The effects of low volume resistance training with and without advanced techniques in trained participants.

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Abstract

Aim: This study examined low volume resistance training (RT) in trained participants with and without advanced training methods.

Methods: Trained participants (RT experience 4$\pm$3 years) were randomised to groups performing single set RT; ssRM (n = 21) performing repetitions to self-determined repetition maximum (RM), ssMMF (n = 30) performing repetitions to momentary muscular failure (MMF), and ssRP (n = 28) performing repetitions to self-determined RM using a rest pause (RP) method. Each performed supervised RT 2x/week for 10 weeks. Outcomes included maximal isometric strength and body composition using bioelectrical impedance analysis.

Results: The ssRM group did not significantly improve in any outcome. The ssMMF and ssRP groups both significantly improved strength ($p \leq 0.05$). Magnitude of changes using effect size (ES) was examined between groups. Strength ES's were considered large for ssMMF (0.91 to 1.57) and ranging small to large for ssRP (0.42 to 1.06). Body composition data revealed significant improvements ($p \leq 0.05$) in muscle and fat mass and percentages for whole body, upper limbs and trunk for ssMMF, but only upper limbs for ssRP. Body composition ES's ranged moderate to large for ssMMF (0.56 to 1.27) and ranged small to moderate for ssRP (0.28 to 0.52). ssMMF also significantly improved ($p \leq 0.05$) total abdominal fat and increased intracellular water with moderate ES's (-0.62 and 0.56 respectively).

Conclusion: Training to self-determined RM is not efficacious for trained participants. Training to MMF produces greatest improvements in strength and body composition, however, RP style training does offer some benefit.

Keywords: Muscular failure; repetition maximum; rest-pause; volitional fatigue

Introduction

Recent reviews suggest similar increases in strength and hypertrophy between single and multiple set resistance training (RT) protocols proposing intensity of effort to be of most significance for adaptation[1,2]. Attaining maximal intensity of effort by training to momentary muscular failure (MMF) maximally recruits motor units through the size principle[3-5]. Further, load or total repetitions prior to reaching momentary muscular failure, appears of less importance also[6,7].

Whilst evidence suggests training to MMF, confers the greatest adaptation many studies have considered repetition maximum (RM) protocols yet imply participants exercised to MMF. Ambiguity regarding definition of *'intensity of effort'* in RT has been discussed recently[4,5], as has the vagueness surrounding definition and practical application of RM[8,9]. We have previously defined MMF as the point at which a person is unable to perform anymore concentric contractions without change to posture or repetition duration[1]. However, when attempting to reach MMF a person completing a repetition must always *attempt* a further repetition for confirmation. As such, MMF occurs when a person cannot produce sufficient force to complete their current repetition[10], and RM would be defined as the number of *complete* repetitions prior to MMF. In practice, however, prescription of training to an RM necessitates prior load determination regularly for a *true* RM. Should the exercise be ended once the trainee determines they could not complete further repetitions if attempted (i.e. they predict MMF on the next repetition), this might be considered *volitional fatigue* or *self-determined RM*, not a true RM or MMF. Indeed it is difficult to tell whether persons reported as training to RM have or have not done so, or if they in fact trained to MMF[10]. Even experienced trainees in fact under-predict the number of possible repetitions to MMF[11]. These distinctions are important as some suggest the success of low volume RT is dependent upon sufficient intensity of effort achieved through training to MMF[9].

Strength and hypertrophy adaptations are greater in untrained persons compared to advanced trainees where response diminishes with training experience[2]. Advanced trainees involved in RT for many years make nominal improvements and often demonstrate a plateau[12]. Though training to MMF appears the most important variable determining improvements in strength and hypertrophy, and could be considered an advanced technique, others speculate that adaptation might be optimised through manipulation of other RT variables (i.e. load, volume) to accommodate the range of potential adaptive mechanisms[13]. Further, this might become even more imperative when considering trained populations. Thus many advocate the use of advanced training methods based on knowledge of adaptive mechanisms in addition to anecdotal experiences[13,14].

One such method recommended for trained persons is rest-pause (RP) training[14,15]. Considering potential mechanisms of muscular adaptation[13], RP training may optimise both load and volume in unison creating greater mechanical tension, metabolic stress and muscle damage, by allowing a greater number of repetitions with a heavier load due to brief rest periods between repetitions. However, this method shows limited evidence, and has been described and applied with differing methodological approaches.

Keogh, et al.[16] considered acute muscle activation of RP training compared to heavy weight training (HWT- defined as 6-repetition maximum (RM)). They described RP training as normal isoinertial concentric actions, followed by 2 second unloaded rest period at the end of each contraction. Significantly lower values were reported for concentric and eccentric EMG of the pectoralis major for the final repetition with RP compared to HWT. Marshall, et al.[17] considered muscle activation for RP describing their protocol as using a fixed volume-load (20 repetitions of the squat exercise) involving an initial set performed to MMF (~10-12 repetitions) and subsequent sets performed to MMF as required using short (e.g. 20 second) inter-set rest intervals in order to achieve the desired volume-load. They reported higher activation for 4 of 6 muscles for the RP method compared to two other protocols equated for volume and load but not to MMF. Finally, Mentzer and Little[15] advocate RP training for advanced trainees and anecdotally recommend the use of single maximal repetitions (e.g. 1RM) interspersed with ~10 second rest intervals suggesting that following only a few repetitions it might be necessary to reduce the load by ~10%, and persons should perform 4-6 repetitions.

