Effects of a Modified German Volume Training Program on Muscular Hypertrophy and Strength

Theban Amirthalingam, Yorgi Mavros, Guy C. Wilson, Jillian L. Clarke, Lachlan Mitchell, and Daniel A. Hackett

Discipline of Exercise and Sport Science, University of Sydney, Sydney, Australia

Abstract

Amirthalingam, T, Mavros, Y, Wilson, GC, Clarke, JL, Mitchell, L, and Hackett, DA. Effects of a modified German volume training program on muscular hypertrophy and strength. *J Strength Cond Res* 31(11): 3109–3119, 2017—German Volume Training (GVT), or the 10 sets method, has been used for decades by weightlifters to increase muscle mass. To date, no study has directly examined the training adaptations after GVT. The purpose of this study was to investigate the effect of a modified GVT intervention on muscular hypertrophy and strength. Nineteen healthy men were randomly assign to 6 weeks of 10 or 5 sets of 10 repetitions for specific compound resistance exercises included in a split routine performed 3 times per week. Total and regional lean body mass, muscle thickness, and muscle strength were measured before and after the training program. Across groups, there were significant increases in lean body mass measures, however, greater increases in trunk ($p = 0.043$; effect size [ES] $= -0.21$) and arm ($p = 0.083$; ES $= -0.25$) lean body mass favored the 5-SET group. No significant increases were found for leg lean body mass or measures of muscle thickness across groups. Significant increases were found across groups for muscular strength, with greater increases in the 5-SET group for bench press ($p = 0.014$; ES $= -0.43$) and lat pull-down ($p = 0.003$; ES $= -0.54$). It seems that the modified GVT program is no more effective than performing 5 sets per exercise for increasing muscle hypertrophy and strength. To maximize hypertrophic training effects, it is recommended that 4–6 sets per exercise be performed, as it seems gains will plateau beyond this set range and may even regress due to overtraining.

Key Words resistance training, bodybuilding, weightlifting, multiple-sets, muscle mass, bulking

Address correspondence to Daniel A. Hackett, daniel.hackett@sydney.edu.au.

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Introduction

Resistance training is an integral part of an exercise program for apparently healthy, chronic disease, and athletic populations. Although there are numerous fitness and health benefits associated with resistance training (6,40), many people perform resistance training due to its effectiveness for increasing muscle mass and strength (17). Designing a resistance training program requires knowledge of acute training variables including frequency, intensity, and volume (sets × repetitions) (22). To maximize the training effect requires the appropriate manipulation of acute program variables. Current muscular hypertrophy and strength guidelines recommend a lower number of sets per exercise for novice/intermediate than for advanced trainers (1–3 and 3–6, respectively) (3). Thus, these guidelines support the notion that as resistance training experience increases, muscular hypertrophy and strength gains are optimized with higher (≥3 sets per exercise) compared with lower resistance training volumes (<3 sets per exercise).

Meta-analyses by Krieger (23,24) found that 2–3 sets of resistance exercises compared with a single set was associated with approximately 40% greater muscular hypertrophy and strength increases. Furthermore, there was a dose-response, with higher training volumes leading to greater hypertrophy and muscular strength gains. Krieger (23,24) also noted that an apparent plateau in muscular hypertrophy and strength may occur around 4–6 sets per exercise. However, Marshall et al. (26) found that after a 6-week intervention of 1, 4, and 8 sets of squats at 80% of one-repetition maximum (1RM) in trained subjects, muscular strength was only significantly greater for 8 sets than for 1 set. Therefore, it appears that the upper threshold to the dose-response relationship for resistance training volume, at least for muscle strength, may extend beyond 6 sets per exercise. It should be noted, however, that a minimum intensity of ≥65% 1RM is required to optimize gains in muscular hypertrophy and strength (33). When matched for volume, 6 weeks of resistance training at a higher intensity shows greater gains in muscular strength but not hypertrophy compared with a lower intensity resistance training intervention (32). Given that training with higher intensities requires greater recovery time between sets, it would be therefore more feasible to accumulate higher training volumes with moderate intensities within a given session duration.

German volume training (GVT), or the 10 sets method, is advocated as an effective training practice to enhance muscular hypertrophy (25,36). Anecdotally, GVT originated in Germany in the 1970s and was used by national weightlifting coaches to increase muscle mass of their athletes in the off-season. A GVT session traditionally involves performing 10 sets of 10 repetitions (i.e., 100 repetitions) for a compound resistance exercise, using this method for no more than 2 exercises in a training session (4). Sets are performed with loads of ~60% 1RM or 20RM to allow for the high training volume to be attained, and recovery between sets is relatively short (~60–90 seconds) to induce greater metabolic stress (e.g., buildup of metabolites such as lactate) (4). Metabolic stress is thought to be an important factor implicated in the promotion of exercise-induced muscle hypertrophy (30) and may be accentuated with higher volume protocols such as GVT (14).

