Master's thesis

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The Chronic Effects of Agonist-Antagonist Paired Set Resistance Training on strength and Muscle Mass Development

Master's thesis in Human Movement Science
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Abstract (english)

Background: Resistance training can improve muscle strength, muscle size and several other health parameters. Because of these effects regular resistance training is recommended to the general population, but apparently due to lack of time, many do not meet these recommendations. Superset training (SS) has been suggested to be a time efficient alternative to traditional resistance training (TT). Thus, the objective of this study was to compare the chronic effects of SS vs TT, with respect to muscle strength and muscle mass over ten weeks of training.

Method: Thirty healthy adults were included in a three-week adaptation phase, and then randomized to 10 weeks of SS or TT. Participants trained bench press and seated rows twice per week using, 6 and 12 repetition maximum loading in an alternating manner. Baseline tests were performed at the end of the adaptation phase (week 3) and post tests were performed at the end of the intervention (week 13). Study outcomes include between group changes in muscle mass and muscle strength from baseline- to post test. The SS workout was completed in about half the time of the TT session. Twenty-four participants were included in the final analysis.

Results: No significant between group differences were found. The SS group improved one repetition maximum (1RM) in bench press by 10kg vs 8.8kg in the TT group (CI: -2.45 – 4.76; P=0.513), and by 10.5kg vs 15.2kg (CI: -10.65 – 1.18; P=0.111) in seated rows. The SS group increased muscle mass by 0.56kg vs 0.29kg (CI: -0.13 – 0.67; P=0.176) in the TT group. Both groups showed significant within group improvements.

Conclusion: SS appears to be a time efficient alternative to TT for improving muscular strength and muscle mass.

Abstrakt (norsk)

Bakgrunn: Styrketrening kan forbedre muskelstyrke, muskelstørrelse og mange andre helsefaktorer. På grunn av disse effektene anbefales regelmessig styrketrening til den generelle befolkningen, men tilsynelatende av mangel på tid, mislykkes mange i å oppfylle disse anbefalingene. Supersettrening (SS) er foreslått som et tidseffektivt alternativ til tradisjonell styrketrening (TT). Derfor var målet med denne studien å sammenligne de kroniske effektene av SS opp mot TT med tanke på muskelstyrke og muskelmasse over ti uker med trening.

Metode: Tretti friske voksne ble inkludert i en tre ukers tilvenningsfase og ble deretter randomisert til 10 uker med SS eller TT. Deltakerne trente benkpress og sittende roing to ganger per uke, med 6RM og 12RM belastning på en rullerende måte. Baselinetester ble utført ved slutten av tilpasningsfasen (uke 3) og posttester ble utført ved slutten av intervensjonen (uke 13). Studiens hovedutfall var endringer i muskelmasse og muskelstyrke mellom gruppene fra baseline til posttest. Supersettøkta ble gjennomført på halvparten av tiden, sammenlignet med den tradisjonelle økta. Tjuefire deltakere ble inkludert i den endelige analysen.

Resultat: Ingen signifikante forskjeller mellom gruppene ble funnet. SS-gruppen forbedret sin maksstyrke (1RM) i benkpress med 10kg vs 8,8kg (CI: -2.45 – 4.76; P=0,513) i TT-gruppa, og med 10,5kg vs 15,2kg (CI: -10.65 – 1.18; P=0,111) i sittende roing. SS-gruppa økte muskelmassen med 0,56kg vs 0,29kg (CI: -0.13 – 0.67; P=0,176) i TT-gruppa. Begge treningsmetodene viste signifikant forbedring innenfor gruppene.

Konklusjon: SS ser ut til å være et tidseffektivt alternativ til TT for å forbedre muskelstyrke og muskelmasse.

Acknowledgments

Funds and facilities for this study were provided by the Norwegian University of Science and Technology. I wish to thank Vegard Moe Iversen (main supervisor) and Marius Steiro Fimland (secondary supervisor) for guidance throughout the process. I also would like to thank Bjørnar Unhjem for collaboration and Mats Holst Aandahl and Fabian Schwendinger for helping out with testing.

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1. Introduction

Regular resistance training (RT) has been found to enhance both muscle strength and muscle size (Ratamess et al., 2009) and improves cardiovascular fitness, bone mass, functional ability and psychological well-being (Steele et al., 2012; Weil, 2008). Thus, the American College of Sports Medicine (ACSM) recommend all healthy adults engage in RT twice or thrice a-week (Ratamess et al., 2009).

RT refers to any exercise that causes the muscles to contract against external resistance (e. g. free weights, exercise machines or own bodyweight) with the expectation of increasing muscle strength, tone, mass, and/or endurance (Weil, 2008). The muscles can be trained by performing single-joint exercises such as biceps curl and knee extensions, or multi-joint exercises such as squats and deadlift. Both variations are useful in an RT program, but for the general population Ratamess and colleagues recommend that emphasis be put on multi-joint exercises because it is more time efficient and effective for increasing overall strength, and also its transferability to daily activities (Ratamess et al., 2009).

An observational study on the prevalence of RT in the general population showed that just over 13% reported to have engaged in some form of RT during the week leading up to the study (Humphries et al., 2010). It could be a variety of reasons for the relatively low participation rate, but the same study showed an association between lack of time and levels of leisure time physical activity among 2194 adults. A failure to engage in physical activity is likely to have a negative effect on public health and overall well-being (WHO, 2018).

Given the notion of time being the main barrier to RT, it is likely that more people would engage in RT if training sessions could be designed in a way that reduces the duration at little or no expense of training effects. Reduced rest between sets and exercises will result in a more compromised workout and reduce the total duration. Traditionally, 2-5 minutes rest between sets is recommended, but it is evidence that in untrained individuals, shorter rest periods could be sufficient to achieve significant increases in muscular strength (Grgic et al., 2018).

The amount of rest between sets and exercises significantly affects metabolic, hormonal, and cardiovascular responses to an acute bout during RT, as well as performance of subsequent sets and training adaptations. A study showed that when the training goal is muscular hypertrophy, the combination of moderate intensity sets with short rest periods of 30-60 seconds might indicate the best alternative to increase levels of growth hormone. This can contribute to the hypertrophic effect (Freitas de Salles et al., 2009), which opens up for the possibility to reduce rest periods in order to get a more time efficient RT session.

1.1 Could SS solve the issue of time being a barrier for RT?

Traditional resistance training (hereafter referred to as TT) refers to a training module where the exercises are performed separately, with rest between each set. An example of a typical TT session would be three sets of bench press with rest between each set, before doing three sets of seated rows with rest between each set.

