International Journal of EXERCISE SCIENCE

Original Research

Multi-joint vs. Single-joint Resistance Exercises Induce a Similar Strength Increase in Trained Men: A Randomized Longitudinal Crossover Study

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ABSTRACT

International Journal of Exercise Science 13(4): 1677-1690, 2020. The type of exercise is a relevant resistance training-variable that might be manipulated in order to induce significant increases in muscle strength. The aim of this study was to analyze the influence of multi-joint vs single-joint resistance exercises on maximal strength. Sixteen resistance-trained men (age: 23.1 ± 4.4 years; body mass: 86.0 ± 12.8; height: 177.9 ± 6.4 cm; training experience: 4.2 ± 3.4 years) performed one of the following training protocols for six weeks: MULTI, consisting of only multi-joint exercises or SINGLE, consisting of only single-joint exercises. Subjects were then submitted to a three-week washout period, before being submitted to the other protocol for another six weeks. A linear periodization model was adopted in which external load was increased and the repetition range was decreased every two weeks. Maximal dynamic strength of bench press ($1RM_{BENCH}$) and squat exercises ($1RM_{SQUAT}$), a percentage variation of total load lifted (ΔTLL) and internal training load (ITL) were measured. Similar increases in $1RM_{BENCH}$ (MULTI: 10.8%, $p < 0.001$; SINGLE: 5.5%, $p < 0.001$) and $1RM_{SQUAT}$ (MULTI: 19.7%, $p < 0.001$; SINGLE: 19.0%, $p < 0.001$) were observed after the MULTI and SINGLE protocols. A decrease in TLL was detected for both exercise protocols; however, the SINGLE protocol induced a greater decrease, compared to the MULTI protocol (-35 ± 11% vs -42 ± 5%, respectively; $p = 0.026$). A greater ITL for the MULTI was observed when compared to the SINGLE (12.1%; $p < 0.001$). In conclusion, resistance training protocols with different exercise modalities seem to produce similar strength increases in resistance-trained men.

KEY WORDS: Muscle strength, resistance training, compound exercise, isolation exercise, exercise selection

INTRODUCTION

Muscular strength can be defined as the capacity to produce force (5). The development of this physical capacity enhances the performance of many physical tasks that are relevant for both quality of life and sports (3, 27). It is well established that the regular practice of resistance training (RT) can significantly increase muscular strength (1). Muscular strength is maximized by the appropriate manipulation of RT variables such as intensity, volume, frequency, rest interval, movement velocity, selection and order of exercises, muscular actions and range of motion (1).

One of the variables that has evoked a great deal of interest is the type of exercise employed (12). Generally, resistance exercise can be classified according to the number of joints involved in a specific movement, and resistance exercises are commonly named as multi-joint (MULTI) or single-joint (SINGLE) exercises (13). Multi-joint exercises have traditionally been viewed as more effective than single-joint exercises for increasing maximal strength, muscle activation, metabolic stress and to more closely mimic daily tasks and sports-specific movement patterns (1, 23). In contrast, single-joint exercises have been suggested as beneficial owing to reduced technical and coordinative demands (6, 25). Additionally, single-joint exercises may be better suited for targeting specific muscles and correcting imbalances between muscle groups compared to multi-joint exercises (12, 20). Although the nature of the exercise may affect the neuromuscular adaptations, this topic is still under investigated, especially in resistance-trained individuals.

Gentil et al. described a similar improvement in elbow flexor strength following protocols containing exclusively MULTI vs SINGLE exercises in untrained men after ten weeks (13). Similar results were also reported by Barbalho et al. and Gentil et al., in which untrained participants submitted to a MULTI plus SINGLE program showed no additional increment in strength compared to an only MULTI training protocol (2, 14). In addition, Giannakopoulos et al. reported a greater increase in internal and external rotation peak torque for MULTI vs. SINGLE groups (15). However, a lower number of sets was performed for the latter during the intervention period, which limits inferences about the real effects of the type of exercises in strength outcomes. Indeed, the data collection of the total training volume performed during RT-interventions may represent a relevant tool in order to better understand eventual distinct responses induced by MULTI and SINGLE protocols, since this variable seems to strongly influence muscular adaptations induced by a training program (19). However, the analysis of the influence of chronic protocols of different types of exercise and neuromuscular adaptations is lacking in trained individuals.

Thus, the purpose of the present study is to verify the effects of performing different resistance-training protocols (MULTI vs SINGLE) on neuromuscular performance in resistance-trained men. The initial hypothesis is that a MULTI protocol will induce a greater strength gain compared to the SINGLE protocol, since a greater muscle mass is activated and a higher absolute load is implemented in such exercises, which in turn, could maximize motor unit recruitment and force production.

