Decreases in the number of repetitions between sets is indicative of concentric failure in strength training with trained men

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ABSTRACT. The practice of strength training (ST) promotes several benefits such as increased strength, endurance, muscle strength, hypertrophy, as well as changes in body composition. Concentric failure (CF)Several studies show that exercise until CF may be more efficient in promoting positive adaptations about hypertrophy and muscle strength, however, it is still unclear at which time of the exercise CF is achieved. The number of repetitions (NR) performed in each set may be influenced by fatigue caused by CF training. The objective was to analyze the response of the NR between sets as indicative of CF within a session of ST. The study included fourteen trained men (25.0 ± 3.5 years old) (5 ± 4 years) who performed three sets with 75% of 1(repetition maximum) (RM) until CF with fixed rest interval between sets. Statistical analysis: Data normality was tested according to the Shapiro-Wilk test. Subsequently the one-way ANOVA of repeated measures was used to compare the variance of the means between the moments and, when necessary, the post hoc test was used for multiple comparisons using Bonferroni correction. Percentage variations of decreasing NR between sets were found, being from the 1st vs. 2nd set (45,3 ± 14,6 %;), 2nd vs. 3rd set (41,4 ± 19,5%), and 1st vs. 3rd set (67,8 ± 15,1%). The NR can be used to identify if the exercise is being performed up to the CF, considering that the NR between sets decreases substantially due to acute metabolic changes.

Keywords: Resistance training; Neuromuscular fatigue; Muscle strength.

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INTRODUCTION

The practice of strength training (ST) promotes several benefits such as increased strength, endurance, muscle power, hypertrophy, as well as alterations in body composition (Bird, Tarpenning, & Marino, 2005, Paoli, Moro, & Bianco, 2015), factors that contribute to improving the quality of life in the general context (ACSM, 2009).

In addition, there are a lot of evidences of the benefits in the performance improvement item in various sports modalities (Blagrove, Howatson, & Hayes, 2018, Crowley, Harrison, & Lyons, 2017, Zghal et al., 2019). However, to maximize the efficiency of ST in promoting such benefits, it is essential that its prescription be systematized, considering the countless variables that should be controlled according to the objective and/or limitations of each individual (Carpinelli, Otto, & Winett, 2004).

Thus, concentric failure (CF), characterized as the execution of repetitions until the impossibility of moving the load and consequently completing one of the phases of muscle contraction (Izquierdo et al., 2007), is an important variable for determining the intensity and/or volume of training, factors that play important roles in neuromuscular adaptations (Cadore et al., 2012, Gorostiaga et al., 2012, Kraemer et al., 1999).

Several studies show that training with CF may be more efficient in promoting positive adaptations in hypertrophy and muscle strength (J. P. Fisher, Steele, Bruce-Low, & Smith, 2011, Pinto et al., 2014, Willardson, 2007). However, contradictory findings are demonstrated in some studies (Izquierdo et al., 2007, Sampson & Groeller, 2016). These

contradictory results, among other factors, may come from the clinical difficulty in measuring and confirming the CF or not in an ST session.

Considering that the performance of series with CF recruits and promotes fatigue in all muscle fibers, regardless of the load (kg) used (Dankel et al., 2017), our hypothesis considers that the wear/use of energetic substrates involved in the process of muscle contraction with this characteristic (Ascensão et al., 2003), may influence the number of repetitions (NR) performed between the sets, considering that short intervals (≤ 2min.) commonly used in ST sessions would not be sufficient to reestablish the energetic substrates.

Therefore, the analysis of the response of the NR between the sets can be an important parameter to confirm or not of the CF, since a decrease in the NR between the sets can be expected in this situation. In moreover, several studies using submaximal sets did not report a decrease in NR between sets(Carrasco-Poyatos, Ramos-Campo, & Rubio-Arias, 2019, J. Fisher, Steele, Bruce-Low, & Smith, 2011, Yan et al., 2019, Yoon, Ha, Kang, & Ko, 2019).This knowledge can clarify the role of CF occurrence or not in a training session, allowing the use and control of this parameter in the various contexts of ST prescription. Therefore, the aim of this study was to analyze the response of the NR between sets as indicative of CF within a session of ST.