Volume in RT (i.e. single and multiple sets) has been examined extensively with similar results regardless of its manipulation. However, though RP training may have the potential to augment adaptations through optimisation of a variety of potential mechanisms (mechanical tension, metabolic stress and muscle damage) the technique has yet to be examined as a chronic training intervention alone or in comparison to typical low volume approaches such as training to MMF. Thus the present study aimed to evaluate the efficacy of low volume RT in a trained population with or without the use of advanced techniques, specifically, training to MMF and RP training. It was hypothesised that the use of advanced techniques in low volume RT would enhance strength and body composition outcomes and that RP training would result in the greatest adaptations.

Materials and Methods

Study Design

A randomised controlled trial was adopted with three experimental groups examining three RT interventions in trained participants upon strength and body composition. The study design was approved by the relevant ethics committee at the author's institution.

Participants

Participants were required to have no medical condition for which RT is contraindicated to participate. Participants were existing clients at the facility where the research was undertaken. At the facility participants kept detailed records of their training and based upon these all had been regularly engaged in full body RT ~2x/week, training to a self-determined RM, for at least 12 months prior to participation. Power analysis of research using low volume RT in trained participants[18] was conducted to determine participant numbers (n) using an effect size (ES), calculated using Cohen's *d*[19], of 1.02 for the improvements in strength. Participant numbers were calculated using equations from Whitley and Ball[20] revealing each group required 15 participants to meet required power of 0.8 at an alpha value of $p \leq .0.05$. Written informed consent was obtained from all participants.

Seventy nine participants (males n = 54, females n = 25) were initially identified and recruited through a public leisure facility where the research was conducted. A CONSORT diagram highlighting participant numbers for enrolment, allocation, follow-up and analysis stages is available as supplementary material. No initial dropouts were recorded after eligibility assessment so seventy nine participants were randomised using a computer randomisation program to one of three groups performing low volume single set RT; a group training to their self-determined RM (ssRM; n = 21), a group training to MMF (ssMMF; n = 30), and a group training using RP method (ssRP; n = 29).

Equipment

Strength was measured using an isometric testing device (Strength Meter, Kieser Training AG, Zürich) combined with resistance machines also used for training (MedX, Kieser Training AG, Zürich). The Strength Meter is a mobile device for combined use with the resistance machines used here. The meter is inserted into holes on the weight stack guide rod such that when the movement arms are exerted against their movement is prevented. Internal strain gauges upon its upper and lower side measure electrical signals and convert to a force in newtons (N). Procedures for strength testing are discussed below. Body composition including body mass, whole body muscle and fat mass and percentage, visceral fat rating (total abdominal fat – see below), bone mass, muscle and fat mass and percentage for individual body segments (Left and right upper and lower limbs and trunk), total body water, and both extra- and intra-cellular water was estimated using bioelectrical impedance (Tanita MC 180, Tanita Co., Ltd, Japan). This device is reported as valid compared with dual energy X-ray absorptiometry for estimating total and segmental body composition in healthy adults[21], however, 'visceral fat rating' has been reported better representative of total abdominal fat compared with magnetic resonance imaging[22] and is referred to as such herein.

Participant Testing

Maximal isometric strength was tested for left and right knee extension and flexion, trunk flexion, chest press, and elbow flexion. Test positions for each were standardised between participants. For knee extension participants were tested with the shank at 70 degrees relative to the thigh, and at 80 degrees for knee flexion. For trunk flexion participants were tested at 15 degrees of flexion with their arms crossed over their chest and hands placed upon their opposite shoulders. For chest press participants were tested with their elbows at 90 degrees in the frontal plane and 0 degrees in the transverse plane relative to the torso. Finally, for elbow flexion participants were tested at 115 degrees of elbow flexion with the upper arms rested upon the machines pad. On each test the following procedure was followed. After a warm-up consisting of 4 full range of motion repetitions using a light load and a repetition duration of ~10 seconds (4-2-4 seconds for concentric, isometric hold, and eccentric phases respectively) participants made contact with the movement arm and lifted to the point where the movement arm was locked for testing. They then gradually increased effort against the movement arm taking ~3 seconds to reach maximal effort, maintaining maximal effort for ~1 second, and then gradually reducing effort to rest taking ~3 seconds. An initial practice attempt using just 50% of perceived maximal effort was permitted and then four attempts at maximal isometric contractions for each test. Twenty seconds between each attempt was allowed and the highest measurement was recorded. Testing was supervised by one instructor; however, they did not provide verbal encouragement. Testing was performed twice, on separate days (at least 48 hours apart to avoid residual fatigue or soreness) before and after the intervention and the highest results from either were used. Body composition was tested on a separate day from strength testing both before and after the intervention following the manufacturer's guidelines.

Participant Training (ssRM, ssMMF, ssRP)

