol SEQ 1	"Immediately –≤ 20s"	EMG, 10 RM load, maximum voluntary isometric contractions	A significant ↑in EMGs activity was noted in the PM (z = -2.353, p = 0.019) following PE of the triceps, indicating that PE of a synergistic secondary mover may result in higher neuromuscular activation of the primary mover in a compound exercise.
Soares et al. (2016)	14 M trained (age: 25.5 ± 4.0 years, height: 174.9 ± 4.1 cm and total body mass: 80.0 ± 11.1 kg)	SEQ. 1: Elbow extension on the high pulley (pushdown) + bench press, load (10RM), with an interval of 30 minutes between exercises; SEQ. 2 (Pre-exhaustion): Elbow extension on the high pulley (pushdown), load (10RM) + bench press, load (10RM), until the FMM; SEQ. 3 (Traditional): The reverse order was followed (bench press + pushdown).	30 minutes in the SEQ. 1; "Immediately", in SEQ 2 and SEQ 3.'	Total training volume; blood lactate concentration; EMG of the PM and TB muscles and RPE.	Higher total volume of training was observed in the SEQ. 1, in relation to SEQ 2, but not SEQ 3. No significant differences were observed for the other variables evaluated.

Golás et al. (2017)	8 M, with experience in strength training (age: 26 ± 3.8 years; body mass: 85 ± 5 kg, height: 176 ± 9.5 cm).	Session A: bench press - one repetition, 95% 1RM + 5 minutes break + (Pre-exhaustion) 4 sets of inclined crucifix with dumbbells, load (10RM) + 5 minutes break + bench press - one repetition, with 95% of 1RM.; Session B: followed the same sequence as session A, replacing the inclined crucifix with the shoulder flexion with dumbbells; Session C: followed the same sequence as session A, replacing the inclined crucifix with the elbow extension with dumbbells, in a supine position;	2 minutes interval between each of the 4 series of exhaustive exercises. 5 minutes interval between the last "pre-exhaustive" series and the bench press.	EMG of the PM, DA and TB muscles.	The EMG activity of TB ↑ in the execution of the bench press at 95% of 1RM in session C, when the elbow extension was performed as a pre-exhaustive exercise. No differences were found for any of the muscles in the other training conditions.

M = men; W= woman kg = kilogram; cm = centimeters; SEQ = sequence; EMG = electromyography, PE = pre-exhaustion; WPE = without pre-exhaustion; SP = priority system; TRT: traditional resistance training; RM = maximum repetition: 10RM = 10 maximum repetition; FMM = momentary muscle failure; RF = rectus femoris; VL = vastus lateralis; GM = gluteus maximus; BB = biceps brachii; n. = number; reps = repetitions; s = seconds; TB = triceps brachii; DA = anterior deltoid; PM = pectoralis major; Seq. = sequence; RPE = rate of perceived exertion; ↑= increase; ↓ = decrease.

Table 2. Summarization of the chronic effects of the pre-exhaustion method on body composition, dynamic muscle strength and muscle hypertrophy.

Authors year	Sample	Intervention Time	Exercise Protocol/ loads	Transition interval between isolated and multi-joint exercise	Evaluations	Results
Fisher et al. (2014)	11 M and 30 W, with experience in strength training, divided into 3 groups: PE (n = 14. Age: 49 ± 6 years; body mass: 72.27 ± 17.13 kg, height: 167.37 ± 9.67 cm; male / female ratio : 2:12); PER (n = 17. Age: 47 ± 12 years; body mass: 69.86 ± 16.47 kg, height: 168.52 ± 4.57 cm; male / female ratio: 4:13); CO (n = 8. Age: 47 ± 13 years; body mass: 68.78 ± 16.61 kg, height: 169.04 ± 8.15 cm; male / female ratio: 3: 5).	12 weeks; 2 sessions per week.	PE Group: Crucifix (pec-fly - machine) + Bench press (machine) / Knee extension (leg extension) + Leg press / Pull over (machine) + Pulled at the front (pull-down - machine). PER Group: The same sequence as the PE, maintaining the rest interval between exercises (60s). CON Group: Bench press (machine) + Leg press + Pulled at the front (pull-down - machine) + Crucifix (pec-fly - machine) + Knee extension (leg extension) + Pull over (machine) + Trunk flexion (machine) + Trunk extension (machine), with 60 s of rest between exercises.	PE - between isolates and compounds: "As brief as logistically possible: ≤ 5s"; between finishing each compound exercise and beginning the next isolation exercise: 120s; PER - 60 s between each exercise, removing the PE method whilst maintaining the same overall rest duration and exercise order; CON - standard interval: 60 s.	Strength endurance test, verified by the total training volume, with an estimated load for 8 to 12 RM, in leg press exercises, bench press and pull in the high pulley. Body mass (kg), body fat percentage (%) and fat free mass.	No significant differences were found for any of the variables analyzed.