METHODS

Experimental approach to the problem

This is an interventional study, consisted of two visits to the laboratory. The first visit consisted of signing the term of free and informed consent, anthropometric assessments and the test of one maximal repetition (1RM) in the bench press with a guided bar. In the second visit after 72 hours, the exercise protocol was performed using 3 sets with CF (Izquierdo et al., 2007) and verbal stimulation in all sets (Figure 1). It was used 1min30sec. interval between the sets using the load of 75% of 1RM(Alves et al., 2019). The volunteers came to the laboratory at the same time of day in both visits, and they were instructed to not perform any type of physical exercise for at least 48 hours before the tests (Lima, 2006). Additionally, the volunteers were instructed to maintain regular diet and sleep quality during the study.

Subjects

A priori sample analysis revealed that to achieve a 0.5 effect size (ES) with a power of 0.8 and significance of 0.05 a total of 9 participants would be necessary. Therefore, fourteen trained men were recruited to account for eventual attrition. To be considered trained, the voluntaries answered a questionnaire stating that they were practicing ST for some period ≥ one years without interruption. Exclusion criteria reported by questionnaire were: i) history of neuromuscular metabolic, hormonal or cardiovascular disease II) use of any medication that could influence hormonal or neural muscle function; and III) to have any orthopedic limitation that could interfere with the performance of the tests. The participants were informed about the experimental procedures and all possible risks and discomfort related to the study and signed the informed consent. The study protocol that was approved by the local institutional ethics Committee CAAE: 56907716.5.0000.5083.

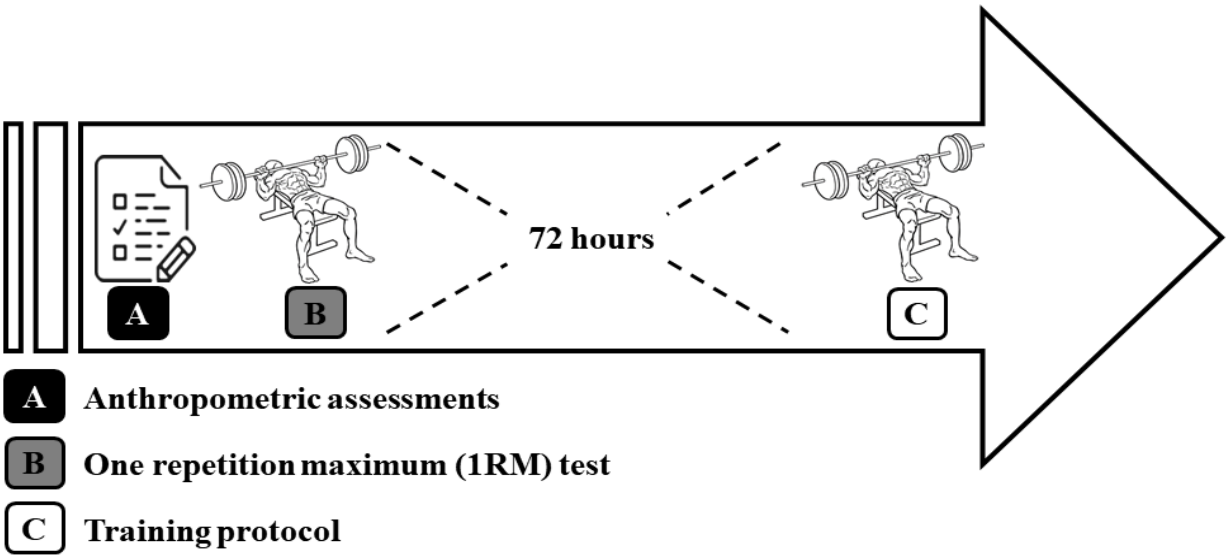

Figure 1. Design of study.

Anthropometric Measurements

The body mass was evaluated by means of an electronic/digital scale with precision of 50 grams (minimum weight 1kg and 50g-maximum 150 kg) of the brand Lider®, model P-150M. Height was measured by means of a Sanny stadiometer, (measuring range: 40 cm up to 210 cm). With the values of these two variables, the body mass Index (BMI) of the volunteers was calculated using the equation below:

BMI = body mass (kg)/height (m^2) (OMS, 2014)

Additionally, the relative strength was calculated using the equation: Maximum weight (1RM)/body weight (kg) (Syrotuik et al., 2000).