Currently, it is unknown whether greater muscular hypertrophy gains can be achieved with GVT (10 sets method) compared with training performed with sets on the upper end of the range commonly used by resistance trainers (5 sets). Therefore, the purpose of this study was to investigate and compare muscular adaptations after a high-volume training program using 10 sets of 10 repetitions (10-SET) vs. a lower-volume training program using 5 sets of 10 repetitions (5-SET). Only the sets performed for the first 2 exercises in each training session were manipulated, whereas the sets performed for all other exercises included in the 6-week intervention were the same for the 2 groups. It was hypothesized that significant increases in muscular hypertrophy would result after 10 sets compared with 5 sets per exercise, whereas no differences would be found between groups for muscular strength due to the same relative training intensities being used. To our knowledge, no previous study has examined the effect of a GVT intervention on muscular hypertrophy and strength. Findings from this study can assist strength and conditioning coaches, athletes, and advanced resistance trainers with the prescription of resistance training for maximizing muscular hypertrophy gains.

Methods

Experimental Approach to the Problem

To ensure that subjects could tolerate the high physical demands of the training interventions, especially the 10-SET group, recruited subjects needed to have at least 1 year resistance training experience. Furthermore, subjects needed to be currently performing at least 3 resistance training sessions per week consistently during the previous 3 months. To aid in the potentiation of muscle protein synthesis after training sessions, both groups consumed a whey protein concentrate supplement 30 minutes post exercise, as is usually practiced by experienced resistance trainers. A randomized experimental design was used to determine whether 10-SET results in superior muscular adaptations compared with 5-SET results. Muscular hypertrophy was assessed via dual energy x-ray absorptiometry (DXA) (whole body and regional) and ultrasound (muscle thickness of the limbs). Muscular strength was assessed via the 1RM of the bench press, lat pull-down, and leg press. Statistical analyses were used to assess changes (pre- and posttraining) in muscular adaptations between the 10-SET and 5-SET groups.

A modification to the traditional GVT was used in this study and involved the inclusion of assistive exercises performed after completion of 2 exercises performed for 10 sets. The rationale behind adding additional exercises was to create a training program that would be more consistent with a split routine, commonly used by experienced resistance trainers targeting muscular hypertrophy. Furthermore, including additional exercises would be beneficial for study compliance and reducing the risk of participant dropout. Also, it would potentially decrease the risk of subjects detraining or performing extra training outside of the study. In particular, we hypothesized that these risks would be greater for subjects randomized to the 5-SET group, where a total of 10 sets per training session would be performed if only 2 exercises were prescribed. Experienced resistance trainers targeting muscular hypertrophy generally perform a minimum of 20 working sets comprising a variety of exercises. Therefore, it was decided that 3 assistive exercises performed for 3–4 sets each would be included per training session. A total of 21 and 31 sets for the 5-SET and 10-SET groups, respectively, would be performed per training session. Thus, the total sets per session used in this study would represent the mean and upper range commonly used by bodybuilders (15). Also, the squats and deadlifts, which are traditionally used in GVT, were omitted from the training program as many subjects did not regularly perform these exercises in their previous training. The leg press and lunges were selected are suitable substitutions for the squats and deadlifts.

Subjects

Nineteen healthy men aged 19–24 years volunteered to participate in the present study. Subjects did not have any existing musculoskeletal disorders, were not allergic to whey protein, and reported to have not used anabolic steroids or any other legal or illegal agents known to increase muscle size during the previous year. Before data collection, the researchers informed all subjects of the purpose of the study, the experimental procedures, and all the potential risks involved. Informed consent documents were signed for all subjects before participation, which was approved by the University of Sydney Human Research Ethics Committee.

Training Program. The subjects trained for 6 weeks, completing 3 sessions per week (totaling 18 training sessions) with at least 24 hours between sessions. Subjects were randomly assigned to either the 10-SET (n = 10; age = 21.8 ± 2.1 years; body mass = 77.5 ± 7.1 kg; height = 1.8 ± 7.7 m) or 5-SET (n = 9; age = 22.4 ± 2.9 years; body mass = 74.8 ± 12.1 kg; height = 1.8 ± 8.3 m) group via a computer-generated random numbers list. Resistance training experience was 3.5 ± 1.0 years and 4.8 ± 4.8 years for the 10-SET and 5-SET groups, respectively. The training program consisted of a "split routine," which involved performing different exercises targeting specific muscle groups in each training session during a week. Briefly, session 1 targeted the chest and upper back (flat bench press, incline bench press, lat pull-down, and seated row), session 2 targeted the legs (leg press, lunges, leg extension, leg flexion, and calf raisers), and session 3 targeted the shoulders and arms (shoulder press, upright row, bicep curls, and tricep push-down). During the course of a training week, the 10-SET and 5-SET groups performed the same exercises as illustrated in Table 1.