			Exercise load: equivalent to 12RM. Speed of execution of the exercises: 2: 4 s conc / ecc. to FMM.			
Aguiar et al. (2015)	27 untrained M, divided into 3 groups: CO (n = 9. Age: 20.0 ± 1.8 years; body mass: 75.0 ± 8.8 kg, height: 176.4 ± 8.1 cm; 1RM: 106.4 ± 2.6 kg); TR (n = 9. Age: 20.9 ± 2.0 years; body mass: 73.7 ± 9.4 kg, height: 173.8 ± 6.9 cm; 1RM: 107.4 ± 3.9 kg); PE (n = 9. Age: 21.0 ± 1.9 years; body mass: 69.8 ± 11.2 kg, height: 174.4 ± 2.2 cm; 1RM: 106.6 ± 4.5 kg).	3 weeks of familiarization (3 sessions per week) + 8 weeks of strength training (2 sessions per week).	PE Group: 1 series of isolated knee extension in the leg extension, load (20% of 1RM), until FMM + 3 series of 8 to 12 reps. isolated knee extension, load (75% of 1RM), with 1 minute interval. Group TR: 3 sets of 8 to 12 reps. isolated knee extension, load (75% of 1RM), with 1 minute interval. Group CO: There was no training.	30 seconds between the pre-exhaustive series (20% 1RM) and the first conventional series (75% 1RM).	1RM in the leg extension; cross-sectional area (AST) of the VL, VM, VI and RF muscles; total training volume; total number of repetitions and muscle work index (% RMS), with a 60% load of 1RM. Nutrition control.	The inclusion of pre-exhaustive exercise in the strength training sessions provided ↑ in the maximum strength (1RM), in the CSA of the evaluated muscles and in the strength resistance of the quadriceps.
Trindade et al. (2019)	31 untrained M (age: 31.37 ± 6.83 years; height: 175.29 ± 5.52 cm; body mass: 82.04 ± 13.61 kg; 1RM leg press: 339.86 ± 61.17 kg; 1RM leg extension: 121.71 ± 11.93 kg) separated	9 weeks; 2 sessions per week (3 weeks of familiarization)	TRT group (n = 12) performed three sets at 45◦ of leg press exercise at 75% of 1RM, PE group (n = 12) completed a set to failure on a leg extension machine prior to the leg	PE: immediately before (≤10 s) TRT: 1 minute	Maximum strength, muscle thickness, nutrition control and body composition.	PE group ↑ in maximal strength on leg press (16 ± 8%) and leg extension (17 ± 11%), while the TRT group improved by 15 ± 9 and 11 ± 4%, respectively. The

	into 3 groups: TRT, PE, CO.		press, and the control (CON) group (n = 7) did not train. Participants were advised to maintain the cadence of 20 repetitions per minute (1s conc: 2s ecc) with 1 min of rest interval between sets.			thickness of the quadriceps muscles ↑ for both intervention groups. Specifically, the post-training thickness of the vastus lateralis was significantly higher for PE (55%) compared to the CO group. The TRT group presented a greater loss of total and thigh fat mass when compared with the PE method. These results were found in the presence of a lower training load for the PE group.

M = men; W = women; PE = pre-exhaustion; PER = pre-exhaustion, with an interval between isolated and multi-joint exercise; CO = control; TRT = traditional resistance training; conc./ecc. = concentric / eccentric; CSA = Cross-sectional area; kg = kilogram; cm = centimeters; RM = maximum repetition; FMM = momentary muscle failure; RF = rectus femoris; VL = vastus lateralis; VM = vastus medialis; VI = vastus intermedius; % RMS = percentage of root mean square; s = seconds.