Training was conducted 2x/week (at least 48 hours between sessions) for 10 weeks. Participants were asked to refrain from any other training during this period. Each group performed a single set of the following exercises in this order; hip extension, knee extension, knee flexion, trunk flexion, pull-over, pull-down/pull-ups, chest press, biceps curl. The ssRP group performed a warm-up set of 5 repetitions using 50% of their training weight prior to their working set. The ssMMF group also performed a pec deck exercise prior to the chest press and the ssRP group performed a seated row instead of pull-down to avoid participants having to wait in a stretched position between repetitions as the movement arms start position required standing to grasp it. Rest between each exercise lasted only as long as required to move from one exercise to the next. The following loads relative to measured strength values were utilised; ssRM used 60%, ssMMF used 80%, and RP used 90%. Each group used a repetition duration of ~10 seconds (4-2-4 seconds) and performed each exercise through full range of motion. The ssRM group performed repetitions until they reached their self-determined RM, meaning when they determined inability to complete further repetitions if attempted (i.e. they predicted MMF on the next repetition and thus ceased the set at that point). The ssMMF group performed repetitions to the point of MMF (i.e. when they reached a point of concentric failure during a repetition). The ssRP group also performed repetitions to self-determined RM, however, after each complete repetition they rested for ~5-20 seconds at the bottom of the range of motion before performing the next repetition. Load was progressed for each group by 5% once participants attained certain conditions; the ssRM group was progressed once they were able to complete more than 12 repetitions before reaching self-determined RM, the ssMMF group was progressed once they were able to complete more than 9 repetitions before reaching MMF, the ssRP group was progressed once they were able to complete more than 18 repetitions before reaching self-determined RM. Thus relative work volume was approximately matched between the ssRM (60% load x ~12 repetitions) and ssMMF (80% load x ~9 repetitions) groups but was greater in ssRP due to both increased load and repetitions (90% load x ~18 repetitions).

Data Analysis

Some participants were unavailable for follow up or dropped out of the study citing lack of time. For strength outcomes data was available from 66 participants (ssRM n = 16, ssMMF n = 24, ssRP n = 26). For body composition outcomes data was available from 49 participants (ssRM n = 8, ssMMF n = 21, ssRP n = 20). The majority of outcomes did not meet assumptions of normality when examined using a Kolmogorov-Smirnov test and so non-parametric analysis was utilised. Baseline data was compared between groups using a Kruskal-Wallis one way analysis of variance to determine whether randomisation had succeeded. Wilcoxon Signed Ranks Exact test was used to compare across the independent conditions for changes in each of the dependent variables. Statistical analysis was performed using SPSS statistics computer package (vs.20) and $p \leq .05$ set as the limit for statistical significance. Further, 95% confidence intervals (CI) were calculated in addition to ES using Cohen's *d*[19] for each outcome to compare magnitude of effects between groups where an ES of 0.20-0.49 was considered as small, 0.50-0.79 as moderate and ≥0.80 as large.

Results

Particpants

Participant demographics are shown in Table 1. Comparison between groups did not reveal any significant differences at baseline.

Strength

Table 2 shows pre and post, mean changes and ES for maximal isometric strength for each group and exercise. Comparison between groups did not reveal significant differences in strength for any exercise at baseline. Wilcoxon Signed Ranks Exact test revealed no significant changes from pre to post for the ssRM group. The ssMMF group presented significant changes in knee extension for both the left ($Z = -3.586$, $p < 0.001$) and right (Z = -3.572, p < 0.001) limbs, trunk flexion (Z = -3.772, p < 0.001), chest press (Z = -3.772, p < 0.001) and elbow flexion (Z = -4.114, p < 0.001). The ssRP group presented significant changes in knee extension for both the left (Z = -2.299, p = 0.022) and right (Z = -3.660, p < 0.001) limbs, knee flexion for the left limb (Z = -1.969, p = 0.049), trunk flexion (Z = -3.353, p = 0.001), chest press (Z = -4.026, p < 0.001) and elbow flexion (Z = -3.660). ES for significant strength changes in the ssMMF group were considered to be large (0.91 to 1.57). ES for significant strength changes in the ssRP group were considered to range from small to large (0.42 to 1.06). Average relative increases in strength ranged from 12.39% to 48.94% for ssMMF group, and 10.76% to 34.40% for the ssRP group.

Body Composition

Full pre and post, mean changes and ES for body composition data for each group are included in the supplementary materials. Comparison between groups did not reveal significant differences in body composition data for any variable at baseline. Wilcoxon Signed Ranks Exact test revealed no significant changes from pre to post for the ssRM group. The ssMMF group presented significant changes in muscle percentage (Z = -2.837, p = 0.005), fat mass (Z = -3.164, p = 0.002), fat percentage (Z = -2.913, p = 0.004), total abdominal fat (Z = -2.449, p = 0.014), right arm muscle mass (Z = -3.541, p < 0.001), fat mass (Z = -3.475, p = 0.001) and fat percentage (Z = -3.747, p < 0.001), left arm muscle mass (Z = -2.813, p = 0.005), fat mass (Z = -3.337, p = 0.001) and fat percentage (Z = -3.425, p = 0.001), trunk fat mass (Z = -2.851, p = 0.004) and fat percentage (Z = -3.095, p 0.002), and intra-cellular water (Z = -2.104, p = 0.035). The ssRP group presented significant changes in right arm muscle mass (Z = -2.423, p = 0.015), fat mass (Z = -2.041, p = 0.041) and fat percentage (Z = -2.541, p 0.011), and left arm muscle mass (Z = -2.265, p = 0.024) and fat percentage (Z = -2.014, p = 0.044). ES for significant changes in the ssMMF group were considered to range from moderate to large (0.56 to 1.27). ES for significant changes in the ssRP group were considered to range from small to moderate (0.28 to 0.52). Average relative increases in upper limb muscle mass ranged from 2.19% to 3.11% for ssMMF group, and 1.52% to 2.33% for the ssRP group.

Discussion

This study examined addition of advanced training methods to low volume RT for trained participants. Results suggested low volume RT performed to self-determined RM may be insufficient to induce further strength and body composition adaptations in trained persons as evidenced by lack of significant changes and marginal ES's for the ssRM group. This may be due to even experienced trainee's underestimating possible repetitions to MMF when performing low volume RT thus impacting intensity of effort[11]. Meta-analyses have concluded low volume RT is less efficacious than higher volume RT[23,24]. These analyses have however received criticism[25,26] and it is argued that if intensity of effort is sufficiently high then low volume RT is as efficacious as higher volume RT[1,2,9]. Others, however, argue that for maximal adaptations many RT variables should be manipulated to accommodate the myriad potential adaptive mechanisms including muscular tension, metabolic stress and muscle damage[13].