METHODS

The intervention period lasted for 19 weeks. On week one, each subject performed one-repetition maximum (1RM) tests twice (test and re-test, separated by 48 hours) employing barbell back squat ($1RM_{SQUAT}$) and barbell bench press ($1RM_{BENCH}$) exercises, in order to measure lower and upper limb maximal strength, respectively. Subsequently, according to baseline relative strength values, volunteers were randomly allocated into one of the following training protocols: MULTI (consisting of exclusively multi-joint exercises) or SINGLE (consisting of exclusively single-joint exercises). The following day (24-hr afterwards), all subjects were familiarized with standard procedures adopted in all RT exercises, such as body position, cadence, range of motion, and rest between sets and exercises. On weeks two to seven (microcycles 1-6), all subjects were submitted to the experimental protocol (Table 1). The same strength tests ($1RM_{SQUAT}$ and $1RM_{BENCH}$) used in week one were performed on week eight. Subjects were then exposed to a washout period (weeks nine to eleven). 1RM tests were performed again on week twelve and groups were then crossed, so that all subjects who had previously performed MULTI were allocated to the SINGLE protocol, and vice versa (microcycles 1-6). Finally, on week 19, 1RM tests were performed again. Subjects were instructed to abstain from any other exercise program during the intervention period. All tests were supervised by the same researcher. The Total Load Lifted (TLL) and the Internal Training Load (ITL) were calculated for every RT session in order to compare the accumulated external and internal training load between experimental groups and during the intervention period.

Participants

Sixteen Caucasian, resistance-trained men (age: 23.1 ± 4.4 [range 18-35] years; total body mass: 86.0 ± 12.8 kg; height: 177.9 ± 6.4 cm; body mass index: 27.4 ± 7.2 Kg/m^2; training experience: 4.2 ± 3.4 years) participated in this randomized crossover design study. The sample size was established by a priori power analysis based on a pilot study, where the $1RM_{SQUAT}$ was assessed as the outcome measure with a target effect size difference of 0.75, an alpha level of 0.05, and a power ($1-\beta$) of 0.80 (10). All subjects were resistance-trained, performing RT on a minimum of three days per week for at least one year at the University's RT Gym. All subjects had regularly performed all exercises utilized in the training intervention and the strength tests (minimum frequency of once a week) for at least one year before entering the study. Moreover, subjects were free from any existing musculoskeletal disorders, had no history of injury with residual symptoms (pain, "giving-away" sensations) in the trunk, upper and lower limbs within the last year and stated that they had not taken anabolic steroids or any other illegal agents known to increase muscle size at the time or during the previous year. Thus, participation in the study required the subjects to answer negatively to all questions in the Physical Activity Readiness Questionnaire (PAR-Q) and have a minimum 1RM parallel back squat of 1.25x total body mass and a 1RM bench press of at least equal to total body mass (19). This study was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science and all subjects read and signed an informed consent document, approved by the Methodist University of Piracicaba Research Ethics Committee (#19/13) (22).

Protocol

The MULTI and SINGLE protocols are outlined in Table 1. Three weekly sessions, interspaced by 48 hours (Monday, Wednesday and Friday), were performed for six weeks in each training protocol. A linear periodization model was adopted, in which external overload was increased and the repetition range was decreased every two weeks. For the first two weeks, volunteers performed three sets of 10-12 maximum repetitions (RM). On the following two weeks, three sets of 8-10 RM were adopted. Finally, for the last two weeks, three sets of 4-6RM were performed. Subjects were instructed to perform concentric and eccentric phases for two seconds each. All sets were carried out to the point of voluntary concentric failure, defined as the inability to perform another concentric repetition while maintaining adequate technique. The external overload was adjusted for each exercise, as needed, on successive sets to ensure that subjects achieved failure in the target repetition range. One to two minutes were adopted for passive recovery between sets and exercises, respectively. All training sessions were directly supervised by the research assistants to ensure the correct performance of the respective routines. All participants received a standardized verbal encouragement during each training session. Subjects were instructed to fill in a training log, describing external load data and repetitions performed for every exercise. Before the training intervention period, all subjects underwent 10RM testing to determine individual initial training loads for each exercise (16). Attempts were made to progressively increase the load lifted each week while maintaining the target repetition range. No injuries were reported and the adherence to the program was 100% for all groups.

Table 1. Training protocols for experimental conditions.