Group assignment was to 10 or 5 sets (10-SET, 5-SET) of the first 2 compound exercises of each training session (e.g., session 1: flat bench press and lat pull-down) (Table 1). The same number of sets (i.e., 3–4 sets) for the assistive exercises was performed by both groups during a training session. Subjects performed 10 repetitions (with the exception of abdominal crunches where 20 repetitions were performed) or the maximal number of repetitions possible if failure occurred prior. The relative loads used ranged from 60 to 80% 1RM (depending on the exercise and progression) and remained constant for an exercise during each training session (i.e., load was not reduced to enable the targeted number of repetitions to be performed). All subjects warmed-up for the first 2 exercises of each session by performing 2 sets of 10–12 repetitions at 10–20% lighter loads than targeted relative loads. Rest intervals between sets commenced at 60 seconds but were increased to 90 seconds during the last few sets. There was 60 seconds recovery between exercises. On the last set of each exercise, subjects were instructed to perform as many repetitions as possible to the point of concentric failure (i.e., volitional fatigue). The training load was increased by approximately 5–10% in the next session when subjects were able to perform at least 10 repetitions with correct technique for the final set and 10 repetitions for each of the previous sets for a given exercise. During all sets, repetitions were performed in a controlled manner during both the concentric (~1 second) and eccentric (~2 seconds) phases. All training sessions were directly supervised by the research team to ensure that subjects adhered to the resistance training protocol described above. Also, subjects were instructed to refrain from performing any additional resistance training for the duration of the study.

Body Composition. A whole-body DXA scanner (Lunar Prodigy; GE Medical Systems, Madison, WI, USA) was used to measure body composition. Total and regional lean tissue, and fat mass were determined using the system's

Table 1. Resistance training protocol.*

Session 1			Session 2			Session 3		
Exercise	Load	Sets × repetitions	Exercise	Load	Sets × repetitions	Exercise	Load	Sets × repetitions
Flat bench press†	60% 1RM	10 or 5 × 10	Leg Press†	80% 1RM	10 or 5 × 10	Shoulder Press†	60% 1RM	10 or 5 × 10
Lat pull-down†	60% 1RM	10 or 5 × 10	Dumbbell Lunges†	70% 1RM	10 or 5 × 10	Upright Row†	60% 1RM	10 or 5 × 10
Incline bench press	70% 1RM	4 × 10	Leg Extensions	70% 1RM	4 × 10	Tricep Push-downs	70% 1RM	4 × 10
Seated row	70% 1RM	4 × 10	Leg Curls	70% 1RM	4 × 10	Bicep Curls	70% 1RM	4 × 10
Crunches	close to RM	3 × 20	Calf Raisers	close to RM	3 × 20	Sit-ups with twist	close to RM	3 × 20

*RM = repetition maximum.
†10 and 5 sets, respectively, for these exercises (10-SET, 5-SET).