In this study two further groups of trained participants performed low volume RT using advanced training methods. One group trained to MMF (ssMMF) and the other used a version of the RP method (ssRP). Though significant improvements in strength were found in both ssMMF and ssRP groups for all exercises tested (with the exception of knee flexion - though the ssRP significantly improved left knee flexion strength), the magnitude of improvements differed between the groups. The ssMMF group demonstrated ES's considered as large for all significantly improved exercises, and were similar or greater compared with the ssRP group. Results were similar for body composition changes. The ssMMF group demonstrated significant improvements in total muscle and fat percentage coincident with significant reduction in fat mass and non-significant increase in muscle mass. Whole body changes for the ssRP did not achieve significance and ES's were lower compared with the ssMMF. Though significant changes were not seen for lower body segments in either group, both ssMMF and ssRP showed significant improvements in muscle mass, fat mass and fat percentage for both upper limbs (and the trunk also for ssMMF), however, ES's were ~≥50% greater for the ssMMF group.

Recent research has reported significant and meaningful changes in both strength and body composition with low volume RT for trained participants when utilising single sets per exercise performed to MMF[27]. These and the present results support the importance of intensity of effort in RT, and potentially the importance of motor unit recruitment, by training to MMF. Though the ssRP group trained with both a greater relative load and, due to the between repetition rest employed, a greater repetition volume, mechanical tension, metabolic stress, and muscle damage might have been enhanced for this group facilitating adaptations. The ssRP group, however, did not train to MMF instead stopping at self-determined RM. Training to MMF maximally recruits motor units perhaps offering greatest potential for muscular adaptation[1-3]. Previous studies examining similar methods employing intra-set rest and RP style RT demonstrate greater acute muscle activation and potentially improved chronic effects from training to high intensity of effort.

Goto, et al.[28] compared two groups performing RT with their pre-determined 10RM. The first group performed all 10 repetitions in each set without rest (NR), whilst the second group rested 30 seconds mid-way through the set (e.g. between the 5th and 6th repetitions - WR). Increases in cross-sectional area of the quadriceps were significantly greater for NR compared to WR (12.9 ±1.3% vs. 4.0 ±1.2% respectively). This suggests continuous, sequential recruitment of motor units in the NR group potentially enhanced muscle hypertrophy, whilst the WR group allowed some motor units to recover preventing recruitment of higher threshold motor-units.

As noted Keogh, et al.[16] reported that RT performed using a 6RM with continuous repetitions (though not clarified specifically as being performed to MMF) compared to the same workload performed RP style, using a 2 second unloaded rest period at the end of each repetition, produced significantly greater muscle activation. Marshall, et al.[17], utilising a different application of RP training where participants performed a set repetition number (20 repetitions) by performing repetitions to MMF then rested 20 seconds before continuing to MMF again until all repetitions were completed, reported greater muscular activation with this protocol compared to two other work matched non-continuous protocols. Keogh, et al.[16] attributed lower activation values to the amount of rest between repetitions, suggesting that their RP protocol might produce inferior strength and hypertrophy than traditional HWT due to absence of constant muscular tension. However, Marshall, et al.[17] reported significantly higher activation for their RP protocol, likely due to the constant muscular tension and repetitions to MMF.

Different methods of applying RP style training exist; either throughout a regular set of RT (to RM or MMF) or employed at the end of a set of RT to MMF. Future studies might therefore examine whether these variations produce differing adaptations and whether or not adaptations resulting from RP style RT performed to MMF differ from conventional RT performed to MMF.

A further finding from this study was the effect of RT to MMF upon total abdominal fat. The ssMMF demonstrated significant reduction in this outcome with a moderate ES. Though previous studies suggest RT can produce reductions in visceral fat a recent meta-analysis concluded RT was not significantly greater compared with controls and that aerobic exercise was more efficacious[29]. However, this meta-analysis included only studies using computed tomography or magnetic resonance imaging. These methods better represent visceral fat and as noted the testing conducted in this study more validly estimates total abdominal fat[22]. It may be the case that the reduction in total abdominal fat reported was due to reduction in subcutaneous abdominal fat.

Though our results suggest intensity of effort through training to MMF, and thus perhaps motor unit recruitment, is important for optimal improvements in trained persons, alternative mechanisms may also be influential. Increased intra-cellular water content has been speculated to contribute to hypertrophic adaptation, due to its influence upon processes mediating protein synthesis and degradation, and that highly glycolytic exercise, resultant lactate accumulation, and recruitment of fast twitch motor units maximises this response[13]. Indeed, Ribeiro et al.[30] recently examined an RT program in untrained participants designed to emulate characteristic higher volume 'body-building' training. Participants trained for 16 weeks 3x/week performing 10-12 full body exercises using 3 sets per exercise and performing repetitions using a load permitting 8-12 before reaching MMF. They reported significant improvements in total body and intra-cellular water with moderate ES's. The authors considered the specific nature of the RT program employed, using higher volume and moderate repetition range, may be responsible for their findings. Our results, however, also revealed significant improvements in intra-cellular water, and non-significant improvement in total body water, for the ssMMF group with moderate ES's. Though the RT interventions between our study and Ribeiro et al.[30] differed in many respects, both utilised RT to MMF. Thus changes in intra-cellular water content resulting from RT to MMF may be one of the mechanisms through which it maximises muscular adaptations.