	Microcycles 1-2	Microcycles 3-4	Microcycles 5-6
MULTI (n=16)	3x8-12RM	3x8-10RM	3x4-6RM
	Barbell Bench press	Barbell Bench Press	Barbell Bench Press
	Inclined Barbell Bench Press	Inclined Barbell Bench Press	Inclined Barbell Bench Press
	Inclined Barbell Row	Inclined Barbell Row	Inclined Barbell Row
	Lat Pulldown	Lat Pulldown	Lat Pulldown
	Parallel Barbell Back Squat	Parallel Barbell Back Squat	Parallel Barbell Back Squat
SINGLE (n=16)	3x8-12RM	3x8-10RM	3x4-6RM
	Dumbbell flat fly	Dumbbell flat fly	Dumbbell flat fly
	Peck Deck	Peck Deck	Peck Deck
	Straight-arm Cable Pulldown	Straight-arm Cable Pulldown	Straight-arm Cable Pulldown
	Dumbbell reverse fly	Dumbbell reverse fly	Dumbbell reverse fly
	Leg Extension	Leg Extension	Leg Extension

Note. MULTI = multi-joint exercises condition; SINGLE = single-joint exercises condition

Upper and lower-body maximum strength were assessed by 1RM testing in the bench press ($1RM_{BENCH}$) and parallel back squat ($1RM_{SQUAT}$) exercises. Subjects refrained from any exercise other than activities of daily living for at least 48 hours before baseline testing and at least 48 hours before testing after the study. Maximum strength testing was consistent with recognized guidelines, as established by Haff and Triplett (16). Before testing, subjects performed a general warm-up consisting of five minutes of cycling (Schwinn; AC Sport, Vancouver, Washington, USA) at 60-70 rpm and 50w. Subsequently, a specific warm-up set of the given exercise of five repetitions was performed at ~50% of 1RM, followed by one to two sets of 2–3 repetitions at a load corresponding to ~60–80% of 1RM. Participants then performed sets of one repetition of increasing weight for 1RM determination. The external load was adjusted by ~5-10% in subsequent attempts until the subject was unable to complete one maximal muscle action. The 1RM was considered as the highest load lifted. A three to five-minute rest was employed between each successive attempt. All 1RM determinations were performed within five attempts.

Successful $1RM_{BENCH}$ was achieved if the subject displayed a 5-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor), lowered the bar to touch his chest, and executed full elbow extension. The grip width was standardized at 200% of biacromial width. In the $1RM_{SQUAT}$, subjects were required to squat down so that the top of the thigh was parallel to the ground (~90 degrees of knee joint flexion) for the attempt to be considered successful, as determined by a research assistant who was positioned laterally to the subject. The participant's feet were always positioned at hip-width apart.

The $1RM_{BENCH}$ testing was conducted before the $1RM_{SQUAT}$ with a 20-minute rest period separating tests. Strength testing was carried out using free weights. Recordings of feet and hand placement were made during familiarization strength testing and then used for pre- and post-intervention performance tests, as well as at all training sessions. All testing sessions were supervised by the research team to achieve a consensus for success on each attempt and were performed at the same period of the day (6:00–8:00p.m). All participants received a standardized verbal encouragement during the tests. The test-retest intraclass correlation coefficient (ICC), coefficient of variation (CV) and the typical error of the measurement (TEM), calculated from the data collected during the familiarization period and the pre-intervention period for $1RM_{BENCH}$, were 0.989, 0.8% and 2.05 kg, respectively. The ICC, CV and TEM for $1RM_{SQUAT}$ were 0.990, 0.7% and 1.95 kg, respectively.

Total load lifted (TLL = sets x repetitions x external load [kgf]) was calculated from training logs filled out by the research assistants for every RT session. Only repetitions performed through a full range of motion were included for analysis. The ΔTLL described the relative (%) difference in the TLL between microcycle 6 and microcycle 1 (e.g. TLL in the microcycle 6 minus the TLL in the microcycle 1).

Subjects reported their session-RPE (sRPE), according to the OMNI-Resistance Exercise Scale (OMNI-RES), validated to measure RPE in RT (24). Subjects were shown the scale ten minutes after each session and asked: "How intense was your session?" and were instructed to make certain that their RPE referred to the intensity of the whole session, rather than to the most recent exercise intensity (8). The internal training load (ITL) for each session was calculated by multiplying the total number of repetitions performed in the session by the sRPE (26). Total ITL (ITL_{TOTAL}) was the sum of all RT weeks. Data are expressed in arbitrary units (A. U.).