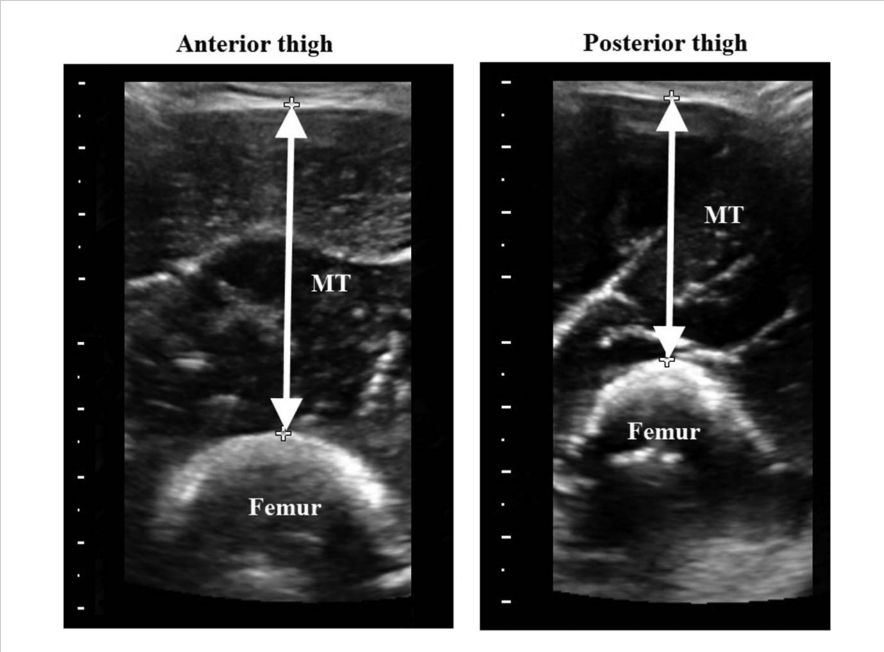

Figure 1. Examples of ultrasound image showing the transverse scans of the anterior thigh (left) and the posterior thigh (right) at 50% of thigh length. MT = muscle thickness.

software package enCORE 2011 (version 13.60.033; GE Healthcare). Scans were performed under standardized conditions (early morning, overnight fasted, and standardized body positioning on the scanning bed), by 2 licensed operators (G.C.W. and Y.M.) with subjects scanned once by each assessor (G.C.W. and Y.M.) at baseline for interrater reliability. The interrater reliability was excellent for lean body and fat mass (intraclass correlation coefficient [ICC]: 0.98–0.99 and coefficient of variance [CV]: 1.1–2.4%, respectively). The precision of soft-tissue analysis for a Lunar DPX-L instrument (regarded by the manufacturers to be similar to the Lunar Prodigy), established by repeat measurements of humans on 4 successive days, has been reported as 1 and 2% for lean body and fat mass, respectively (20).

Muscle Thickness Measurements. Ultrasound imaging was used to obtain measurements of muscle thickness of the muscle groups located on the upper arm and thigh. Measurements were taken on the right limb using a Philips iU22 (Philips Ultrasound, Bothell, WA, USA) ultrasound machine and a curvilinear 1- to 5-MHz transducer. A single, experienced, accredited sonographer (J.L.C.) performed all the testing. The ultrasound probe was placed perpendicular to the tissue interface at each measurement site and sufficient water-soluble transmission gel was applied to obtain an optimal image with minimal compression of the tissues. Muscle thickness dimensions were obtained by measuring the distance from the subcutaneous adipose tissue-muscle interface to the muscle-bone interface, as used in previous research (1). For the upper arm, measurements were taken on the anterior (biceps brachii) and posterior (triceps brachii) surfaces at 50% distal between the acromion process of the scapula to the lateral epicondyle of the humerus. The thigh measurements were taken on the anterior (combination of rectus femoris and vastus intermedialis) and posterior (combination of semimembranosus, semitendinosus, and adductor magnus) surfaces at 50% of between the inguinal fold to the superior margin of the anterior surface of the patella. Examples of muscle thickness images of the anterior and posterior thigh are shown in Figure 1. Images were obtained 48–72 hours before the commencement of the study and after the final training session in an effort to help reduce the possibility of swelling in the muscle after training, confounding the results. The repeatability of the ultrasound measurements was assessed on 2 separate days (greater than 72 hours apart) in 6 of the subjects. The test-retest ICC and CV for muscle thickness ranged from 0.97 to 0.98 and 2.6–7.0%, respectively.

Maximal Strength Assessments. The 1RM test was used to assess maximal strength for the bench press (flat), lat pull-down, and leg press. Subjects were instructed to refrain from any exercise other than activities of daily living for at least 48 hours before baseline and posttraining testing. The 1RM protocol used was consistent with the American College of Sports Medicine (3). In brief, the subjects performed a general warm-up (i.e., light cardiovascular exercise) lasting approximately 5 minutes. A specific warm-up was then performed which involved completing a set of 5 repetitions at ~50% of the subject's perceived 1RM for a given exercise followed by 1 to 2 sets of 2–3 repetitions at a load corresponding to ~60–80% 1RM. After an ~2-minute rest, subjects then performed an estimated maximal effort repetition. If this lift was successful, another lift was attempted with a heavier load (~5–10% increments) with 3–5 minutes of rest between attempts. This cycle was continued until the subject was unable to complete a lift, with the 1RM being the heaviest load that was successfully lifted.