Our search found only three studies that investigated the chronic effects of PE. All interventions lasted more than eight weeks and the assessments included measures of strength, hypertrophy and body composition. An important point that must be emphasized is that one of the three chronic studies investigated the effects of one set of exhaustive exercise performed before the training session with the same isolated exercise, the leg extension (2), which is not original proposal of the PE method. Furthermore, only two studies attempted to control nutritional intake (12,32), which raises the possibility of confounding results for measures of body composition and muscle hypertrophy.

DISCUSSION

Jones (16) claimed that to achieve desired results from PE, exercise order must be arranged so that a single-joint movement is carried out to muscular failure and then immediately ("not even two seconds of rest") followed by performance of a multi-joint exercise to muscular failure. Additionally, the load used in the isolated exercise should be light, so that "20, 30 or more repetitions" can be perform; and that the load usually used in the multi-joint exercise should be reduced by "approximately 50%". Jones (16) also recommends that the "point of failure" will not be reached due to the failure of the "weak link", but by the exhaustion of the target muscles; and, that a single set of this strategy, per training session, is necessary to start the application of the method, and no more than three sets per session would be sufficient for individuals experienced in this practice.

Arthur Jones suggested some combinations of exercises (that, according to him, could be used to train a specific muscular structure much harder than usually is with conventional exercises) as examples of the PE application: lateral dumbbell raise immediately prior to military press, and pullover immediately followed by pull-down. Although many of these strategies can be applied in training centers, respecting the transition time (such as the combination of free weights and machines); Jones himself developed a specific equipment, the "*Nautilus Compound Leg Machine*" (leg extension, and leg press, in the same equipment) and "*Nautilus double shoulder Machine*" (the lateral raise exercise, and an overhead press), that allowed to perform both single and multi-joint exercises with a simple change of position in the device - eliminating the need to move between different machines (9). In these examples, the PE principle was applied with a target muscle rather than a "weak link".

This discussion seems to be relevant for future studies about the PE method. Considering that, the selection of the exercises can directly interfere in the morphological adaptations of the target muscle itself (6). For example, while the bench press exercise is effective for the hypertrophy of the major pectoralis and triceps brachii (24), a greater hypertrophy for the major pectoralis is observed when compared to the triceps brachii, and it is not effective for the long head of the triceps brachii itself (6,24). In this case, the "lying triceps extension" could be used as PE, as additional stimuli for hypertrophy of the long head of the triceps brachii (6,36).

Half a century later, research have investigated the acute and chronic effects of several "pre-exhaustion" strategies, but none of these studies have reproduced the method as suggested by

Jones. Therefore, it is necessary to consider not only the findings from individuals studies on the topic, but also the employed PE routine (i.e. exercises used, load, transition interval) when attempting to draw conclusions from the available literature.

Surface EMG analysis can provide information about the effects of PE on muscle activation. It is necessary to consider that the aim of the PE method is to fatigue the "target muscle" by performing a single-joint exercise to failure, and then immediately thereafter performing a multi-joint exercise. Therefore, an increase in EMG amplitude of the target muscle would be expected as result of recruiting additional motor units, raising firing rates and/or synchronization (19,31). To the contrary, however, none of the reviewed studies observed this outcome. It also should be noted that the amplitude of the EMG cannot be used to predict or infer hypertrophic responses (34).

A condition that should be detached is the behavior of the EMG activity of the synergistic muscles during the execution of a multi-joint exercise, following the exhaustion of the agonist muscle; as observed in the studies from Gentil et al. (13) and Brennecke et al. (7). In these studies, the authors reported a higher activation of the triceps brachialis in the bench press, after the pre-exhaustion performed in the peck-deck/chest-fly. This tendency to a migration of the demand to the synergist muscle following the exhaustion of the agonist muscle as also suggested by Augustsson et al. (4), was called "muscle substitution". The possibility to use PE to increase the activation of the synergists muscles requires future investigations; including the chronic effects of the supposed phenomenon.

To note, there is a large variety of protocols in the above-mentioned studies. Although the studies used a short interval for the exercise transition (immediately after), Augustsson et al. (4) applied loads equivalent to 10RM for both exercises, different from the original proposal for the PE method. Gentil et al. (13), and Brennecke et al. (7) also used 10RM loads for both exercises (isolated and multi-joint). Future studies should consider the use of lower intensities in the isolated exercises, performed to failure, before the multi-joint exercises; as suggested by the original hypothesis of PE (16).