Statistical Analysis

The normality and homogeneity of the variances were verified using the Shapiro-Wilk and Levene tests, respectively. The mean, standard deviation (SD), 90% and 95% confidence intervals (CI) were used after data normality was assumed. Dependent t-tests were used to compare mean values of the $1RM_{BENCH}$ and $1RM_{SQUAT}$ between-groups (MULTI-SINGLE and SINGLE-MULTI) at pre-intervention before washout (BEFORE) and pre-intervention after washout (AFTER); ΔTLL (week six–week one) and ITL_{TOTAL} between-conditions (MULTI vs. SINGLE). Additionally, dependent t-tests were used to compare mean values of the $1RM_{BENCH}$ and $1RM_{SQUAT}$ within-groups at post-intervention period before washout (week eight) versus at pre-intervention period after washout (week twelve). A 2x2 repeated measures ANOVA (interaction conditions [MULTI and SINGLE] × time [pre- vs. post-intervention]) was used to compare the dependent variables, $1RM_{BENCH}$ and $1RM_{SQUAT}$. Post-hoc comparisons were performed with the Bonferroni test (with correction). Assumptions of sphericity were evaluated using Mauchly's test. Where sphericity was violated ($p < 0.05$), the Greenhouse–Geisser correction factor was applied. In addition, effect sizes were evaluated using a partial eta squared (η^2_p), with < 0.06, 0.06-0.14, and > 0.14, indicating a small, medium, and large effect, respectively (28). The effect size (*d*) in absolute difference (pre vs post 6-week) was calculated in raw values of the variables using the standardized difference, based on Cohen's d units by means (*d*-value) (9). The *d* result was qualitatively interpreted using the following thresholds: < 0.2; trivial, 0.2 - 0.6; small, 0.6 - 1.2; moderate, 1.2 - 2.0; large, 2.0 - 4.0; very large, and > 4.0; extremely large. If the 90% confidence limits were overlapped (within- and between-group), small positive and negative values for the magnitude were deemed unclear; otherwise, this magnitude was deemed to be the observed magnitude (17). The smallest worthwhile change (SWC) in the $1RM_{BENCH}$ and $1RM_{SQUAT}$ was calculated by the formula SWC = typical error of measurement (TEM) x 90% confidence intervals (CI) (7). Hence, the TEM was multiplied by 1.746 to establish the 90%CI, according to the distribution of probability for t(16) as $p < 0.10$; i.e. degrees of freedom (DF - 16). The TEM for these measurements were 2.05 and 1.95 kg for $1RM_{BENCH}$ and $1RM_{SQUAT}$, respectively (4). SWC was used as a trivial area (gray bar) of the smallest true individual change of subjects (17). All analyses were performed using SPSS-22.0 software (IBM Corp., Armonk, NY, USA). An alpha of 5% was used to determine statistical significance.

RESULTS

No significant between-group difference was noted at any baseline time for $1RM_{BENCH}$ (AFTER, $p = 0.604$ and BEFORE, $p = 0.676$) and $1RM_{SQUAT}$ (AFTER, $p = 0.749$ and BEFORE, $p = 0.575$). Additionally, a significant reduction between week eight (post-intervention before wash-out) and week 12 (pre-intervention after wash-out) was observed for $1RM_{BENCH}$ and $1RM_{SQUAT}$ in both groups (MULTI-SINGLE and SINGLE-MULTI, all $p < 0.05$), indicating that the wash-out period was sufficient to cause reductions in strength levels.

A significant main effect of time ($F_{1,30}$ = 70.266, p < 0.001, η^2_p = 0.701), and a condition x time interaction ($F_{1,30}$ = 7.547, p = 0.010, η^2_p = 0.201) were observed for $1RM_{BENCH}$. Both conditions showed a significant increase from baseline to post-intervention of 10.4 ± 5.2 kg, 95% confidence interval [$CI_{95\%}$] = 8.2 - 12.7 kg (Δ% = 10.8, p < 0.001, d = 0.60 [$CI_{90\%}$ = 0.32 - 0.88]) and 5.0 ± 5.1 kg [$CI_{95\%}$= 2.8 - 7.2 kg] (Δ% = 5.5, p < 0.001, d = 0.32 [$CI_{90\%}$ = 0.17 - 0.47]) for the MULTI and SINGLE protocols, respectively (Table 2). Post-hoc analysis showed no significant difference between groups at the pre- (p = 0.965) and post-intervention times (p = 0.431). The effect size in absolute difference (post six weeks - pre) was moderate between the MULTI vs SINGLE protocols (d = 1.06 [$CI_{90\%}$ = -1.2 - 3.3]) (Figure 1).