The criteria for successful 1RM attempts in each of the 3 exercises are described below. For the bench press, the load

Table 2. %1RM and total volume load during the initial and final weeks of training.*†‡§

	10-SETS		5-SETS	
	Initial (wk)	Final (wk)	Initial (wk)	Final (wk)
%1RM				
Bench press‖	60.7 ± 3.7	64.2 ± 3.8	63.1 ± 4.9	68.8 ± 5.9
Lat pull-down‖	58.8 ± 3.8	60.8 ± 4.3	60.4 ± 3.9	64.4 ± 4.0
Leg press‖	67.3 ± 6.3	80.8 ± 8.8	65.0 ± 4.6	82.9 ± 4.5
Total volume load (kg)				
Bench press	4,582.5 ± 851.7	5,078.3 ± 775.0¶	1,845.0 ± 700.0	2,328.8 ± 765.9
Lat pull-down	3,961.7 ± 711.5	3,862.0 ± 689.4¶	1,595.8 ± 407.7	1,825.5 ± 444.1
Leg press	20,906.7 ± 3,941.6	24,888.3 ± 3,424.2¶	10,116.9 ± 2,636.3	12,940.6 ± 3,051.2

*%1RM = percentage of one repetition maximum.
†Initial week %1RM was calculated from loads used during week 1 in relation to baseline 1RM. Final week %1RM was calculated from loads used during week 6 in relation to posttesting 1RM.
‡Total volume load for each exercise was calculated from load × repetitions.
§Data presented as mean ± *SD*.
‖%1RM significantly increased from initial to final week but was not significantly different between groups.
¶Total volume load significantly greater for 10-SETS than for 5-SETS ($p < 0.001$).

needed to be brought down close to the chest, then without the bar "bouncing off" the chest, the bar was lifted until the elbows were almost straight. The lat pull-down needed to be performed in a manner where the bar moved from an overhead position with elbows almost straight to the top of the chest and then returning to the starting position. For both the bench press and lat pull-down, subjects needed to display minimal back arching and swaying, respectively, during the 1RM attempts. The leg press needed to be performed in a manner where subjects commenced the attempt through extending their hips and knees until the knees were almost straight and then returning the load until their knees were flexed to approximately 90°. Assessing of 1RM was conducted using the same piece of equipment and at approximately the same time of day. The exercise set-up (posture and hand grip) and order of exercises were standardized during both the pre- and posttests (bench press, leg press, and lat pull-down). The repeatability of the maximal strength tests was assessed on 2 separate days (greater than 72 hours apart) in 6 of the subjects. The test-retest ICC and CV for muscular strength ranged from 0.90 to 0.92 and 4.9–6.0%, respectively.

Diet. The dietary intake was obtained via a 3-day food diary and analyzed via FoodWorks (Xyris Software Pty, Ltd., Brisbane, Queensland, Australia) before and after the experimental training period. Throughout the study, subjects were encouraged to increase their caloric intake by 1,000–2,000 kJ above their estimated daily energy requirements, which was calculated via wearing a SenseWear armband (HealthWear; Bodymedia, Pittsburgh, PA, USA) during 3 consecutive days before the training period. To acquire the extra amount of calories, subjects were advised to eat slightly bigger portions during each meal of their usual diet and to avoid taking any supplements other than that provided in the course of the study. A protein supplement was consumed by subjects within 30 minutes post exercise to allow for greater muscle protein synthesis. The supplement (Venom whey protein concentrate; The Ausray Group, Queensland, Australia) provided contained 30.8 g of protein, 0.2 g of fat, and 0.9 g of carbohydrate.

Statistical Analyses

Baseline characteristics including age, height, total body mass, resistance training experience, body composition, muscle thickness, and muscular strength were compared between groups using an independent *t*-test. Sequential linear mixed-effects models with repeated measures and an unstructured covariance matrix were used to determine the effects of 10-SET vs. 5-SET over time for all dependent variables (i.e., total and lean body mass, fat mass, % body fat, muscle thickness, and 1RM) using an intention-to-treat analytic strategy. Relative effect sizes were calculated using the following formula: mean change (10-SET) − mean change (5-SET)/pooled *SD* of baseline scores (35). Therefore, positive effect sizes favored the 10-SET group and negative effective sizes favored the 5-SET group. The effect sizes (±) were interpreted as small, medium, and large if they were 0.2, 0.5, and 0.8, respectively (9). All analyses were performed using SPSS version 22.0 for Windows (IBM Corp, Armonk, NY, USA). Data are presented as mean ± *SD*. The level of significance was set at $p \leq 0.05$, and trends were declared at $p = 0.05$ to ≤ 0.10.