In a review, Robbins et al. (2010) examined a less time consuming type of resistance training, called superset training or paired set training (hereafter referred to as SS). By manipulating the rest intervals between sets, SS makes it possible to uphold total volume and training intensity, while reducing the duration of the training session.

The term "superset" refers to groups of two or more exercises paired together, meaning they are performed successively with little or no rest between. Preferably exercises are paired in an agonist-antagonist fashion or upper-lower body fashion, but the term is also used to describe protocols grouping exercises targeting the same muscle group (Robbins, Young, Behm, & Payne, 2010). An example of a superset combination in an agonist-antagonist fashion would be one set of bench press, immediately followed by one set of seated rows.

1.2 Agonist-antagonist paired set training

The efficient coordination of agonist and antagonist muscles is one of the important early adaptations in resistance training responsible for large increases in strength and torque (Baker & Newton, 2005). This appears to be achieved by a neural strategy of enhanced reciprocal inhibition of the antagonist musculature (Robbins et al., 2009). This means that the body becomes able to coordinate the right muscles into the exercise, and relax muscles that are not contributing the execution of the movement.

Research suggests that antagonist pre-loading may result in acute performance enhancement of the agonist musculature. Baker and Newton (2005) reported that power output in bench press throw was significantly greater when preceded by a set of ballistic bench pulls than in a set of bench press throws with no intervention, even though the muscle activity in agonist musculature was not affected.

Acute studies comparing SS and TT protocols consisting of bench pull and bench press or bench press throw showed no difference between groups with regard to total volume load over three consecutive sets, leading to the conclusion that SS may be as effective as TT in terms of volume load maintenance and efficiency (Robbins, Young, Behm, & Payne, 2010; Robbins, Young, & Behm, 2010). There were no differences in muscle activity between the two conditions, indicating neuromuscular fatigue was not greater with SS than TT. These results may suggest the possibility to perform the same amount of work in less time, at no expense of training effects.

More acute studies have presented results indicating that SS training is substantially more exhausting than TT (Paz et al., 2017; Weakley et al., 2017), leading to the suggestion that SS training would be very difficult to sustain in the long run, resulting in less adherence to such training programs. More studies are therefore needed to look further into these claims and evaluate if it is possible for the general population to engage in SS training for a sustained period of time.

To our knowledge there are only two known longitudinal intervention studies on superset training. White et al. (2011) studied the change in muscle strength and muscle cross sectional area in 31 untrained women after 12 weeks of training back squats and leg press. The researchers found significant improvements in musculus vastus lateralis strength and cross sectional area under both conditions, but no differences between groups. They also found that if interset rest time between the two groups were matched at 1 min, the SS group demonstrated superior workout efficiency compared to the TT group.

Robbins et al. (2010) conducted a study on superset training utilizing agonist-antagonist exercises. The participants were experienced in resistance training, and the study put considerable emphasis on power output. Existing literature indicates that SS could be equally effective as TT in enhancing muscle strength and muscle mass, but no studies have looked into the effects of superset training on untrained individuals performing agonist-antagonist exercises. Thus, the purpose of this study is to compare the chronic effects of SS compared to TT with regards to one repetition maximum (1RM) in bench press and seated rows, as well as muscle mass.

2. Method

2.1 Study design

This study was conducted in collaboration with fellow master student Bjørnar Unhjem (Unhjem, 2020), and looks into the effects on the agonist-antagonist combination of bench press and seated rows, whereas the other study focused on the upper-lower body combination of lateral pulldown and leg press. The same participants performed all four exercises during the same workout. This was a single blinded RCT assessor on the effects of superset training vs traditional resistance training. All participants engaged in a three-week resistance training introduction phase prior to baseline testing and randomization. Following randomization to superset- or traditional resistance training, participants continued their respective training program for 10 weeks. Randomization was performed using block randomization with unknown block sizes in a web based randomization program (WebCRF3), provided by The Unit for Applied Clinical Research. All activities took place at the Norwegian University of Science and Technology, St. Olav´s Hospital.

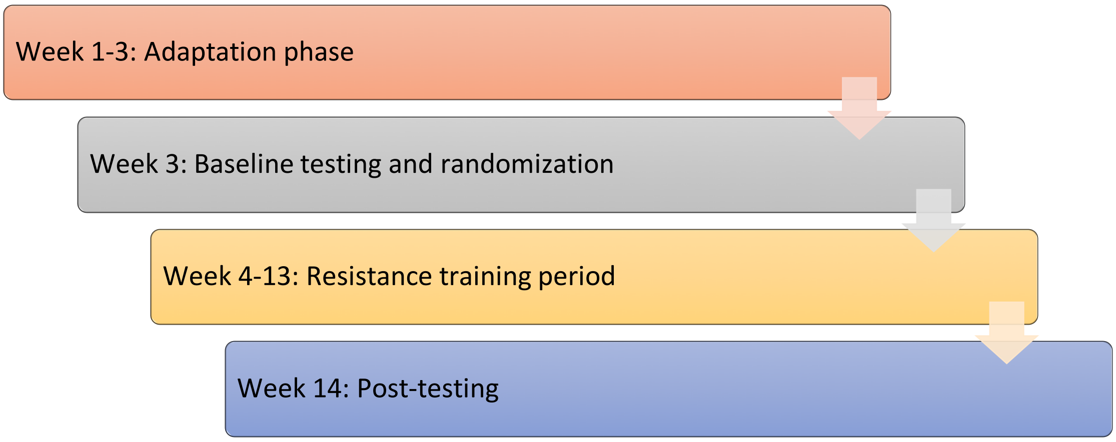


Figure 1: Study timeline

Approval for processing of personal data was given by Norwegian Centre for Research Data, and all subjects gave written informed consent before undertaking testing and training. The study was performed in accordance with the Declaration of Helsinki and presented in accordance with Consort Statement, as well as registered at https://clinicaltrials.gov , ID: NCT04038177.

2.2 Subjects

A total of 30 healthy men and women were included in the study. Based on inclusion criteria, the participants had to be between the age of 18 and 45, and were recruited mainly through social media advertisement. The participants stated that they had not participated in regular resistance training during the last six months. Participants were not eligible if they had any known severe somatic condition (e.g., autoimmune and systemic inflammatory diseases, cancer, severe osteoporosis), severe psychiatric condition, or if they had other contraindications for heavy resistance training (e.g. shoulder pain). When in doubt, the participant was asked to consult with relevant health care professionals. During the study they were encouraged to continue their habitual lifestyle, and stay away from additional resistance training. 26 participants completed the baseline tests, and were then randomly allocated to one of two groups; superset training (SS; n=13) or traditional resistance training (TT; n=13), as shown in table 1.