Golas et al. (14) investigated the EMG activity of the pectoris major, anterior deltoid, and triceps brachialis during sets of bench press at 95% of 1RM, before and after the PE of each one of these muscles in separated sessions. The authors reported a higher EMG activity of the triceps brachialis (adjusted by the % of the maximum isometric voluntary contraction) during the execution of the bench press performed after the exhaustion of the triceps brachialis, as compared with the bench press without the previous exhaustion of the triceps muscle. It is important to consider that the load as equivalent to 10RM, (approximately 70% of 1RM) to perform four sets of elbow extension with dumbbells, in a supine position, with a rest interval of 2 minutes between sets. The authors also used 5 minutes between the end of the last PE set and the beginning of the bench press. The original proposal for the PE method recommends a pre-exhaustive set at low load followed by an immediate transition to the multi-joint exercise, thus very different from the above-mentioned protocols.

To note, Guarascio et al. (15) pre-exhausted the elbow extensors and observed an increase in EMG of the pectoris major muscle during the bench press exercise (≤ 20 seconds following the exhaustive set). Loads for both exercises were set at 10RM. Soares et al. (29) did not observe any difference in pectoris major and triceps brachii EMG following two types of PE (elbow extension on the high pulley + bench press, or the reverse order). Again, this is not the original idea of PE, since triceps brachialis is the "weak point" during the multi-joint bench press exercise. Indeed, the demand imposed on the pectoralis major could be attenuated when the isolated exercise for the synergist muscle triceps brachii is performed before the bench press (6). Although the PE of the synergist muscles have been suggested by Tan (30), under the argument that other muscles, considered priority, would be more demanded on multi-joint exercises, more research is required to investigate the chronic effects of the PE of the synergist muscles on the hypertrophy of the primary muscles.

Although not intended to investigate the original version of the PE, Júnior et al. (26) found that one set of leg extension with 30% of 1RM and 60% of 1RM increased vastus lateralis activation during leg press exercise (60% of 1RM); without differences between protocols of PE. The training protocols were not designed to muscle failure in the exercises, limiting repetitions to fifteen. This is the unique study reporting an increase in the EMG of the agonist muscle activated in the isolated and multi-joint exercise. Thus, if the priority is to increase the EMG of the target muscle, it seems reasonable to apply a pre-activation set, before the multi-joint exercise, instead of a pre-exhaustive set.

Training volume is an important variable to increase strength and hypertrophy gains (11). Thus, some of the acute effects of the PE method on training volume could have applicability to long-term adaptations.

It is important to recognize that the use of PE method tends to decrease the volume reached in a multi-joint exercise. This behavior was observed in the studied from Augustson (4); Gentil et al. (13); Brennecke et al. (7); Vilaça-Alves et al. (35) and Soares et al. (29). In summary, if the same load is used in the multi-joint exercise (comparison between with and without PRE), a lower number of repetitions are completed (lower volume); while if the target is a certain number of repetitions to be reached, the load in the multi-joint exercise should be reduced [7;26]; as also suggested by Jones [5].

For the calculation of the total training volume future studies with PE should consider to sum the volume of the isolated and multi-joint exercises as proposed by Trindade et al. (32). This condition would be more fair in a comparison between traditional and PE protocols (23).

RPE has been proposed as practical tool to monitor RT load (20). Only one study investigating the PE method used the RPE. In the study of Vilaça-Alves et al. (35) the pre-exhaustion of the biceps brachialis promoted a decrease in the performance of the front lat pull-down exercise accompanied by a higher RPE. However, the protocol proposed by Vilaça-Alves et al. (35) did not reproduce the original version of the PE; either by the rest interval between the exercises (90s), or by the load used for the isolated exercise (70% of 1RM). Future studies should try to investigate the original proposal of the PE, and to evaluate the global load of the training session by RPE.

Advanced RT methods such as PE are strategies used by coaches, weightlifters, and bodybuilders to maximize gains in strength and muscle hypertrophy (3). Although Aguiar et al. (2) used the same exercise for the pre-exhaustive set (leg extension), and for the remaining sets, this study raised important points to be considered. The inclusion of one exhaustive set with 20% of 1RM, immediately (30s) before high load sets, resulted in superior gains in muscle strength (leg extension 1RM). To note, the use of an isolated exercise for pre-exhaustion plus the same exercise for the following sets is not the original idea of the PE.