A significant main effect of time ($F_{1,30}$ = 134.094, p < 0.001, η^2_p = 0.817), but no condition x time interaction ($F_{1,30}$ = 0.010, p = 0.922, η^2_p = 0.000) was observed for $1RM_{SQUAT}$. Both conditions showed a significant increase from baseline to post-intervention of 22.3 ± 9.7 kg [$CI_{95\%}$ = 18.1 - 26.4 kg] (Δ% = 19.7, p < 0.001, d = 1.07 [$CI_{90\%}$ = 0.57 - 1.60]) and 21.9 ± 11.8 kg [$CI_{95\%}$ = 16.8 - 26.9 kg] (Δ% = 19.0, p < 0.001, d = 1.06 [$CI_{90\%}$ = 0.57 - 1.60]) for the MULTI and SINGLE protocols, respectively (Table2). The effect size in absolute difference (post 6 weeks - pre) was trivial between the MULTI vs SINGLE protocols (d = 0.03 [$CI_{90\%}$ = -0.22 - 0.28]) (Figure 1).

Figure 1 shows individual comparisons between participants for the absolute 1RM difference from pre to post. The MULTI protocol presented a higher number of participants that benefited in the $1RM_{BENCH}$, when compared to the SINGLE protocol (ten vs two subjects, respectively). The MULTI and SINGLE protocols presented the same number of participants that benefited in the $1RM_{SQUAT}$ (15 subjects). The difference variation observed ranged from 0 to 22 kg for the $1RM_{BENCH}$ and 0 to 37 kg for the $1RM_{SQUAT}$ in the MULTI protocol and from 0 to 12 kg for the $1RM_{BENCH}$ and from 4 to 40 kg for the $1RM_{SQUAT}$ in the SINGLE protocol.

Table 2. Pre and Post Muscle Strength measures.

Variables	Pre (Mean±SD) [$CI_{95\%}$]	Post (Mean±SD) [$CI_{95\%}$]	Δ%	Cohen (ES) *d value* [$CI_{90\%}$]	ANOVA 2x2 Time *P value*	ANOVA 2x2 Time*Group *P value*
$1RM_{BENCH}$ (kg)						
MULTI	91.3 ± 15.9 [83.5 - 99.0]	101.1 ± 17.0* [92.8 - 109.4]	10.8	0.60 [0.32 - 0.88]	<0.001	0.010
SINGLE	91.5 ± 15.8 [83.8 - 99.2]	96.5 ± 15.8* [88.8 - 104.2]	5.5	0.32 [0.17 - 0.47]	<0.001	
$1RM_{SQUAT}$ (kg)						
MULTI	113.1 ± 18.2 [104.2 - 122.0]	135.4 ± 23.3* [124.0 - 146.8]	19.7	1.07 [0.57 - 1.60]	<0.001	0.922
SINGLE	115.1 ± 19.7 [105.5 - 124.8]	137.0 ± 21.4* [126.5 - 147.5]	19.0	1.06 [0.57 - 1.60]	<0.001	

Note. MULTI = multi-joint exercises condition; SINGLE = single-joint exercises condition; $1RM_{BENCH}$ = one maximal repetition test in bench press exercise; $1RM_{SQUAT}$ = one maximal repetition test in parallel back squat exercise; d = Effect Size. *Significantly greater than the corresponding pre-intervention value (P <0.05).