Finally, a curious result found in this study regards the bilateral differences in strength gains for knee extension and flexion. Previous research examining unilateral strength gains in response to bilateral RT for the lower limbs has reported similar adaptations[31]. The reason for our different results are not clear. It has been found that bilateral training may induce differential changes between the limbs in maximal integrated EMG during knee extension[32], thus bilateral differences here may be due to neuromuscular adaptation. It might be speculated that this relates to the dominant limb during bilateral exercises. Unfortunately we did not clarify our participant's dominant limbs, nor have previous studies[31,32], and thus this cannot be clarifies. However, that there was not a clear trend towards greater gains in either the right or left limb that was consistent across the groups suggests this may merely be an anomaly within our results.

It is worth noting the strengths and limitations of this study. Firstly, this study was conducted in trained participants and thus adds to the relatively sparse data existing on this population. Further the ssRM and ssMMF groups were matched for relative work volume allowing examination of the role of training to MMF in low volume RT for trained persons. However, the use of isometric strength testing specific to the resistance machines used in the study limits the extent to which results can be extrapolated to other strength tasks. Further, though bioelectrical impedance analysis for estimating body composition is a practical method, it is not considered the gold standard nor can it determine muscular hypertrophy in the form of CSA changes. Future research should consider the use of more validated measures such as magnetic resonance imaging, computed tomography or ultrasound which would also provide greater information regarding muscle hypertrophic and architectural changes. Finally, there was variation in exercise selection between the groups, particularly for practical reasons for the ssRP group, and so between group differences might be influenced by this factor. Also after randomisation the ratio of males to females differed slightly between the groups with proportionately more females in ssRM>ssMMF>ssRP. Though we might expect the greater number of males in the ssRP group to result in greater improvements this was not found, however, the greater results for the ssMMF compared with the ssRM may be due to this factor.

Conclusion

These results suggest significant and meaningful improvements in strength and body composition are possible in trained participants using low volume RT when advanced techniques are utilised. Contrary to our original hypothesis, our results suggest training to MMF offers the most efficacious results; however, RP style training also produced significant improvements. Studies on RP to date have been acute and utilised differing applications of this method. This is the first chronic study to our knowledge and so future chronic research should compare differing applications of RP methods and also RP style RT performed to MMF. Training to MMF also increased intra-cellular water which may facilitate the greater improvements resulting from such training. We recommend trained participants should incorporate RT to MMF in their training regimes to maximise results.

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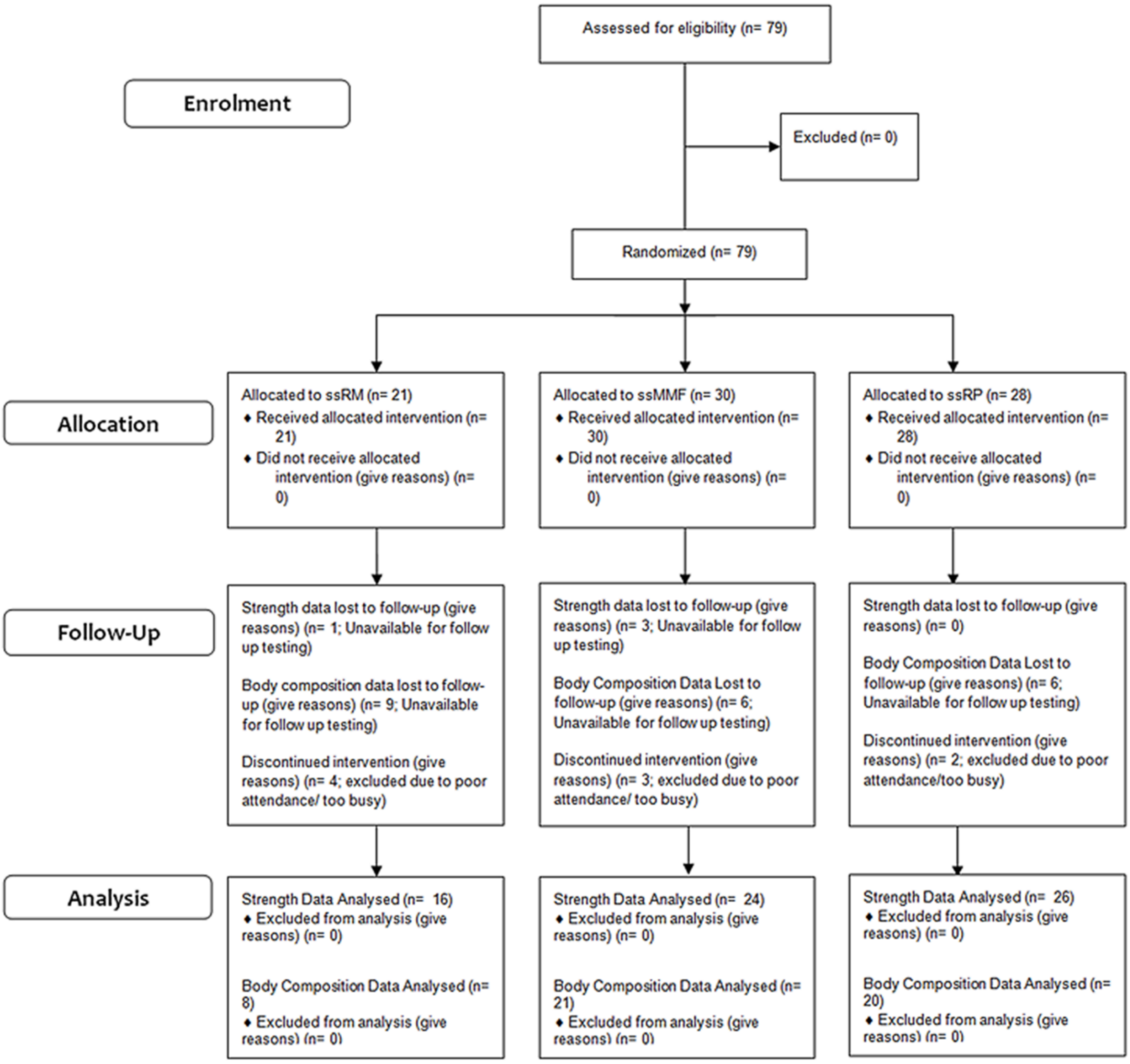
Table & Figure Titles