Fisher et al. (12) concluded that the inclusion of PE to a RT program was not more advantageous for strength gains as compared to traditional RT. However, the authors used the maximum number of repetitions with a submaximal load as a strength measure, while this would better reflect muscle endurance. Moreover, there was no mention to test and retest reliability.

In the study from Trindade et al. (32), there was no difference between PE versus traditional RT for the gains in strength (leg press and leg extension), despite the higher total training volume achieved in the traditional protocol. The higher effect size for gains in strength for the leg extension in PE may be explained by the use of this specific exercise, which was not used in the traditional group. The absence of differences in 45°leg press maximal strength may be associated with the untrained status of the subjects in the previous six months, for which muscle failure would not be necessary to increase muscle strength (22).

Of the two studies that investigated the effects of the PE method on body composition, only the study from Trindade et al. (32) provided a nutritional control during the intervention. This should be considered as an important confounding variable in the study from Fisher et al. (12).

Fisher et al. (12) utilized a sample composed by men and women to investigate the chronic effects of the PE, and concluded that there was no difference between conditions on body mass, lean body mass, and fat mass. The authors used plethysmography to estimate body composition, without any evaluation of body segments, or target muscles. Trindade et al. (32) used dual-energy x-ray absorptiometry (DXA) to analyze body composition and had nutritional control. The higher total training volume may have been advantageous to reduce body fat percentage (total body and lower limb), and to increase lean body mass (total body), while both PE and traditional RT displayed similar increase in lower limb lean mass.

Only two studies evaluated measures of hypertrophy and both reported nutritional control. Aguiar et al. (2) evaluated the muscle cross-sectional are (CSA) from quadriceps muscles by magnetic resonance. Both training protocols resulted in muscle hypertrophy, while the inclusion of a pre-exhaustive set was more effective to increase the CSA of the quadriceps muscles (vastus lateralis, vastus intermedius, vastus medialis, and rectos femoris). Although the protocol did not reproduce the original hypothesis of the PE method, this study reveals an effective strategy of a pre-exhaustive set at low load, with subsequent sets at high load.

Trindade et al. (32) used ultrasound measured to evaluate muscle thickness of vastus lateralis, vastus medialis, rectus femoris (proximal and distal measures for each muscle), and gluteus maximus muscles. There was no difference between protocols, while the group submitted to PE displayed a higher magnitude (large: 2.12) in the proximal region of the vastus lateralis versus the control group (trivial: 0.40). There was no increase in gluteus maximus thickness, regardless of the intervention group.

The combination of isolated exercises at low load with high load multi-joint exercises seems to be interesting for the selective hypertrophy of the quadriceps. It is important to mention that the subjects were experienced in RT, while they were six months without training in the moment of the intervention. Moreover, the PE method was designed to intensify the training of highly trained subjects, and the influence of the method in this population needs to be investigated.

In the study from Aguiar et al. (2), an additional exhaustive set increased the total training as compared to a traditional training without the pre-exhaustive set, while there was no difference in the training volume from both groups in the three sets with 75% of 1RM (leg extension). To note, the authors did not aim to test the initial hypothesis of the PE, but to analyze the inclusion of a pre-exhaustive set in the same exercise (leg extension) with 20% of 1RM, just before traditional high load sets. The rest interval between the exhaustive set and the traditional sets was 30 seconds, and this transition may have been sufficient to maintain the performance in the three subsequent sets (3 sets of 8-12 repetitions at 75% of 1RM, with 1 minute of rest between them).

On the other hand, the study from Trindade et al. (32) revealed that the PE protocol resulted in a lower total training volume (number of repetitions X sets X load), even with the sum of the volume obtained in the isolated exercise (leg extension) for the PE group. This result seems to be consistent with the application of the method, while in this condition a reduction in the volume would be expected after the execution of pre-exhaustion exercise. To note, the decrease in the total training volume did not impair gains in strength and muscle mass.

From a general perspective, the review showed that regardless of the PE protocols that did not follow the initial proposition idealized by Jones, the chronic results of the studies by Aguiar et al. (2) and Trindade et al. (32) were promising for hypertrophy and strength. PE in the way that both studies proposed demonstrated significant increases in muscle strength and hypertrophy. Therefore, we can suggest that adding a low load set to the main exercise results in hypertrophy and muscle strength gains; while these results are fairly superior or similar.