Table 1: Characteristics of participants enrolled in the 10-week training period. All values are presented as means (Standard deviation).

	Traditional group	Superset group	Total
Number (n)	13	13	26
Age (year)	28 (7)	27 (5)	28 (6)
Male (n)	6	7	13
Female (n)	7	6	13
Height (cm)	172 (9)	176 (9)	174 (9)
Weight (kg)	74 (20)	71 (9)	72.3 (15)
Body Mass Index (kg/m^2)	24.7 (4.2)	22.9 (2.4)	23.8 (3.5)

2.3 Training intervention

The training intervention started with a three-week familiarization phase, with emphasis on learning correct form and technique in the exercises. The participants had a total of five workouts leading up to the baseline test, including two 6RM workouts and three 12RM workouts. In this period, they performed two sets of each exercise, with 2,5-minute rest between sets. The duration of these workouts were around half an hour, including warm-up and each workout was recorded in a training diary. The results were used to estimate the initial load of the *1RM* baseline tests for each participant. 1RM is the maximum load an individual is able to lift for one repetition. For the estimations, a web based strength calculator as well as individual adjustments based on observations of the participants was applied (Strength level, 2019).

During the intervention period the participants trained twice a-week, including one 6RM- and one 12RM workout in an undulating periodization manner, with approximately 48 hours separating the two workouts. Each training session started with a warmup set on each exercise with a load of 50-70% of the predetermined workout load for that particular session, followed by two minutes of rest. The workout intensity for the 6RM workout was about 80-90% of 1RM for the first set, because several pioneering studies indicates that training with loads corresponding to 1– 6 RM, mostly 5– 6 RM, was most effective for increasing maximal dynamic strength (Berger, 1962; O'Shea, 1966; Weiss, 1999). All sets were performed to muscular failure without adjusting the load between sets. The same procedure was done for the 12RM workout apart from the load, which was around 60-70% of 1RM for the first set, in accordance with ACSM guidelines for hypertrophy adaptations. When the participants achieved the desired number of repetitions (6 or 12 depending on days) for at least two sets of an exercise, the load was increased by two and a half kilos for that particular exercise before the next workout session to ensure progressive overload of the targeted muscle groups. Bench press preceded seated rows in every session, and a training diary was recorded for each participant throughout the study.

2.4 SS vs TT

In the superset workout the participants performed one set of bench press directly followed by one set of seated rows. The participants had 2,5 minutes of rest between like exercises, meaning the count-down started at the end of each set in the bench press. This was repeated three times, as shown in figure 2a. Three sets with this superset combination took about seven minutes to complete. The full workout, including lateral pulldown and leg press, took about 14 minutes.

As for the traditional resistance training session, the participant performed three sets of bench press with two-and-a-half-minute rest between sets (as shown in the figure 2b), before doing the same for the seated rows. Three sets with this exercise combination in a traditional fashion took about 17 minutes to complete. The full workout, including lateral pulldown and leg press, took about 34 minutes.

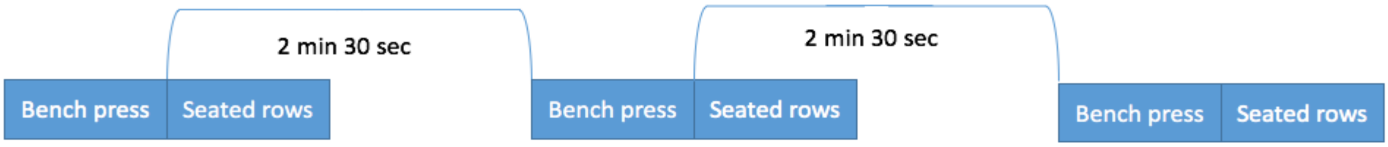


Figure 2a: Typical superset workout

Figure 2b: Typical traditional workout

2.5 Exercise description

2.5.1 Bench press

The participants were instructed to hold the bar so that forearms made a 90-degree angle with the bar in the lower position of the movement, as shown in figure 3a. Control of the bar were required before lowering it to the chest. The bar had to touch the chest in the lower position, and arms had to be straight in the upper of the position of the movement for a repetition to be approved. Assisted liftoff were accepted.

Equipment used for this exercise was a standard weightlifting bar weighing 20 kilograms, along with standard weight plates of 1.25 kg, 2.5 kg, 5 kg, 10 kg, 15 kg and 20 kg. The bench was set in a flat position.

2.5.2 Seated rows

The participants were instructed to grab the handle with both hands and sit back, with feet placed on the footrest as shown in figure 3c. Upper body had to be straight and fixed throughout the exercise. They were told to start with arms straight, and pull the handle all the way up to the belly, as shown in figure 3d, then return to starting position while maintaining a straight back.

This exercise was performed on a combined row- and pulldown cable machine (214 Gymleco) using a middle width neutral grip handle (R106 Gymleco multi pull handle), with increments of 5 kilograms. In order to make increments of 2.5 kilograms, smaller separate discs were added. To keep track of time during resting intervals, a Select stop watch was used.