- Figure 1. CONSORT diagram
- Figure 2. Strength Meter used in combination with resistance machines for measuring isometric strength.
- Table 1. Participant demographic characteristics
- Table 2. Pre, post, mean change and effect sizes for strength data
- Table 3. Pre, post, mean change and effect sizes for body composition data


Assessed for eligibility (n= 79)
Enrolment
Excluded (n= 0)
Randomized (n= 79)
Allocation
Allocated to ssRM (n= 21)
♦ Received allocated intervention (n= 21)
♦ Did not receive allocated intervention (give reasons) (n= 0)
Allocated to ssMMF (n= 30)
♦ Received allocated intervention (n= 30)
♦ Did not receive allocated intervention (give reasons) (n= 0)
Allocated to ssRP (n= 28)
♦ Received allocated intervention (n= 28)
♦ Did not receive allocated intervention (give reasons) (n= 0)
Follow-Up
Strength data lost to follow-up (give reasons) (n= 1; Unavailable for follow up testing)
Body composition data lost to follow-up (give reasons) (n= 9; Unavailable for follow up testing)
Discontinued intervention (give reasons) (n= 4; excluded due to poor attendance/ too busy)
Strength data lost to follow-up (give reasons) (n= 3; Unavailable for follow up testing)
Body Composition Data Lost to follow-up (give reasons) (n= 6; Unavailable for follow up testing)
Discontinued intervention (give reasons) (n= 3; excluded due to poor attendance/ too busy)
Strength data lost to follow-up (give reasons) (n= 0)
Body Composition Data Lost to follow-up (give reasons) (n= 6; Unavailable for follow up testing)
Discontinued intervention (give reasons) (n= 2; excluded due to poor attendance/too busy)
Analysis
Strength Data Analysed (n= 16)
♦ Excluded from analysis (give reasons) (n= 0)
Body Composition Data Analysed (n= 8)
♦ Excluded from analysis (give reasons) (n= 0)
Strength Data Analysed (n= 24)
♦ Excluded from analysis (give reasons) (n= 0)
Body Composition Data Analysed (n= 21)
♦ Excluded from analysis (give reasons) (n= 0)
Strength Data Analysed (n= 26)
♦ Excluded from analysis (give reasons) (n= 0)
Body Composition Data Analysed (n= 20)
♦ Excluded from analysis (give reasons) (n= 0)


RESET

Table 1. Participant demographic characteristics

	ssRM	ssMMF	ssRP	p
Age (years)	42±7	45±8	42±7	0.410
Stature (cm)	180.25±10.63	178.38±9.53	179.05±7.80	0.811
Body Mass (kg)	80.64±17.68	77.54±14.20	76.48±14.74	0.826
BMI	24.65±3.89	24.30±3.67	23.75±3.74	0.669
Training Experience (years)	4±3	4±5	4±5	0.534
Gender Ratio (Males:Females)	1.67:1	2.43:1	3.33:1	N/A

Note: Results are mean ±SD

Table 2. Pre, post, mean change and effect sizes for body composition data

Group	Pre	Post	Change	95% CI	p	ES
Knee Extension L						
ssRM	1003.31±391.96	1104.25±300.09	100.94±235.34	-24.46 to 226.33	0.098	0.22
ssMMF	969.04±377.16	1122.67±393.88	153.63±164.76	84.05 to 223.20	<0.001	0.93
ssRP	1097.35±439.73	1174.54±373.04	77.19±184.48	2.68 to 151.71	0.022	0.42
Knee Extension R						
ssRM	1048.94±362.20	1095.50±284.20	46.56±210.62	-65.67 to 158.80	0.313	0.22
ssMMF	966.04±382.73	1129.29±368.93	163.25±166.45	92.96 to 233.54	<0.001	0.98
ssRP	1090.46±423.10	1222.69±377.64	132.23±124.53	81.93 to 182.53	<0.001	1.06
Knee Flexion L						
ssRM	541.25±134.15	526.69±124.56	-14.56±103.70	-69.82 to 40.70	0.552	-0.14
ssMMF	477.75±175.01	512.58±152.24	34.83±163.90	-34.38 to 104.04	0.568	0.21
ssRP	500.92±157.23	553.73±167.42	52.81±121.61	3.69 to 101.93	0.049	0.43
Knee Flexion R						
ssRM	532.19±139.21	538.63±157.39	6.44±103.51	-48.72 to 61.60	0.679	0.06
ssMMF	511.83±175.18	553.63±167.19	41.79±141.72	-18.05 to 101.64	0.242	0.29
ssRP	547.04±180.50	579.54±184.81	32.5±138.82	-23.57 to 88.57	0.218	0.23
Trunk Flexion						
ssRM	229.00±105.42	250.75±107.30	21.75±61.81	-11.19 to 54.69	0.211	0.35
ssMMF	195.96±100.74	272.833±130.78	76.88±84.03	41.39 to 112.36	<0.001	0.91
ssRP	246.54±128.92	307.54±134.92	61.00±77.10	29.86 to 92.14	0.001	0.79
Chest Press						
ssRM	1202.56±473.00	1261.75±497.19	59.19±130.83	-10.53 to 128.90	0.079	0.45
ssMMF	1310.54±512.60	1441.08±502.61	130.54±108.55	84.71 to 176.38	<0.001	1.20
ssRP	1422.00±587.45	1607.00±637.25	185.00±197.37	105.28 to 264.72	<0.001	0.94
Elbow Flexion						
ssRM	504.19±237.21	516.44±213.71	12.25±51.29	-15.08 to 39.58	0.293	0.24
ssMMF	489.13±211.41	556.83±204.36	67.71±43.09	49.51 to 85.90	<0.001	1.57
ssRP	554.96±230.80	624.96±203.27	93.56±115.82	45.75 to 141.37	<0.001	0.81