Maximum repetition test

The exercise chosen for conducting the research was the bench press. The 1 RM test consisted of previous warming with an underestimated load in 50% of 10 repetition maximum according to the individual's subjective report, followed by a 2-minute interval. According to the formula of Lombardi., (1989)was underestimated the load to perform the first attempt of the 1RM test, being characterized by the ability to perform a complete repetition with the highest amount of weight/kg in a given exercise, the evaluated had up to five attempts for the realization of the test, being adopted five minutes between attempts, whenever it could perform the complete movement with a given load was added between five and 20% of the load already used, in the inability to perform 1 repetition with a given load was adopted the load used in the previous sets as the 1RM of the individual. Thus, the research was carried out using 75% of 1RM found at the end of the test mentioned above.

Table 1. Characteristics of the participants.

Variables	Mean ± SD
Age (years)	25,0 ± 3,5
Body mass (kg)	89,9 ± 16,3
Height (m)	1,77 ± 0,08
Body mass index (kg/m^2)	28,0 ± 4,0
Training Experience (years)	5 ± 4
Relative strength	1,14 ± 0,1

Exercise protocol

The exercise session consisted in the realization of a warming up at 50% of 10 RM, followed by an interval of 4 minutes, then was performed 3 sets with 75% of 1RM until CF and interval of 1min30sec., between the sets. The volunteers performed all the sets with maximum amplitude, allowing a slight contact of the bar with the sternal at the end of the eccentric phase and complete extension of the elbow in the concentric phase.

The cadence used for this study was two seconds for eccentric phase and one second for concentric phase without pauses between phases, in the last repetitions was found an impossibility to maintain the cadence due to the establishment of fatigue. The feet remained in contact with the floor during all sets, as well as the head and trunk remained in contact with the bench, avoiding any movement that could alter the motor pattern of the movement.

During all the sets, verbal stimulus was performed by the same researcher in order to maximize the performance of the individuals. The CF was characterized by the insistence of three seconds in the respective phase unsuccessful in overcoming the resistance and performing the complete phase of the movement (Izquierdo et al., 2007).

Statistical analysis

Data are presented as mean ± standard deviation. Data normality was tested according to the Shapiro-Wilk test. The one-way Anova was used to compare the variance of the averages between the moments. When necessary, the post-hoc test was used for multiple comparisons using Bonferroni correction. The percentage value for training load prescription was normalized by the 1RM test at baseline.

Additionally, the size of *Cohen's D effect* (Cohen, 1988) was calculated from the difference between sets to examine the magnitude of the effect of the sets on the NR. The d values obtained were used to define the effect size as trivial (d <0.2), little (0.2 <d <0.5), medium (0.5 <d <0.8) and great (d> 0.8)(Cohen, 1988). All analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 20.0. The significance level of p≤ 0.05 was adopted for all statistical tests.

RESULTS

The 1RM baseline test was 99.4 ± 20.2 kgs. One-way anova with repeated measures showed effect of the moment on the NR [F(1.54, 20.08) = 90.530; P<0.001] (Table 2). The post-hoc Bonferroni showed significant difference in the NR between all sets (Figure 2).

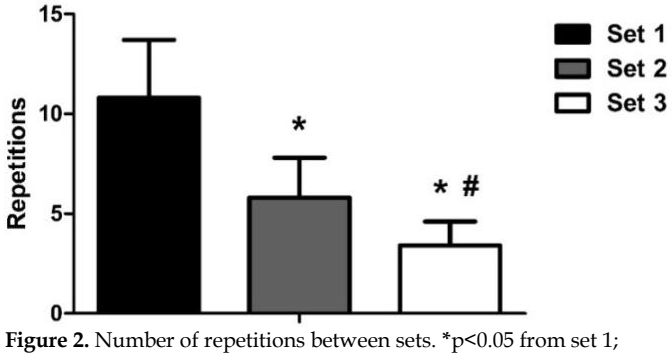

Figure 2. Number of repetitions between sets. *p<0.05 from set 1; #p<0.05 from set 2.

Table 2. Comparison of the number of repetitions between the sets.

Bench press exercise	Number of repetitions	Mean decrease of repetitions	P*	Effectsize
Set 1	10.8 ± 2.9	5.0*	< 0.001	-2.12
Set 2	5.8 ± 2.0			
Set 2	5.8 ± 2,0	2.4*	0.012	-1.64
Set 3	3.4 ± 1.2			
Set 1	10.8 ± 2.9	7.4*	< 0.001	-3.52
Set 3	3.4 ± 1.2			

* Difference between sets (P<0.05).