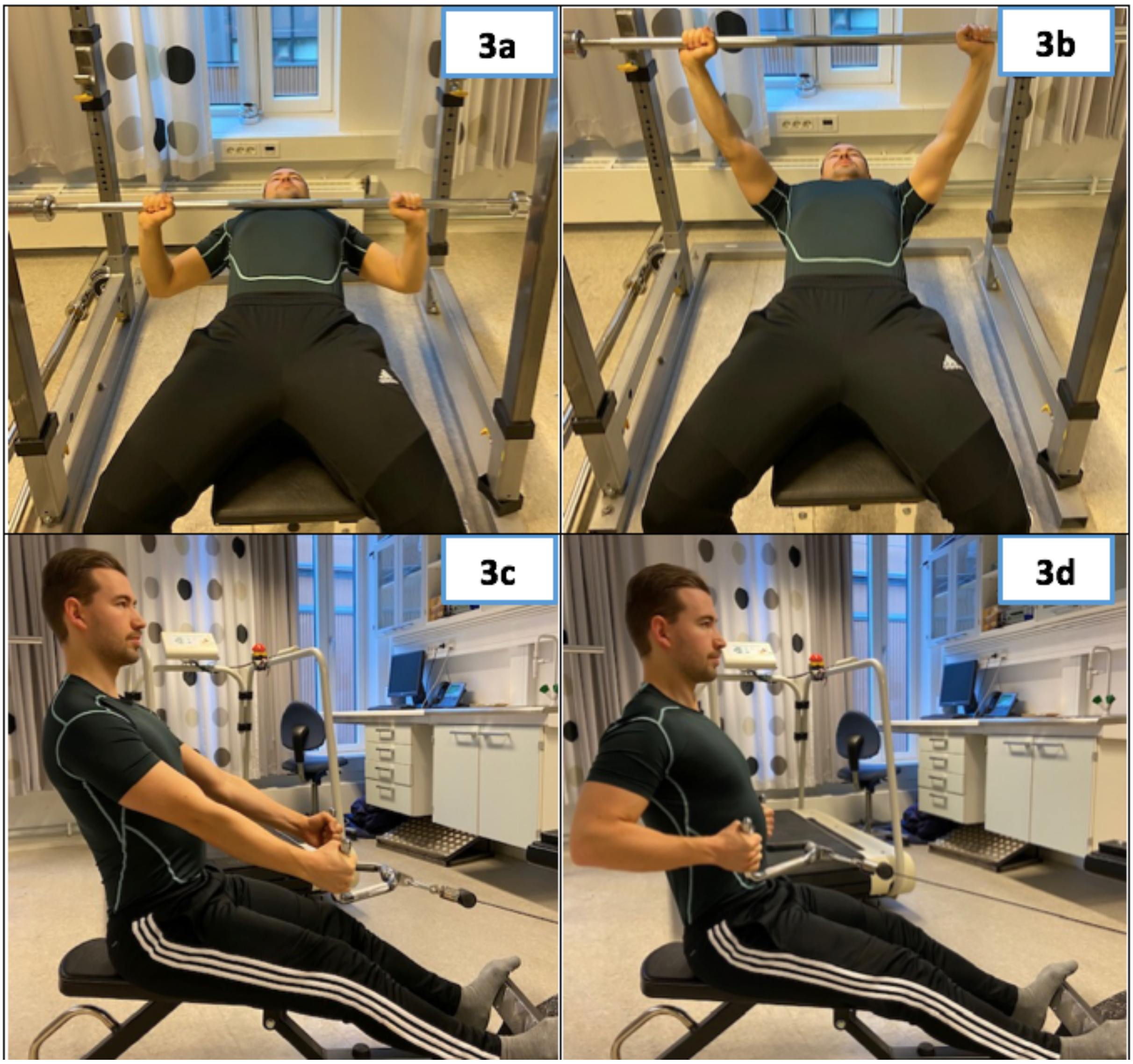


Figure 3: 3a = starting position for bench press; 3b = end position for bench press; 3c = starting position for seated rows; 3d = end position for seated rows

2.6 Outcomes and testing procedures

Outcomes were assessed at baseline (at the end of the adaptation phase) and at the end of the intervention period. The primary outcomes of this study were changes in strength – assessed through 1RM tests, and changes in muscles mass – assessed through InBody tests.

2.6.1 InBody test

The body composition tests were performed using an InBody 720, which has been shown to be a valid alternative to dual-energy x-ray absorptiometry with regards to muscle mass (Anderson et al., 2012). The body composition tests were carried out prior to the 1RM strength tests and in accordance to specific InBody guidelines, meaning the participants had to refrain from food and beverages for two hours, as well as empty their bladder just before testing. The same procedure was repeated at the end of the training intervention.

2.6.2 1RM testing

Before testing 1RM strength, the participants did two warm-up sets of that particular exercise, the first at 50-60% of estimated 1RM for 12 repetitions, and then 3 repetitions at 70-85% of estimated 1RM. After two warm-up sets followed two minutes of rest before the first attempt at 1RM. Each participant´s estimated 1RM were calculated based on the last 6RM workout. In order to perform a valid 1RM test, the participants had to record at least one successful and one unsuccessful attempt. They had a maximum of 5 attempts.

1RM tests in bench press were performed in the same way as described in the exercise description, with assisted liftoff if desired by the participant. The same procedure was repeated for the seated rows, and an attempt was successful when the wrist aligned with the iliac crest/crista iliaca. Baseline tests and post tests were performed approximately at the same time and in the same order to ensure similar conditions.

2.6.3 Blinding

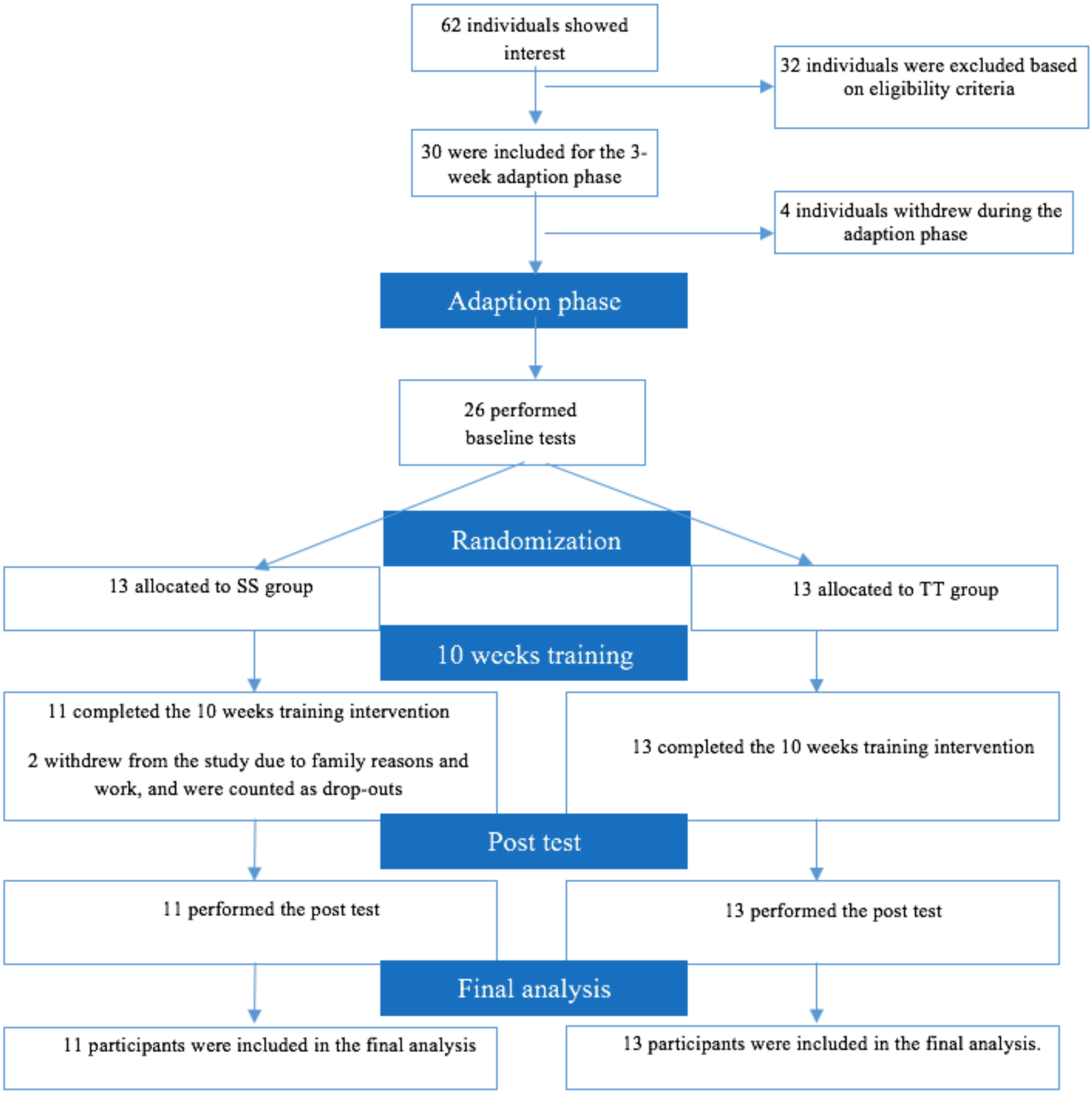
The researchers themselves were responsible for carrying out the baseline tests, whereas external test leaders were in charge of the post tests to keep the researcher blind and avoid possible bias in the results. Blinding of the participants were not possible due to the nature of the study. The external test leaders were experienced weightlifters and trained in the test protocols.