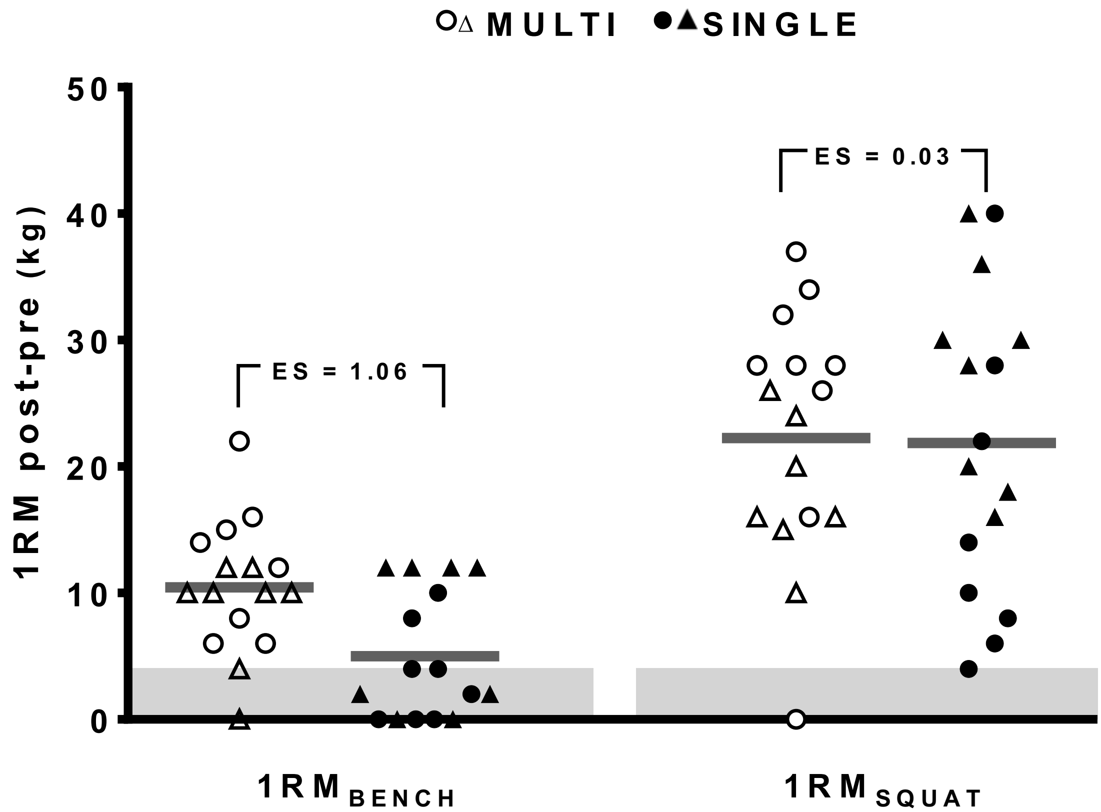

Figure 1. Univariate scatterplot with means of absolute difference from pre to post in 1RM test for the bench press ($1RM_{BENCH}$) and parallel barbell back squat ($1RM_{SQUAT}$) exercises for MULTI (withe circles and triangles) s and SINGLE (black circles and triangles) conditions. Trivial grey areas were the smallest worthwhile change (SWC) (see methods). Circles represent MULTI-SINGLE (received MULTI intervention first) and triangles SINGLE-MULTI (received SINGLE intervention first).

A greater decrement in TLL (ΔTLL) was observed in the SINGLE protocol, when compared to the MULTI protocol: -42 ± 5% *versus* -35 ± 11%, respectively (p = 0.026, d = 0.83 [$CI_{90\%}$ = 0.23 - 1.40]) (Figure 2). A significant difference between conditions was noted, with a greater ITL_{TOTAL} for the MULTI protocol, when compared to the SINGLE protocol: 14700 ± 900 A. U. *versus* 13117 ± 1141 A. U., respectively (Δ% = 12.1, p < 0.001, d = 1.54 [$CI_{90\%}$ = 0.82 - 2.30]) (Figure 2).