Note: Results are mean ±SD; 95% CI for changes; p values for pre to post comparisons analysed using Wilcoxon Signed Ranks Exact test; ES = Cohen's *d*

Table 3. Pre, post, mean change and effect sizes for body composition data

Group	Pre	Post	Change	95% CI	p	ES
Whole body						
Muscle Mass (kg)						
ssRM	60.30±11.41	59.68±12.30	-0.65±1.90	-2.21 to 0.96	0.441	-0.33
ssMMF	59.46±10.57	59.90±10.75	0.44±1.21	-0.11 to 0.99	0.139	0.36
ssRP	59.07±11.33	59.45±11.35	0.37±1.86	-0.50 to 1.24	0.073	0.20
Muscle Percentage						
ssRM	75.43±7.24	75.67±6.59	-0.76±2.49	-2.84 to 1.31	0.575	-0.31
ssMMF	76.79±5.50	77.75±5.88	0.96±1.26	0.39 to 1.54	0.005	0.76
ssRP	77.40±6.14	78.13±5.95	0.73±2.14	-0.27 to 1.73	0.062	0.34
Fat Mass (kg)						
ssRM	17.19±8.61	17.57±8.05	0.38±1.58	-0.94 to 1.70	0.889	0.24
ssMMF	14.99±6.20	14.12±6.35	-0.86±0.99	-1.32 to -0.41	0.002	-0.87
ssRP	14.30±6.42	13.77±6.33	-0.54±1.73	-1.35 to 0.28	0.173	-0.31
Fat Percentage						
ssRM	20.61±7.64	21.41±6.93	0.8±2.63	-1.40 to 3.00	0.673	0.30
ssMMF	19.19±5.76	18.17±6.17	-1.02±1.32	-1.62 to -0.42	0.004	-0.77
ssRP	18.54±6.46	17.78±6.24	-0.76±2.28	-1.83 to 0.31	0.076	-0.33
Total Abdominal Fat (rated 1 to 59)						
ssRM	6.25±4.23	6.50±4.00	0.25±0.46	-0.14 to 0.64	0.157	0.54
ssMMF	6.38±3.51	6.10±3.43	-0.29±0.46	-0.50 to -0.08	0.014	-0.62
ssRP	5.45±3.03	5.30±3.08	-0.15±0.93	-0.59 to 0.29	0.477	-0.16
Bone Mass (kg)						
ssRM	3.18±0.56	3.13±0.61	-0.05±0.96	-0.13 to 0.03	0.141	-0.52
ssMMF	3.10±0.52	3.13±0.53	0.03±0.07	0.00 to 0.06	0.101	0.40
ssRP	3.10±0.54	3.11±0.55	0.01±0.10	-0.04 to 0.06	0.226	0.10
Right Leg						
Muscle Mass (kg)						
ssRM	10.18±2.06	9.96±2.14	-0.22±0.51	-0.65 to 0.21	0.400	-0.43
ssMMF	10.08±1.96	10.07±1.99	-0.01±0.29	-0.14 to 0.12	0.736	-0.02
ssRP	9.96±2.03	10.01±2.03	0.04±0.37	-0.13 to 0.21	0.246	0.12
Fat Mass (kg)						
ssRM	2.83±1.50	3.00±1.47	0.17±0.38	-0.15 to 0.49	0.324	0.44
ssMMF	2.34±0.98	2.30±1.01	-0.04±0.17	-0.12 to 0.03	0.207	-0.25
ssRP	2.36±0.99	2.30±0.98	-0.06±0.26	-0.19 to 0.06	0.267	-0.24
Fat Percentage						
ssRM	20.58±10.45	22.09±10.28	1.15±3.66	-1.54 to 4.57	0.262	0.41
ssMMF	18.34±8.15	18.08±8.42	-0.26±1.48	-0.94 to 0.41	0.554	-0.18
ssRP	18.55±8.04	18.00±7.83	-0.55±1.98	-1.47 to 0.38	0.179	-0.27
Left Leg						
Muscle Mass (kg)						
ssRM	9.96±2.15	9.76±2.17	-0.19±0.40	-0.53 to 0.14	0.306	-0.48
ssMMF	9.80±1.84	9.79±1.88	-0.03±0.25	-0.14 to 0.09	0.501	-0.10
ssRP	9.69±2.01	9.72±2.03	0.03±0.30	-0.11 to 0.17	0.421	0.10
Fat Mass (kg)						
ssRM	2.79±1.38	2.93±1.37	0.14±0.31	-1.12 to 0.41	0.497	0.46
ssMMF	2.34±0.98	2.30±1.01	-0.04±0.15	-0.11 to 0.02	0.130	-0.29
ssRP	2.34±0.94	2.28±0.91	-0.06±0.22	-0.17 to 0.04	0.261	-0.28
Fat Percentage						
ssRM	20.85±10.08	22.04±9.95	1.19±2.82	-1.17 to 3.55	0.398	0.42
ssMMF	18.62±7.78	18.43±8.15	-0.19±1.33	-0.80 to 0.42	0.506	-0.14
ssRP	18.88±7.93	18.39±7.69	-0.49±1.65	-1.26 to 0.28	0.179	-0.30
Right Arm						
Muscle Mass (kg)						
ssRM	3.25±0.79	3.25±0.87	0.00±0.11	-0.09 to 0.09	1.000	0.00
ssMMF	3.26±0.80	3.36±0.84	0.10±0.09	0.06 to 0.14	<0.001	1.10
ssRP	3.27±0.87	3.31±0.89	0.05±0.16	-0.03 to 0.12	0.015	0.28
Fat Mass (kg)						
ssRM	0.92±0.46	0.91±0.41	-0.01±0.07	-0.07 to 0.05	0.581	-0.18
ssMMF	0.81±0.28	0.75±0.29	-0.06±0.06	-0.09 to -0.04	0.001	-1.09
ssRP	0.76±0.32	0.73±0.33	-0.04±0.07	-0.07 to 0.00	0.041	-0.51
Fat Percentage						
ssRM	20.29±7.79	20.45±6.77	0.16±2.07	-1.57 to 1.90	0.612	0.08
ssMMF	19.21±5.18	17.65±5.21	-1.56±1.23	-2.12 to -1.00	<0.001	-1.27
ssRP	18.22±5.91	17.11±6.49	-1.11±2.20	-2.13 to -0.08	0.011	-0.50
Left Arm						
Muscle Mass (kg)						
ssRM	3.25±0.84	3.27±0.94	0.02±0.12	-0.08 to 0.12	0.750	0.16
ssMMF	3.33±0.83	3.40±0.88	0.08±0.11	0.03 to 0.13	0.005	0.73
ssRP	3.30±0.93	3.38±0.98	0.08±0.16	0.00 to 0.16	0.024	0.49
Fat Mass (kg)						
ssRM	0.97±0.51	0.97±0.46	0.00±0.09	-0.07 to 0.07	0.891	0.00