2.7 Statistical analysis

All analyses and figures were prepared in SPSS version 26. Data were checked for normal distribution using a Shapiro-Wilk test and histograms displaying normal curve, and parametric tests were applied to compare groups. Between group differences were assessed independently for all variables using independent samples t-tests., with standard deviations. Between group changes and within group changes are respectively presented as means with confidence interval (CI: 95%), and means with standard deviation (SD). Statistical significance was set to $p<0.05$.

3. Results

Thirty subjects began the study, but four of these subjects dropped out during the adaptation phase and were not included in the baseline testing and the 10-weeks training intervention. Thus, 26 participants were randomized to the SS group or the TT group. Two participants dropped out of the SS group during the training intervention, preventing their data from being utilized. All 24 participants that completed the post tests were included in the primary analysis at the end of the study. The process from recruitment to the final analysis is presented in figure 4.



Figur 4: Flow chart for participants

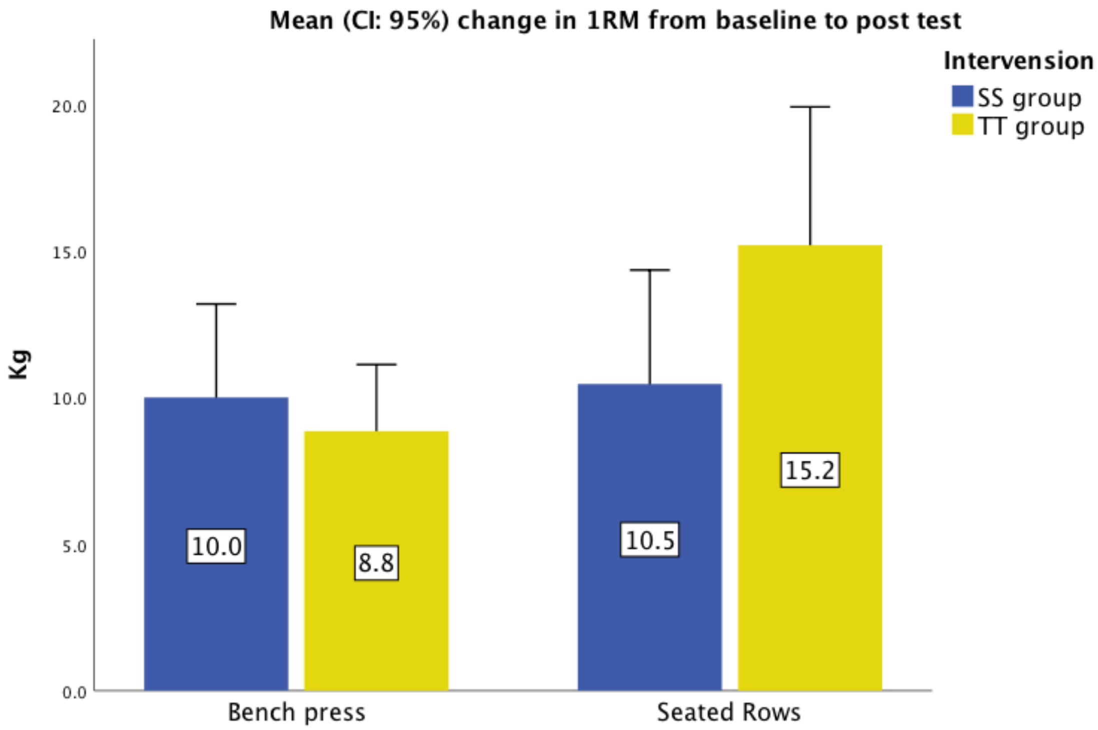
3.1 Between group changes

The SS group compared to the TT group, improved 1RM bench press by +1.2 kg (CI: -2.45 – 4.76; P=0.513), and seated rows by -4.7 kg (CI: -10.65 – 1.18; P=0.111). The difference in muscle mass improvement between the groups was 0.27 kg (CI: -0.13 – 0.67; P=0.176) in favor of the SS group. All test results and within group changes are presented in table 3.