Results

All of the subjects completed the 18 sessions during a 6-week period; however, one subject in the 5-SET group was unable to complete the post-training strength tests due to personal

TABLE 3. Body composition and muscle thickness of participants, before and after 6 weeks of resistance training.*†

	10-SET ($n = 10$)		5-SET ($n = 9$)						
	Pre	Post	Pre	Post	Mean difference	95% CI	p^T	$p^{G \times T}$	ES
Body mass (kg)									
Total	77.5 ± 7.1	79.2 ± 6.9	74.8 ± 12.1	77.5 ± 13.4	−1.00	−0.86 to 2.65	<0.001‡	0.296	−0.10
Lean	61.8 ± 7.4	63.0 ± 6.9	58.3 ± 7.8	60.1 ± 8.1	−0.6	−0.20 to 1.60	<0.001‡	0.122	−0.08
Fat	12.1 ± 6.2	12.7 ± 5.7	13.2 ± 5.9	14.1 ± 6.8	−0.3	−1.16 to 1.45	0.099	0.820	−0.05
%Fat	16.2 ± 7.8	16.7 ± 7.0	18.1 ± 5.6	18.5 ± 5.9	0.1	−1.45 to 1.08	0.484	0.757	<0.01
Regional lean body mass (kg)									
Trunk	28.5 ± 4.2	28.8 ± 4.0	26.5 ± 3.3	27.6 ± 3.6	−0.8	0.03 to 1.59	<0.001‡	0.043§	−0.21
Arms	8.6 ± 0.9	8.9 ± 0.8	7.7 ± 1.4	8.3 ± 1.5	−0.3	−0.05 to 0.67	<0.001‡	0.086	−0.25
Legs	20.6 ± 2.6	21.1 ± 2.4	19.9 ± 3.1	20.0 ± 3.0	0.4	−0.89 to 0.24	0.564	0.246	0.14
Muscle thickness (mm)									
Triceps	42.0 ± 6.6	46.5 ± 4.1	41.1 ± 6.6	43.4 ± 7.5	2.2	−7.02 to 2.77	0.204	0.369	0.35
Biceps	34.6 ± 4.1	34.9 ± 2.2	33.1 ± 5.4	35.5 ± 5.6	−2.1	−2.14 to 6.15	0.137	0.319	−0.40
Anterior thigh‖	53.3 ± 7.8	54.4 ± 7.2	53.1 ± 9.2	55.7 ± 9.7	−1.5	−2.16 to 5.29	0.069	0.384	−0.18
Posterior thigh¶	66.7 ± 6.5	68.9 ± 6.7	66.4 ± 7.7	67.6 ± 5.5	1.0	−5.25 to 3.32	0.454	0.638	0.15

*Pre = pretest; Post = posttest; CI = confidence interval; T = time; $G \times T$ = group × time interaction; ES = effect size.
†Data presented as mean ± *SD*.
‡Significant main effect for time ($p < 0.001$).
§Significant main effect for group × time ($p \leq 0.05$).
‖Refers to a combination of the rectus femoris and vastus intermedialis.
¶Refers to a combination of semimembranosus, semitendinosus, and adductor magnus.

circumstances. The resistance training interventions and 1RM testing were well tolerated by the subjects and resulted in no adverse events. There were no differences between groups for age, height, total body mass, resistance training experience, body composition, muscle thickness, and muscular strength at baseline. The mean duration of the 10-SET sessions was ~64 minutes compared with ~46 minutes for the 5-SET sessions (excluding time required for warm-up sets). Ten repetitions were completed for 74.5 and 77.5% of sets for the 10-SET and 5-SET groups, respectively, whereas all other sets were performed to volitional fatigue. The relative intensity (%1RM) used for the bench press, leg press, and lat pull-down increased during the 6 weeks ($p \leq 0.05$) but was not significantly different between groups (Table 1). The total volume load (load × repetitions) was significantly greater for the 10-SET than was for the 5-SET group at baseline and during the 6 weeks ($p < 0.001$, Table 2). Daily energy intake of subjects in the 10-SET and 5-SET groups increased by 1,020 kJ above their estimated daily energy requirements subsequent to dietary advice ($p \leq 0.05$), but no significant differences were found between groups.

Body Composition

Significant increases across time were found for total and lean body mass, trunk lean body mass, and arm lean body mass ($p \leq 0.001$; Table 3). Total and lean body mass increased for 5-SET by 3.6 and 2.7%, respectively, whereas for 10-SET, it increased by 2.1 and 1.9%, respectively. A significant group × time interaction was found for trunk lean tissue ($p = 0.043$; effect size [ES] = −0.21), favoring the 5-SET group (4.1 vs. 1.0%), whereas a trend was observed for changes in arm lean tissue ($p = 0.083$; ES = −0.25), again favoring the 5-SET group (7.8 vs. 3.4%). No group × time interactions were found for total mass, total or leg lean tissue, fat mass, or % body fat.