Future research should consider more specific criteria to define the sample characteristics; like current uninterrupted training time, time of detraining, previous training experience, exercise technique, and strength level (17); as the PE method was initially designed for trained individuals. At this point, there is a lack for evidence for the use of the PE in highly advanced individuals, bodybuilders or women.

Finally, considering the variety of the proposed methodologies, the literature still lacks sufficient evidence to substantiate the usefulness and effectiveness of the PE method compared with traditional resistance training models, especially with regard to its chronic effects on strength gains, muscle hypertrophy and eventual changes in body composition. Further investigations are necessary with strict control of the suggested variables. Furthermore, the use of some of the methodological variables suggested in the original model of the method; the transition time between the exercises and the loads used in each one requires further clarification, so that the method can be used in conventional training centers.

REFERENCES

1. ACSM. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sport Exerc 687–708, 2009.

2. Aguiar AF, Buzzachera CF, Pereira RM, Sanches VC, Januário RB, da Silva RA, et al. A single set of exhaustive exercise before resistance training improves muscular performance in young men. Eur J Appl Physiol 115(7): 1589–1599, 2015.

3. Angleri V, Ugrinowitsch C, Libardi CA. Are resistance training systems necessary to avoid a stagnation and maximize the gains muscle strength and hypertrophy? Sci Sports 35(2): 65, 2020.

4. Augustsson J, Thomeé R, Hörnstedt P, Lindblom J, Karlsson J, Grimby G. Effect of pre-exhaustion exercise on lower-extremity muscle activation during a leg press exercise. J Strength Cond Res 17(2): 411–416, 2003.

5. Bird SP, Tarpenning KM, Marino FE. Designing resistance training programmes to enhance muscular fitness. Sport Med 35(10): 841–851, 2005.

6. Brandão L, de Salles Painelli V, Lasevicius T, Silva-Batista C, Brendon H, Schoenfeld BJ, et al. Varying the order of combinations of single-and multi-joint exercises differentially affects resistance training adaptations. J Strength Cond Res 34(5): 1254–1263, 2020.

7. Brennecke A, Guimarães TM, Leone R, Cadarci M, Mochizuki L, Simão R, et al. Neuromuscular activity during bench press exercise performed with and without the preexhaustion method. J Strength Cond Res 23(7): 1933–1940, 2009.

8. Carpinelli R. Does the sequence of exercise in a resistance training session affect strength gains and muscular hypertrophy? A critical examination of the evidence. Med Sport 17(1): 37–50, 2013.

9. Carpinelli RN. A Critical Analysis of the Claims for Inter-Set Rest Intervals, Endogenous Hormonal Responses, Sequence of Exercise, and Pre-Exhaustion Exercise for Optimal Strength Gains in Resistance Training. Med Sport 14(3): 126–156, 2010.

10. Carpinelli RN. Critical Commentary on the Stimulus for Muscle Hypertrophy in Experienced Trainees. Med Sport Pract 21(1): 1-37, 2020.

11. Figueiredo VC, de Salles BF, Trajano GS. Volume for Muscle Hypertrophy and Health Outcomes: The Most Effective Variable in Resistance Training. Sport Med 48(3): 499-505, 2018.

12. Fisher JP, Carlson L, Steele J, Smith D. The effects of pre-exhaustion, exercise order, and rest intervals in a full-body resistance training intervention. Appl Physiol Nutr Metab 39(11): 1265-1270, 2014.

13. Gentil P, Oliveira E, De V, Rocha AJ, Nior J, Carmo J Do, et al. Effects of Exercise Order on Upper-Body Muscle Activation and Exercise Performance. J Strength Cond Res 21(4): 1082–1086, 2007.

14. Golas A, Maszczyk A, Pietraszewski P, Stastny P, Tufano JJ, Zajac A. Effects of pre-exhaustion on the patterns of muscular activity in the flat bench press. J Strength Cond Res 31(7): 1919–1924, 2017.

15. Guarascio MJ, Penn C SC. Effects of Pre-Exhaustion of a Secondary Synergist on a Primary Mover in a Compound Exercise. J Exerc Sport Orthop 3(1): 1–4, 2016.

16. Jones A. The Pre-Exhaustion Principle. Naut Train Princ Bull No 1, Available at: http://www.arthurjonesexercise.com/Bulletin1/37.PDF (accessed May 12, 2017), 1971.

17. Junior E, de Salles BF, Dias I, Ribeiro AS, Simão R, Willardson JM. Classification and determination model of resistance training status. Strength Cond J 43(5): 77-86, 2021.

18. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing muscle hypertrophy: A systematic review of advanced resistance training techniques and methods. Int. J. Environ. Res. Public Health 16(24) 4897, 2019.

19. Latasa I, Cordova A, Quintana-Ortí G, Lavilla-Oiz A, Navallas J, Rodriguez-Falces J. Evaluation of the Electromyography Test for the Analysis of the Aerobic-Anaerobic Transition in Elite Cyclists during Incremental Exercise. Appl Sci 9(3): 589, 2019.

20. McGuigan MR, Foster C. A new approach to monitoring resistance training. Strength Cond J 26(6): 42, 2004.

21. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1, 2019.

22. Nóbrega SR, Libardi CA. Is resistance training to muscular failure necessary? Front. Physiol. 7: 10, 2016.

23. Nunes JP, Kassiano W, Costa BD V, Mayhew JL, Ribeiro AS, Cyrino ES. Equating Resistance-Training Volume Between Programs Focused on Muscle Hypertrophy. Sport Med 1–8, 2021.

24. Ogasawara R, Yasuda T, Ishii N, Abe T. Comparison of muscle hypertrophy following 6-month of continuous and periodic strength training. Eur J Appl Physiol 113(4): 975–985, 2013.

25. Prestes J, de Almeida JA, Vieira DCL, Tibana RA. Discussion of "The effects of pre-exhaustion, exercise order, and rest intervals in a full-body resistance training intervention"--Pre-exhaustion exercise and neuromuscular adaptations: an inefficient method? Appl Physiol Nutr Metab = Physiol Appl Nutr métabolisme 40(8): 850–851, 2015.

26. Rocha Júnior VA, Bottaro M, Pereira MCC, Andrade MM, P Júnior PRW, Carmo JC. Electromyographic analyses of muscle pre-activation induced by single joint exercise. Rev Bras Fisioter 14(2): 158–165, 2010.

27. Schoenfeld B, Fisher J, Grgic J, Haun C, Helms E, Phillips S, et al. Resistance Training Recommendations to Maximize Muscle Hypertrophy in an Athletic Population: Position Stand of the IUSCA. Int J Strength Cond 1(1), 2021.

28. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. J Strength Cond Res 24(10): 2857-2872, 2010.

29. Soares EG, Brown LE, Gomes WA, Corrêa DA, Serpa ÉP, da Silva JJ, et al. Comparison between pre-exhaustion and traditional exercise order on muscle activation and performance in trained men. J Sport Sci Med 15(1): 111–117, 2016.

30. Tan B. Manipulating Resistance Training Program Variables to Optimize Maximum Strength in Men: A Review. J Strength Cond Res 13(3): 289–304, 1999.

31. Toro SF Del, Santos-Cuadros S, Olmeda E, Álvarez-Caldas C, Díaz V, San Román JL. Is the Use of a Low-Cost sEMG Sensor Valid to Measure Muscle Fatigue? Sensors 19(14): 3204, 2019.

32. Trindade TB, Prestes J, Neto LO, Medeiros RMV, Tibana RA, de Sousa NMF, et al. Effects of Pre-exhaustion Versus Traditional Resistance Training on Training Volume, Maximal Strength, and Quadriceps Hypertrophy. Front Physiol 10: 1424, 2019.

33. Vigotsky AD, Halperin I, Lehman GJ, Trajano GS, Vieira TM. Interpreting signal amplitudes in surface electromyography studies in sport and rehabilitation sciences. Front. Physiol 8: 985, 2018.

34. Vigotsky AD, Ogborn D, Phillips SM. Motor unit recruitment cannot be inferred from surface EMG amplitude and basic reporting standards must be adhered to. Eur J Appl Physiol 116(3): 657–658, 2016.

35. Vilaça-Alves J, Geraldes L, Fernandes HM, Farjalla R, Saavedra F, Reis VM. Effects of Pre-Exhausting the Biceps Brachii Muscle on the Performance of the Front Lat Pull-Down Exercise Using Different Handgrip Positions. J Hum Kinet 42: 157–163, 2014.

36. Wakahara T, Fukutani A, Kawakami Y, Yanai T. Nonuniform muscle hypertrophy: Its relation to muscle activation in training session. Med Sci Sports Exerc 45(11): 2158–2165, 2013.