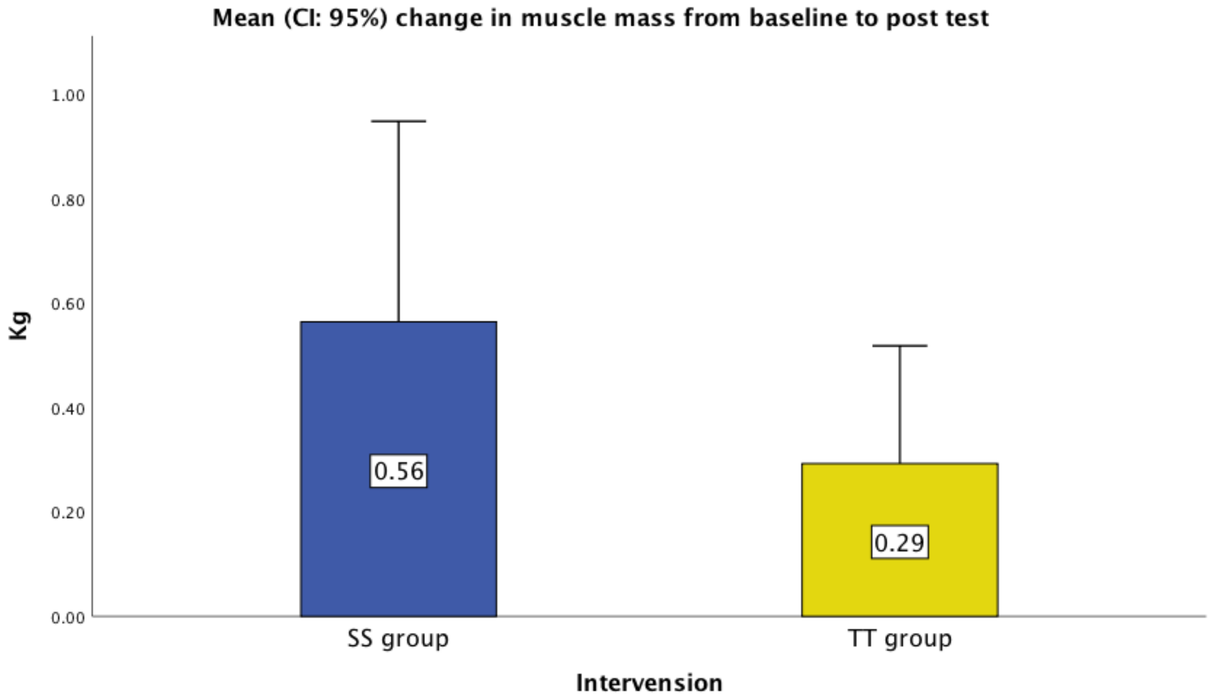
Table 2: Test results presented as means within groups (Standard deviation). All numbers refer to kilograms lifted.

	TRADITIONAL GROUP		SUPERSET GROUP	
	Baseline test	Post test	Baseline test	Post test
BENCH PRESS	44.8 (13.6)	53.6 (16.3)	42.7 (16.0)	52.7 (19.2)
SEATED ROWS	60.2 (14.9)	7.4 (19.6)	59.1 (13.9)	69.6 (17.4)
MUSCLE MASS	3.7 (5.7)	30.9 (5.8)	28.3 (6.5)	28.9 (6.5)

1RM strength and muscle mass increased significantly under both conditions. Mean change for 1RM strength and muscle mass can be seen in figure 5 and 6 respectively.



Figur 5: Superset vs Traditional in 1RM improvement for bench press and seated rows



Figur 6: Superset vs Traditional in muscle mass improvement

The SS group had an average completion rate of 88% of the workouts, and two drop-outs, whereas the TT group completed 89% of the workouts and had no drop-outs.

4. Discussion

The main findings were that the mean differences in 1RM strength in bench press and seated rows, as well as muscle mass, was not statistically significant between groups. Both groups showed significant within group changes from baseline to post test on all parameters. Superset training took about half the time to complete compared to traditional resistance training, and thus appeared to be a more efficient training method, as a number of acute studies have shown previously (Kelleher et al., 2010; Paz et al., 2017; Robbins, Young, Behm, Payne, et al., 2010; Weakley et al., 2017).

This study differs from previous studies on superset training in that the participants were untrained and represented by both genders. The resting time between sets were the same for both groups, and the training programs were designed exclusively to promote muscle strength and muscle hypertrophy.

Previous longitudinal studies on superset training, although scarce in numbers, have demonstrated similar results with no significant differences between superset training and traditional resistance training with respect to strength and muscle mass. White (2011) recruited 31 untrained women to examine the effects of superset training, but unlike this present study the participants performed exercises targeting largely the same muscle groups. The rest time between sets were also different between the two groups, with the superset group getting 2,5-minute rest between sets, compared to 1 minute for the traditional group. The choice of different rest intervals between the two conditions could lead to a difference in hormone responses and metabolic stress, potentially affecting muscular adaptations. The rest periods for the superset groups in White (2011) and this present study was similar, but the traditional group in White (2011) had 1,5 minute shorter rest intervals compared to the traditional group in this present study. Given the similar results with regards to muscle strength and muscle mass between the two studies, it seems that in untrained individuals, superset training is a reasonable alternative to traditional resistance training, regardless of exercise choice and rest intervals.

Robbins, et. al. (2010) recruited fifteen trained males for eight weeks of training. Half of the participants were randomized to SS, and the other half to TT. The first half of the training period put emphasis on back and chest strength, whereas the other half focused on back strength and chest power. The exercises performed were bench press, bench press throw, and bench pull. The amount of reps ranged between 3-6 per set in the workouts focusing on strength, and between 2-6 in the workouts focusing on power. 1RM strength increased significantly in the SS group, but not in the TT group. No significant differences in 1RM strength between groups were detected. The most notable difference between Robbins, et. al. (2010) and this present study was the considerable emphasis on power output in the latter half of the study. Even though power training is likely to have some effect on strength it seems to have little effect on 1RM improvement in trained individuals, especially in the TT group. The use of individuals experienced in weight lifting is another factor likely to have contributed to the relatively low improvement in 1RM strength for both groups. Novice athletes often see a bigger improvement in the initial phase of a training program, compared to experienced athletes. The researchers found no differences between the two groups in terms of 1RM strength, and it is very difficult to know to what degree the focus on power output have contributed positively or negatively to the change in 1RM strength.

While beginners may experience significant strength gains and sufficient recovery between sets by applying rest intervals of 1-2 minutes, Suchomel et al. (2018) have shown that longer rest intervals up to 5 minutes may provide the greatest strength- and power benefits, depending on the individuals training experience, fiber type and genetics. Since Robbins, et. al. (2010) tested experienced weight lifters, it is reason to believe that strength increases would be larger if they utilized longer rest periods between sets. Participants in the traditional group failed to demonstrate significant improvements, and the choice of shorter rest periods could explain these results. As opposed to the participants in Robbins, et. al. (2010), the subjects in this present study were untrained and both groups showed significant improvements, justifying rest intervals shorter than five minutes.