In addition, percentage variations were found to decrease the NR between the sets, and the 1st vs. 2nd set (45,3 ± 14,6 %;), 2nd vs. 3rd set (41,4 ± 19,5%), and 1st vs. 3rd set (67,8 ± 15,1%). However, we did not find differences in the magnitude of NR decreased when comparing set 1 – set 2 vs set 2 - set 3 (p = 0.54).

DISCUSSION

The aim of this study was to analyze the response of the NR between sets as indicative of CF within a session of ST. The results demonstrated significant reductions in NR among all sets, suggesting that the exercise until CF makes it impossible to the maintenance of the same number of repetitions between sets.

Corroborating our findings, Lima et al., (2006) observed significant reductions in the NR after 4 sets until the CF with a load percentage of 70% of 1RM. Interestingly, the differences were found with the interval similar to our study (1min30sec.) as well as with 120 sec., demonstrating that it is necessary to use intervals higher than this to maintain the NR. In the context, Richmond & Godard, (2004) compared the NR performed during sets with different intervals (1, 3 or 5 minutes), the authors reported a significant decrease in the NR performed independently of the interval used. There is lack of evidence suggesting that independent of the rest interval (Richmond & Godard, 2004, Willardson & Burkett, 2005, 2006b), the exercise performed (Willardson & Burkett, 2006b) or even the load (heavy versus light) (Willardson & Burkett, 2006a), the NR tends to decrease in subsequent sets with CF.

However, these findings, as well as our study, don't corroborate with the results found by Lemos, Cardozo &Simão, (2016). The authors submitted trained individuals to do exercise up to CF with different rest intervals between sets, however, no significant differences were found in the reduction of the NR with the use the same interval adopted in our sturdy (1min30sec.). Similar results were reported by Monteiro, Simão e Farinatti (2005), with trained individuals performing two distinct protocols with maximal/CF repetitions without significant differences in the reduction in the NR performed between the sets in both groups.

Nonetheless, this divergence can be explained due to the fact that our study used high professional supervision, with verbal stimulation and correction of the technique, fundamental factors for CF in ST practitioners (Barbosa-Netto, d'Acelino-e-Porto, & Almeida, 2017) that may not have occurred adequately in the studies mentioned above, leaving the submaximal sets.

In addition, metabolic alterations occur in greater magnitude in CF training compared to submaximal (Gorostiaga et al., 2012), as result of several mechanisms such as the excessive increase in the number of hydrogen that dissociate from glycogenolytic and lactic acid. Furthermore, it is suggested that the inability to produce anaerobic adenosine triphosphate (ATP) from PCr and glycogen degradation, mainly in type II fibers [40,41], the corresponding increase in inorganic phosphate (Pi) and its diprotonatedform, H2PO42, increases in [H+], alterations in Ca2+ transport [42], K+ effluxfrom the muscle [43] and yetimpaired neuromuscular transmission or failure of membrane excitation [44], thus interfering in muscle contraction, therefore, in the production of muscle strength and consequently the NR performed (Hernandez, Healy, Giacomini, & Kwon, 2020, Sahlin, Edstrom, & Sjoholm, 1983, Spriet, 1989).

In a study conducted by Hernandez et al., (2020) it was demonstrated that 8min of rest interval between sets are necessary for total recovery of metabolic alterations inherent to training until CF. These findings corroborate our study, since that we used 1min30sec between sets, insufficient time for total recovery, thus causing a reduction of NR between sets (table 2). Thus, we can assume that trainings that do not promote reduction in the NR between the sets, were not performed with CF (Steele, Fisher, Giessing, & Gentil, 2017).

Interestingly, in addition to the originality of our study using high supervision, verbal stimulus, standardization of the exercise technique and characterization of CF, in order to provide maximum performance in highly trained individuals, we found no differences in the magnitude percentage of NR reduction between1set - 2 set (45.3 ± 14.6 %) vs 2set – 3set (41.4 ± 19.5%) (p=0,54),possibly the physiological changes inherent to neuromuscular fatigue similarly influence performance in the first sets. However, our study, as well as the others, did not investigate this phenomenon with sessions with a larger number of sets. Ex. 5-6 sets.