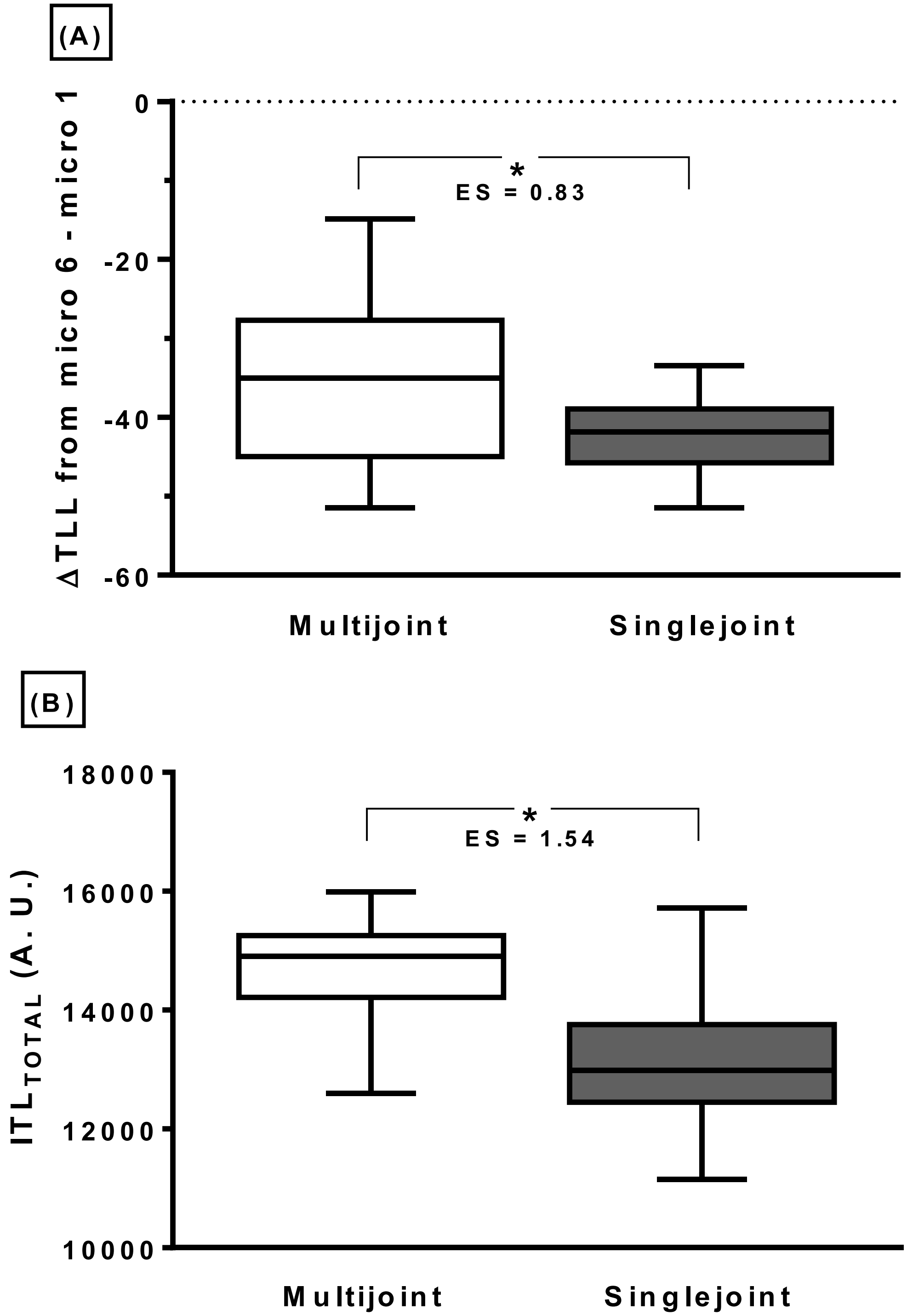

Figure 2. Delta (Δ) relative (%) differences of the TLL at microcycle 6 minus microcycle 1 (A). Total internal training load (ITL_{TOTAL}) during intervention training period (B). *Significant difference between conditions ($p < 0.05$).

DISCUSSION

The aim of the present study was to analyze the chronic effects of two different resistance training protocols that differed in the type of exercises performed (multi-joint vs single-joint exercises). The main finding of the current study was that both protocols produced a similar strength increment. In addition, a greater ΔTLL decrement and lower ITL was observed for the SINGLE protocol.

A significant increase from pre- to post-intervention periods was observed for both groups, but no difference between groups was noted for the $1RM_{BENCH}$ and $1RM_{SQUAT}$ tests. These results do not support the initial hypothesis and corroborate data from Gentil et al., who showed a similar improvement in elbow flexor strength for MULTI vs SINGLE (13). Despite the fact that the overall percentage increases were similar in the two studies (11.1% for Gentil et al. and 11.2% for the present study), comparisons between these two interventions should be made with some caution, since the present study assessed maximal strength of upper limbs through a 1RM test with a bench press exercise, whereas Gentil et al. used an isokinetic dynamometer in order to measure peak torque of elbow flexors (13). Additionally, differences in subjects' training levels between these two studies should be highlighted (untrained vs trained subjects).

Barbalho et al. and Gentil et al. aimed to verify whether adding SINGLE exercises to an exclusive MULTI exercises program would enhance upper- and lower-limb neuromuscular adaptations in untrained women and men, respectively (2,14). One of the experimental groups performed only MULTI exercises, while the other one performed the same protocol with two additional SINGLE exercises. Authors observed no further strength increments for MULTI plus SINGLE, compared to the exclusively MULTI protocol. It is important to note that these researches, in contrast to the present study, did not have an exclusively SINGLE group and used untrained participants, which limits possible comparisons (2,14).

A similar result was reported in the study by de França et al., who described no difference in strength increments between the MULTI vs MULTI plus SINGLE training protocols in previously trained participants after ten weeks (11). Interestingly, the results of the current study showed that the maximal strength increments in the upper (SINGLE: 5.5%; MULTI: 10.8%) and lower limbs (SINGLE: 19.0%; MULTI: 19.7%), assessed through exclusively multi-joint exercise tests (bench press and squat, respectively), were significant for both training protocols. These results were also reported by de França et al., who reported a significant increase in SINGLE exercises 1RM (elbow extension and flexion) for subjects performing the exclusively MULTI protocol (11). Considering all results together, it is reasonable to speculate that the type of exercise does not play a major role in maximal strength increment, suggesting that a general strength increase is possible even when other exercises are implemented in the training routine. A transference effect to other exercises may occur, together with other movements, when the same muscles are recruited.