ssMMF	0.83±0.31	0.79±0.31	-0.05±0.05	-0.07 to -0.03	0.001	-1.03
ssRP	0.79±0.34	0.76±0.35	-0.04±0.08	-0.07 to 0.00	0.054	-0.48
Fat Percentage						
ssRM	21.13±8.43	21.52±7.73	0.39±2.34	-1.57 to 2.35	1.000	0.17
ssMMF	19.25±5.06	18.03±5.06	-1.22±1.20	-1.77 to -0.68	0.001	-1.02
ssRP	18.56±6.11	17.64±6.61	-0.93±1.77	-1.75 to -0.10	0.044	-0.52
Trunk						
Muscle Mass (kg)						
ssRM	33.66±5.74	33.43±6.35	-0.23±1.00	-1.06 to 0.60	0.528	-0.23
ssMMF	33.01±5.32	33.29±5.32	0.28±0.75	-0.06 to 0.62	0.067	0.39
ssRP	32.86±5.69	33.04±5.66	0.18±1.05	-0.32 to 0.67	0.052	0.17
Fat Mass (kg)						
ssRM	9.70±5.68	9.79±5.14	0.09±0.92	-0.69 to 0.86	0.889	0.09
ssMMF	8.68±4.21	8.00±4.29	-0.68±0.79	-1.04 to -0.32	0.002	-0.86
ssRP	8.07±4.51	7.72±4.46	-0.35±1.31	-0.96 to 0.27	0.147	-0.27
Fat Percentage						
ssRM	20.31±8.02	20.90±6.69	0.59±2.58	-1.57 to 2.75	0.866	0.23
ssMMF	19.54±5.93	18.09±6.51	-1.45±1.87	-2.30 to -0.60	0.004	-0.78
ssRP	18.34±7.43	17.49±7.15	-0.85±3.05	-2.28 to 0.58	0.097	0.28
Total Body Water (kg)						
ssRM	44.57±7.73	44.12±8.43	-0.46±1.51	-1.73 to 0.80	0.484	-0.31
ssMMF	44.29±7.72	44.77±7.98	0.48±1.01	0.02 to 0.94	0.079	0.49
ssRP	44.42±8.68	44.59±8.67	0.17±2.54	-1.02 to 1.36	0.089	0.07
Extra-cellular Water (kg)						
ssRM	18.34±3.06	18.19±3.26	-0.15±0.41	-0.49 to 0.19	0.400	-0.37
ssMMF	18.07±2.78	18.15±2.80	0.07±0.33	-0.07 to 0.22	0.348	0.23
ssRP	17.87±3.01	17.98±3.04	0.12±0.34	-0.04 to 0.27	0.226	0.34
Intra-cellular Water (kg)						
ssRM	26.24±4.72	25.93±5.20	-0.31±1.12	-1.24 to 0.63	0.441	-0.27
ssMMF	26.22±4.98	26.63±5.23	0.40±0.72	0.07 to 0.73	0.035	0.56
ssRP	26.56±5.83	26.60±5.67	0.05±2.32	-1.04 to 1.13	0.057	0.02

Note: Results are mean ±SD; 95% CI for changes; p values for pre to post comparisons analysed using Wilcoxon Signed Ranks Exact test; ES = Cohen's *d*