Muscle Thickness Measurements

There were no significant time effects for muscle thickness of the triceps, biceps, anterior thigh, and posterior thigh. A trend was found for a time effect for muscle thickness of the anterior thigh ($p = 0.069$; Table 3). No significant group × time interactions were found for muscle thickness of the triceps, biceps, anterior thigh, or posterior thigh. A small, nonsignificant group × time interaction was found favoring 10-SET compared with 5-SET for muscle thickness of the triceps (10.7 vs. 5.6%, respectively; $p = 0.369$; ES = 0.35), and favoring 5-SET compared with 10-SET for muscle thickness of the biceps (7.3 vs. 0.9%, respectively; $p = 0.319$; ES = −0.40) (Table 3).

Maximal Strength Assessments

Significant increases over time were found for 1RM bench press, lat pull-down, and leg press ($p < 0.01$; Table 4). The 5-SET and 10-SET groups increased 1RM bench press by 14.9 and 6.2%, respectively; 1RM lat pull-down by 15.1 and 4.5%, respectively; and 1RM leg press by 8.1 and 4.7%,

Table 4. Muscle performance before and after the 6-week resistance training period.*†

	10-SET ($n = 10$)		5-SET ($n = 8$)						
	Pre	Post	Pre	Post	Mean difference	95% CI	p^T	$p^{G \times T}$	ES
Strength (1RM)									
Bench press (kg)	79.7 ± 15.5	83.7 ± 12.3	70.7 ± 16.2	81.6 ± 19.5	−6.9	1.52 to 11.73	<0.001‡	0.014§	−0.43
Lat pull-down (kg)	68.7 ± 10.6	71.5 ± 9.8	57.3 ± 12.9	65.9 ± 14.6	−5.8	2.3 to 9.3	<0.001‡	0.003‖	−0.54
Leg press (kg)	295.3 ± 40.2	307.8 ± 36.6	285.2 ± 43.8	308.3 ± 50.3	−10.6	−9.1 to 30.3	0.004‖	0.27	−0.36

*Pre = pretest; Post = posttest; CI = confidence interval; T = time; $G \times T$ = group × time interaction; ES = effect size; RM = repetition maximum.
†Data presented as mean ± SD.
‡Significant main effect for time ($p < 0.001$).
§Significant main effect for group × time ($p \leq 0.05$).
‖Significant main effect for time and group × time ($p < 0.01$).

respectively. Significant group × time interactions were found for 1RM bench press ($p = 0.014$; ES = −0.43) and lat pull-down ($p = 0.003$; ES = −0.54) favoring 5-SET, whereas no group × time interaction was found for 1RM leg press ($p = 0.27$; ES = −0.36).

Discussion

The aim of this study was to investigate the effect of a 6-week modified GVT intervention on muscular hypertrophy and strength in resistance trained men. To the authors' knowledge, this is the first study to directly examine training adaptations after this training system. The primary finding from this study was that despite a larger training volume, the 10-SET group did not achieve greater increases in muscular hypertrophy than the 5-SET group, therefore our hypothesis was not supported. Both groups increased total lean tissue after the 6-week intervention, with greater increases in trunk and arm lean tissue seen in the 5-SET group. However, there were no significant increases in leg lean tissue or measures of muscle thickness within and between groups. The 5-SET had significantly greater muscular strength increases for the upper body exercises, with no difference between groups for the lower body exercise.

Importantly, subjects were 100% compliant with the resistance training intervention, and the training volumes were well tolerated. These findings suggest that in the short term, no extra gains in muscular hypertrophy or strength are achieved through performing a modified GVT program compared with 5 sets of resistance exercises.

Our results are in agreement with Krieger et al. (23) that after ∼4–6 sets per exercise, hypertrophic adaptations are limited by further increases in training volume. Furthermore, it appears that extending the number of sets beyond 5 for upper-body exercises may be counterproductive as observed by greater increases for trunk lean body mass and a trend for arm lean body mass in the 5-SET group. An explanation for this finding may be related to subjects in the 5-SET group using a slightly greater %1RM. Although there were no statistical differences between groups for %1RM used during the study, %1RMs for the bench press and lat pull-down were approximately 5% greater for the 5-SET during the final week. Therefore, this suggests that the 10-SET group had to use a slightly lower %1RM to perform their very challenging training protocol. To date, only 2 studies have investigated the effects of resistance training volume (i.e., high vs. low sets) on changes in muscle mass in resistance-trained subjects (28,29). Both these studies showed no significant difference between higher and lower training volumes. Therefore, despite some of the DXA lean body mass changes tending to favor the 5-SET group, it would be more reasonable to interpret the findings of this study as no differences in muscular hypertrophy when following a modified GVT program compared with 5 sets per exercise.