Therefore, a drop in the NR is expected when performing the training until CF. To some extent, the NR can be used to identify if the exercise is being performed up to the CF. This information can help health professionals working with ST.

As limitations of the study we can consider the use of a single exercise, as well as the interval between the sets and percentage of load, it is not possible to make the use of the results for other situations.

CONCLUSION

The NR can be used to identify if the exercise is being performed up to the CF, considering that the NR between sets decreases substantially due to acute metabolic changes. This finding is important for monitoring the intensity of training, in order to use CF at specific moments of training according to the benefits and risks of training with this characteristic. However, the results of this study cannot be extrapolated to other exercises and related, suggesting the realization of other researches.

CONFLICT OF INTEREST

None to declare.

REFERENCES

Alves, R. R., Viana, R. B., Silva, M. H., Guimarães, T. C., Vieira, C. A., Santos, D. de A. T., & Gentil, P. R. V. (2019). Postactivation Potentiation Improves Performance in a Resistance Training Session in Trained Men. Journal of Strength and Conditioning Research, 00(00), 1-4.

American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Medicine and science in sports and exercise, 41(3), 687-708

Barbosa-Netto, S., d'Acelino-e-Porto, O., & Almeida, M. (2017). Self-Selected Resistance Exercise Load: Implications for Research and Prescription. Journal of Strength and Conditioning Research. 1-25.

Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing Resistance Training Programmes to Enhance Muscular Fitness. Sports Medicine, *35*(10), 841–851.

Blagrove, R. C., Howatson, G., & Hayes, P. R. (2018). Effects of Strength Training on the Physiological Determinants of Middle- and Long-Distance Running Performance: A Systematic Review. Sports Medicine, 48(5), 1117–1149.

Cadore, E. L., Izquierdo, M., Alberton, C. L., Pinto, R. S., Conceição, M., Cunha, G., Kruel, L. F. M. (2012). Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. Experimental Gerontology, 47(2), 164-169

Carpinelli, R. N., Otto, R. M., & Winett, R. A. (2004). A critical analysis of the ACSM position stand on resistance training: Insufficient evidence to support recommended training protocols. Journal of Exercise Physiology Online, 7(3), 1-60.

Carrasco-Poyatos, M., Ramos-Campo, D. J., & Rubio-Arias, J. A. (2019). Pilates versus resistance training on trunk strength and balance adaptations in older women: a randomized controlled trial. PeerJ.

Cohen, J. (1988). The concepts of power analysis. Statistical Power Analysis for the Behavioral Sciences. Hillsdale, NJ: Lawrence Elbaum Associates.

Crowley, E., Harrison, A. J., & Lyons, M. (2017). The Impact of Resistance Training on Swimming Performance: A Systematic Review. Sports Medicine,*47*(11), 2285–2307.

Dankel, S. J., Mattocks, K. T., Jessee, M. B., Buckner, S. L., Mouser, J. G., & Loenneke, J. P. (2017). Do metabolites that are produced during resistance exercise enhance muscle hypertrophy? European Journal of Applied Physiology, 117, 2125–2135.

Fisher, J. P., Steele, J., Bruce-Low, S., & Smith, D. (2011). Evidence-based resistance training recommendations. Medicina Sportiva, 15, 147–162.

Gorostiaga, E. M., Navarro-Amézqueta, I., Calbet, J. A. L., Hellsten, Y., Cusso, R., Guerrero, M.,Izquierdo, M. (2012). Energy metabolism during repeated sets of leg press exercise leading to failure or not. PLoS ONE, 7(7), 1-9.

Hernandez, D. J., Healy, S., Giacomini, M. L., & Kwon, Y. S. (2020). Effect of Rest Interval Duration on the Volume Completed During a High-Intensity Bench Press Exercise. Journal of Strength and Conditioning Research. (Online ahead of print) doi: 10.1519/JSC.0000000000003477

Izquierdo, M., Ibañez, J., González-Badillo, J. J., Häkkinen, K., Ratamess, N. a, Kraemer, W. J.,Gorostiaga, E. M. (2007). Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. Journal of applied physiology (Bethesda, Md. : 1985), 100(5), 1647–1656.

Kraemer, W. J., Häkkinen, K., Newton, R. U., Nindl, B. C., Volek, J. S., Mccormick, M., Evans, W. J. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. Journal of Applied Physiology, 982-992.