SS is perceived to be more exhausting than TT (Paz et al., 2017; Weakley et al., 2017), leading to the suggestion that SS would be very difficult to sustain in the long run. However, two drop outs from the SS group and an average participation rate of 88% of the workouts contradicts this suggestion to some degree. The TT group completed approximately the same amount of workouts (89%), and had no drop-outs. One participant in the TT group only participated in 45% of the workouts, but an exclusion of this participant did not change the results. These findings support the suggestion that SS training is an efficient and sustainable training method.

4.1 Strengths and limitations to the study

The learning of proper form and technique as well as neural adaptations to resistance training is two key factors leading to the so called *novice effect.* The novice effect is typically seen in previously untrained individuals, were one initially gets a rapid increase in strength before the progress slowly fades out. One of the main strengths of this study is the three-week adaptation phase before baseline testing, in an attempt to minimize this effect. In comparison, White (2011) spent the first week of the study assessing joint integrity and health history questionnaires, whereas the second week included three hours of watching, learning and working on the lifts that were involved in the study. It is unlikely that that the novice effect has been excluded after just one week of training, and that the improvements in strength and muscle mass have been affected by the novice effect. Despite hopefully having excluded the novice effect in this present study through the three-week adaptation phase, the participants showed similar improvements as in White (2011).

The addition of progressive overload ensured that the participants avoided plateauing. This is an important principle in strength training, and is vital to keep progressing. While this study increased the load when participants achieved the desired number of repetitions for two consecutive sets, White (2011) utilized the principle of progressive overload by alternating rep ranges, load and number of sets. Since neither studies showed any significant between group differences, the manner of how progressive overload is applied seems to be of little importance in untrained individuals.

As recommended by the ACSM in order to maximize muscular adaptations, the training program applied in this study followed the basic principles of RT; progressive overload, specificity and periodization (Ratamess et al., 2009).

One-on-one guidance in every session, as well as personal motivation and encouragement ensured that every participant went to failure and stayed motivated throughout the study. The researchers were blind to the final test results, as these tests were carried out by external test leaders to avoid conflicting interests and bias, strengthening the results of this study (Kraemer & Ratamess, 2004). However, due to different group sizes it was not possible to retain blinding during the analysis.

The sample size in this study is considered to be relatively small. When mean values is utilized, results derived from a small sample size is vulnerable to extreme values. Especially if between group differences was close to significant, question marks over the role of sample sizes could be raised.

Specific warm-up is known to enhance neuromuscular efficiency for the exercise you are about to perform. In essence, your body gets to rehearse the movements before performing them at a high level of intensity, translating into better performance during working sets (Schoenfield, 2017). The participants in this study did only one warm-up set for each exercise, and often seemed to perform better in the second set, that in the first. It is a question how this have affected the workout with regards to total volume load, but Ribeiro et. al. (2014) found no beneficial effects of warming up with a high number of sets and repetitions in the medium- to high rep ranges in bench press, squats or arm curls.

The study was part of a larger study and the participants did lateral pulldown and leg press, in addition to bench press and seated rows. Performance during workouts could also have been affected by the order in which the participants performed the exercises. Bench press always preceded seated row, but lateral pulldown and leg press were also executed during the same workout. Even though leg press is quite different from bench press in terms of the muscle groups involved, lateral pulldowns and seated rows are very much alike. The order of the exercises alternated each week, meaning the participants could feel exhausted from previous exercises when performing bench press and seated rows late in a workout session. A study on the effect of exercise order on the number of repetitions showed a significant decrement in the number of repetitions in the last exercise of the workout, compared to exercises performed early in the session (Simão et al., 2005).

In addition to early fatigue, lateral pulldowns and leg press contributed to the total volume of each workout session, and may have had an impact on the increase in muscle mass. This is especially important to note since muscle mass were measured in total, and not locally in separate muscle groups. Because these factors were equal for both groups, it is not likely to have a big influence on between group differences, but could have impacted within group changes to some degree.

4.2 Implications for practice and future research

Time efficient training modalities can be beneficial for athletes and the general population. It enables athletes to focus more on technical aspects of their sport, and the general population to find time for training during a stressful day. Because resistance training has been associated with improved health and a decrease in the risk of chronic diseases and disability, time-efficient programs would likely have a considerable effect on the health of the general population.

There is still a void in the literature regarding superset training, and it´s too little evidence to draw any conclusion on the long term effects of this training method. The results from this study, or any other previous studies on superset training, cannot be generalized for other groups of people. Whether this training modality will have similar effects on trained athletes, or older individuals remain unclear. All studies conducted on superset training have been on small sample sizes, and over a relatively short period of time. It is still unknown if it is possible to retain the same progress over a longer period of time, or if there is a time limit for when participants start plateauing or burn out. Future research on this topic should focus on different types of groups, over a longer period of time, and with larger sample sizes.

4.3 Conclusion

The results from this study supports previous notions of SS being a viable option to TT for improving muscular strength and mass in healthy adults. There were no significant differences between groups in any of the outcome measures. Superset training also demonstrated superior workout efficiency (volume per time) over traditional resistance training. Because of the similar increases in outcome measures between groups, superset training may be better than traditional resistance training for short, yet still effective, workouts that could benefit the general population and make it possible to engage in regular resistance training despite limited time available.

References

Anderson, L. J., Erceg, D. N., & Schroeder, E. T. (2012). Utility of multifrequency bioelectrical impedance compared with dual-energy x-ray absorptiometry for assessment of total and regional body composition varies between men and women. *Nutrition Research*, *32*(7), 479–485. https://doi.org/10.1016/j.nutres.2012.05.009

Baker, D. G., & Newton, R. U. (2005). Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/1533-4287(2005)19<202:AEOPOO>2.0.CO;2

Berger, R. A. (1962). Optimum Repetitions for the Development of Strength. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *33*(3), 334–338. https://doi.org/10.1080/10671188.1962.10616460

Freitas de Salles, B., Simão, R., Miranda, F., da Silva Novaes, J., Lemos, A., & Willardson, J. M. (2009). Rest Interval between Sets in Strength Training. *Sports Medicine*, *39*(9), 765–777. https://doi.org/10.2165/11315230-000000000-00000

Grgic, J., Schoenfeld, B. J., Skrepnik, M., Davies, T. B., & Mikulic, P. (2018). Effects of Rest Interval Duration in Resistance Training on Measures of Muscular Strength: A Systematic Review. *Sports Medicine*, *48*(1), 137–151. https://doi.org/10.1007/s40279-017-0788-x

Humphries, B., Duncan, M. J., & Mummery, W. K. (2010). Prevalence and correlates of resistance training in a regional Australian population. *British Journal of Sports Medicine*, *44*(9), 653–656. https://doi.org/10.1136/bjsm.2008.048975

Kelleher, A. R., Hackney, K. J., Fairchild, T. J., Keslacy, S., & Ploutz-Snyder, L. L. (2010). The Metabolic Costs of Reciprocal Supersets vs. Traditional Resistance Exercise in Young Recreationally Active Adults. *JOURNAL OF STRENGTH AND CONDITIONING RESEARCH*, *24*(4), 1043–1051.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine and Science in Sports and Exercise*, *36*(4), 674–688.