Another interesting finding in this study is that, although no between-conditions difference was observed for the $1RM_{BENCH}$, the individual absolute changes in the SINGLE condition (range from 0 to 12 kg) presented 62.5% of low responsiveness (i. e. ten subjects presented absolute changes of below the SWC [4.1 kg]). In the MULTI condition, the individual absolute changes (range from 0 to 22 kg) presented just 12.5% (two subjects) low responsiveness. Moreover, the effect size between conditions in absolute difference (post - pre) was moderate and favorable for MULTI (d = 1.06). For $1RM_{SQUAT}$, both conditions presented only one subject that presented an absolute change of below the SWC (4 kg), demonstrating homogeneity in both the mean (d = 0.03) and individual responses.

The decrement in TLL observed from weeks one to six for both protocols can be explained by the linear periodization model adopted, in which external overload was increased every two weeks and the number of repetitions consequently decreased. Interestingly, a greater decrement in TLL (ΔTLL) was observed in the SINGLE protocol when compared to the MULTI. This result suggests that, from a relative standpoint (e.g. ΔTLL), the MULTI protocol results in a greater capacity to accumulate load, since the relative decrease in TLL was lower in this condition. Although this capacity (lower decrease in TLL) did not translate into a greater strength development, it might help to explain why a higher number of participants in MULTI responded above SWC in $1RM_{BENCH}$ when compared to SINGLE. Indeed, splitting the TLL analysis between upper and lower limbs and its eventual effects in $1RM_{BENCH}$ and $1RM_{SQUAT}$, respectively, might help to better understand our findings. Then, future studies aiming to assess this dose-response relationship between TLL and strength gains, when comparing MULTI and SINGLE protocols, must be encouraged.

The internal training load (ITL) is a useful tool to monitor the physiological stress experienced by an individual during a training session/period (21). For ITL_{TOTAL}, a significant difference between conditions was noted, where the MULTI protocol produced a higher ITL_{TOTAL} compared to the SINGLE protocol (Δ% = 12.1). This result may be explained by the fact that individuals experienced higher average sRPE values when performing the MULTI protocol, compared to the SINGLE (9.6 ± 0.6 vs 8.0 ± 0.6, respectively). Thus, ITL outcomes from the current intervention can be a useful tool for coaches aiming to monitor training load and/or implement periods of higher (primarily MULTI protocol) or reduced (primarily SINGLE protocol) training-induced stress. Moreover, when TLL is not an appropriate tool for comparing different RT protocols (e.g. protocols involving distinct implements and exercises such as free weights, cables, machines, etc.), ITL is a viable and useful option for the control and comparison of training load between conditions, since it standardizes the comparison between periodization in arbitrary units (18).

The present study has some limitations that must be considered when attempting to draw evidence-based inferences. First, the RT protocol period lasted only six weeks. Although this duration was sufficient to achieve a significant increase in muscular strength in both conditions, it is conceivable that results between conditions would have diverged over a longer time frame. The rest intervals adopted during the intervention (one minute between sets) might have also reduced the magnitude of strength increases. Then, distinct results induced by large rest intervals (3-5 min) must not be discarded. Secondly, although subjects were instructed to maintain their habitual dietary intake over the course of the study, no nutritional control was implemented, which may influence performance and strength outcomes. Thirdly, more exercises should have been included in the SINGLE, in order to match the number of trained muscle groups (for example, elbow flexors and extensors, and hip extensors were not stimulated). Both the elbow and hip extensions are joint movements that directly contribute to force production during $1RM_{BENCH}$ and $1RM_{SQUAT}$ tests, respectively. Therefore, the addition of exercises that contain these joint movements in the SINGLE should be considered in future studies. Moreover, maximal strength was evaluated using only multi-joint exercises. The addition of tests evaluating maximal strength gains in single-joint exercise should be considered in future investigations. In conclusion, the present study shows that resistance-trained individuals can present a significant increase in maximal strength of multi-joint exercises following protocols containing exclusively MULTI or SINGLE exercises. Therefore, the selection between MULTI and SINGLE protocols should be based on individual and practical aspects, such as movement specificity, equipment availability and time commitment. This finding has relevant practical implications for those aiming to maximize such RT-induced adaptation and allows personal preference to be considered by coaches/practitioners, helping to promote greater adherence to the training program.

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