Lemos, S; Cardozo, D; Simão, R. (2016). Influência da ordem dos exercícios e do tempo de intervalo de descanso entre séries no desempenho do número de repetições no treinamento para resistência muscular. R. bras. Ci. e Mov, 24(2), 154-161.

Lima, F. V., Chagas, M. H., Corradi, E. F. F., Da Silva, G. F., De Souza, B. B., & Moreira, L. A. (2006). Análise de dois treinamentos com diferentes durações de pausa entre séries baseadas em normativas previstas para a hipertrofia muscular em indivíduos treinados. Revista Brasileira de Medicina do Esporte, 12(4), 175–178.

Lombardi., V. (1989). Beginning weight training: The safe and effective wa*y*. Dubuque, IA: Wm: C. Brown.

Monteiro, W., Simão, R., & Farinatti, P. (2005). Manipulação na ordem dos exercícios e sua influência sobre número de repetições e percepção subjetiva de esforço em mulheres treinadas. Revista Brasileira de Medicina do Esporte, 11(2), 146–150.

Paoli, A., Moro, T., & Bianco, A. (2015). Lift weights to fight overweight. Clinical Physiology and Functional Imaging, 35(1), 1–6.

Pinto, R. S., Correa, C. S., Radaelli, R., Cadore, E. L., Brown, L. E., & Bottaro, M. (2014). Short-term strength training improves muscle quality and functional capacity of elderly women. AGE, 36(1), 365–372.

Richmond, S. R., & Godard, M. P. (2004). The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. Journal of Strength and Conditioning Research, 18(4), 846–849.

Sahlin, K., Edstrom, L., & Sjoholm, H. (1983). Fatigue and phosphocreatine depletion during carbon dioxide-induced acidosis in rat muscle. American Journal of Physiology-Cell Physiology, *245*(1), 15–20.

Sampson, J. A., & Groeller, H. (2016). Is repetition failure critical for the development of muscle hypertrophy and strength? Scandinavian Journal of Medicine and Science in Sports, 26, 375-383.

Spriet, L. L. (1989). ATP utilization and provision in fast-twitch skeletal muscle during tetanic contractions. American Journal of Physiology-Endocrinology and Metabolism, 257(4), 595–605.

Steele, J., Fisher, J., Giessing, J., & Gentil, P. (2017). Clarity in reporting terminology and definitions of set endpoints in resistance training. Muscle and Nerve, 56, 368-374.

Syrotuik, D. G., Bell, G. J., Burnham, R., Sim, L. L., Calvert, R. A., & MacLean, I. M. (2000). Absolute and Relative Strength

Performance Following Creatine Monohydrate Supplementation Combined with Periodized Resistance Training. Journal of Strength and Conditioning Research, 14(2), 182-190.

Willardson, J. M. (2007). The application of training to failure in periodized multiple-set resistance exercise programs. Journal of Strength and Conditioning Research, 21(2), 628–631.

Willardson, J. M., & Burkett, L. N. (2005). A comparison of 3 different rest intervals on the exercise volume completed during a workout. Journal of Strength and Conditioning Research, *19*(1), 23–26.

Willardson, J. M., & Burkett, L. N. (2006a). The effect of rest interval length on bench press performance with heavy vs. light loads. Journal of Strength and Conditioning Research, *20*(2), 396–399.

Willardson, J. M., & Burkett, L. N. (2006b). The effect of rest interval length on the sustainability of squat and bench press repetitions. Journal of Strength and Conditioning Research, 20(2), 400–403.

Yan, J., Dai, X., Feng, J., Yuan, X., Li, J., Yang, L, Lou, Q. (2019). Effect of 12-Month Resistance Training on Changes in Abdominal Adipose Tissue and Metabolic Variables in Patients with Prediabetes: A Randomized Controlled Trial. Journal of Diabetes Research, 1–10.

Yoon, J. R., Ha, G. C., Kang, S. J., & Ko, K. J. (2019). Effects of 12-week resistance exercise and interval training on the skeletal muscle area, physical fitness, and mental health in old women. Journal of Exercise Rehabilitation, 15(6), 839-847.

Zghal, F., Colson, S. S., Blain, G., Behm, D. G., Granacher, U., & Chaouachi, A. (2019). Combined Resistance and Plyometric Training Is More Effective Than Plyometric Training Alone for Improving Physical Fitness of Pubertal Soccer Players. Frontiers in Physiology, 10, 1-11

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