O'Shea, P. (1966). Effects of selected weight training programs on the development of strength and muscle hypertrophy. *Research Quarterly*, *37*(1), 95–102.

Paz, G. A., Robbins, D. W., de Oliveira, C. G., Bottaro, M., & Miranda, H. (2017). Volume Load and Neuromuscular Fatigue During an Acute Bout of Agonist-Antagonist Paired-Set vs. Traditional-Set Training. *Journal of Strength and Conditioning Research*, *31*(10), 2777–2784. https://doi.org/10.1519/JSC.0000000000001059

Ratamess, N., Alvar, B., Evetoch, T., Housh, T., Kibler, B., Kraemer, W., & Triplett, T. (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. https://doi.org/10.1249/MSS.0b013e3181915670

Ribeiro, A. S., Romanzini, M., Schoenfeld, B. J., Souza, M. F., Avelar, A., & Cyrino, E. S. (2014). Effect of different warm-up procedures on the performance of resistance training exercises. *Perceptual and Motor Skills*, *119*(1), 133–145. https://doi.org/10.2466/25.29.PMS.119c17z7

Robbins, D. W., Young, W. B., & Behm, D. G. (2010). The Effect of an Upper-Body Agonist-Antagonist Resistance Training Protocol on Volume Load and Efficiency. *The Journal of Strength & Conditioning Research*, *24*(10), 2632–2640. https://doi.org/10.1519/JSC.0b013e3181e3826e

Robbins, D. W., Young, W. B., Behm, D. G., & Payne, W. R. (2009). Effects of agonist–antagonist complex resistance training on upper body strength and power development. *Journal of Sports Sciences*, *27*(14), 1617–1625. https://doi.org/10.1080/02640410903365677

Robbins, D. W., Young, W. B., Behm, D. G., & Payne, W. R. (2010a). The Effect of a Complex Agonist and Antagonist Resistance Training Protocol on Volume Load, Power Output, Electromyographic Responses, and Efficiency. *The Journal of Strength & Conditioning Research*, *24*(7), 1782–1789. https://doi.org/10.1519/JSC.0b013e3181dc3a53

Robbins, D. W., Young, W. B., Behm, D. G., & Payne, W. R. (2010b). Agonist-Antagonist Paired Set Resistance Training: A Brief Review. *The Journal of Strength & Conditioning Research*, *24*(10), 2873. https://doi.org/10.1519/JSC.0b013e3181f00bfc

Robbins, D. W., Young, W. B., Behm, D. G., Payne, W. R., & Klimstra, M. D. (2010). Physical Performance and Electromyographic Responses to an Acute Bout of Paired Set Strength Training Versus Traditional Strength Training. *The Journal of Strength & Conditioning Research*, *24*(5), 1237–1245. https://doi.org/10.1519/JSC.0b013e3181cc60ec

Schoenfield, B. (2017). *» Warming Up Prior to Resistance Training: An Excerpt from "Strong & Sculpted."* https://www.lookgreatnaked.com/blog/warming-up-prior-to-resistance-training-an-excerpt-from-strong-sculpted/

Simão, R., Farinatti, P. de T. V., Polito, M. D., Maior, A. S., & Fleck, S. J. (2005). Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercises. *Journal of Strength and Conditioning Research*, *19*(1), 152–156. https://doi.org/10.1519/1533-4287(2005)19<152:IOEOOT>2.0.CO;2

Steele, J., McGuff, D., Fisher, J., Bruce-Low, S., & Smith, D. (2012). *(PDF) Resistance training to momentary muscular failure improves cardiovascular fitness in humans: A review of acute physiological responses and chronic physiological Adaptations*. ResearchGate. https://www.researchgate.net/publication/236462397_Resistance_training_to_momentary_muscular_failure_improves_cardiovascular_fitness_in_humans_A_review_of_acute_physiological_responses_and_chronic_physiological_Adaptations

Strength level. (2019). *Strength Level—Weightlifting Calculator (Bench/Squat/Deadlift)*. https://strengthlevel.com/

Suchomel, T. J., Nimphius, S., Bellon, C. R., & Stone, M. H. (2018). The Importance of Muscular Strength: Training Considerations. *Sports Medicine (Auckland, N.Z.)*, *48*(4), 765–785. https://doi.org/10.1007/s40279-018-0862-z

Unhjem, B. (2020). *Masteroppgave (Tittel uavklart)*.

Weakley, J. J. S., Till, K., Read, D. B., Roe, G. A. B., Darrall-Jones, J., Phibbs, P. J., & Jones, B. (2017). The effects of traditional, superset, and tri-set resistance training structures on perceived intensity and physiological responses. *European Journal of Applied Physiology*, *117*(9), 1877–1889. https://doi.org/10.1007/s00421-017-3680-3

Weil, R. (2008, March 9). *Resistance Training Exercises: Benefits, Definition & Examples*. https://www.emedicinehealth.com/strength_training/article_em.htm#how_does_resistance_exercise_work

Weiss, L. (1999). Differential Functional Adaptations to Short-Term Low-, Moderate-, and High-Repetition Weight Training. *Journal of Strength and Conditioning Research*. https://www.academia.edu/19140154/Differential_Functional_Adaptations_to_Short-Term_Low-_Moderate-_and_High-Repetition_Weight_Training

White, J. B. (2011). *Effects of Supersets Versus Traditional Strength Training Methods on Muscle Adaptations, Recovery, and Selected Anthropometric Measures* [Ohio University]. https://etd.ohiolink.edu/pg_10?0::NO:10:P10_ACCESSION_NUM:ohiou1305138820

White, J. B., Hikita, R., & Ogles, B. (2011). *Of the requirements for the degree*. 128.
WHO. (2018). *NCDs | Global action plan on physical activity 2018–2030: More active people for a healthier world*. WHO. http://www.who.int/ncds/prevention/physical-activity/global-action-plan-2018-2030/en/

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