Owing to large physiological and possibly psychological demands associated with GVT (5), this practice is usually limited to periods of approximately 6 weeks to reduce the risk of overtraining and musculoskeletal injuries. Typically, training-induced hypertrophy is considered to be a slow process, with at least 4 weeks required to observe significant muscular hypertrophy in individuals with no previous resistance training experience (11,27). However, the time-course improvements for muscular hypertrophy collected on previously untrained populations should be used as a guide, with improvements in resistance-trained individuals likely to vary as they approach their genetic hypertrophic potential (31). The duration of our study was considered adequate to allow for muscular hypertrophy based on the significant time effect across groups found for the majority of the DXA lean tissue measures. The results from our study indicate that the 5-SET group had a more favorable hypertrophic response in the upper body, but not in the lower body, compared with the 10-SET group. This finding of greater muscular hypertrophy in the upper than in the lower body after resistance training is consistent with findings from previous studies (1,8). Mechanisms that may explain this phenomenon include the lower training response of the legs due to their greater everyday use (10) and the increased hypertrophic capacity of upper body muscles due to greater androgen receptor content (19).

Examining total and regional lean body mass in a homogenous group of subjects (similar in age) with the DXA has been shown to be highly correlated with computed tomography (CT) and magnetic resonance imaging (MRI) (13,37). These latter techniques are considered the gold standard for muscle cross-sectional area, therefore using DXA to assess muscle hypertrophy was considered appropriate. The muscle thickness assessed via ultrasound has also been closely correlated with muscle cross-sectional area measured from CT and MRI (2,34). An advantage of the ultrasound compared with DXA is its ability to make a distinction between individual muscles within a region of the body such as the triceps and biceps for the upper arms. However, in the present study, thickness of individual muscles was only assessed for the upper arm (e.g., biceps brachii and triceps brachii), whereas a combination of muscles were assessed for the thigh measures. Therefore, it could be speculated that some of the muscles assessed during the thigh measures may have been less responsive (e.g., semimembranosus compared with adductor magnus) to the resistance training intervention, thus explaining the nonsignificant changes.

König et al. (21) suggested that training or detraining effect on muscle thickness should only be regarded as valid if changes greater than 10% are observed. However, previous studies have reported significant changes in muscle thickness ranging 5–12% after 6 weeks of resistance training (1), which was similar to the relative change in muscle thickness across groups in our study, however, nonsignificant. It could be argued that the nonsignificant muscle thickness changes found in our study were attributed to a type II error given the small sample size used. However, the DXA lean tissue results suggest that there were an adequate number of subjects for hypertrophy to be observed. A likely explanation for the inconsistency of muscular hypertrophy measures is the greater variance for muscle thickness compared with DXA, as seen by the larger confidence intervals.

Greater increases in muscular strength were not associated with larger training volumes. On the contrary, the 5-SET compared with the 10-SET group experienced a greater increase in upper-body strength. This was unexpected as previous studies have shown that similar increases in muscular strength occur when performing equal or greater than 4 sets per exercise (23,26). As discussed above, the 5-SET group may have had greater potential to increase their strength based on being slightly weaker at the baseline. From the 3 exercises that were used to assess muscular strength, the 5-SET group averaged a 12.7% increase from baseline compared with 5.1% in the 10-SET group. Less trained subjects are known to experience bigger strength gains of ~30% compared with gains of ~5% in trained populations (3,16). Another possibility may be that a period of time was required for the 10-SET group to taper from the high-volume training to produce a "rebound effect" and avoid overreaching (12,18). Marshall et al. (26) found significant increases in muscular strength with 8 sets compared with 1 set, with no differences found for 4 sets after 6 weeks of training. However, after another 4 weeks of a standardized training program with reduced volume, a further increase in muscular strength was observed for the 8 sets compared with the 1-set group.

It is becoming increasingly accepted that muscular hypertrophy is more dependent on training volume, whereas training with loads greater than 80% 1RM compared with lower intensities is more efficacious for muscular strength development in resistance-trained individuals (32). Therefore, greater increases in muscular strength for the 5-SET compared with the 10-SET group could be due to slightly greater relative loads used by the former group as the intervention progressed. However, no differences between groups for the %1RM used throughout the intervention was found. Another possibility may be related to the 10-SET sets that anecdotally may begin to regress. Resistance training performed with volumes too far beyond an "upper threshold" is likely to be counterproductive for strength-related tasks in general and may be more detrimental for dynamic compound compared with isometric activities. Owing to the greater skill complexity of compound exercises, changes in movement mechanics/patterns can result during fatigue which may lead to a reduced training effect. However, it should be emphasized that GVT is used to primarily target muscular hypertrophy and that the training stimulus used is unlikely to have any meaningful effect on muscular strength.

It also appeared that the resistance training intervention targeting the legs (e.g., one session per week) did not provide a sufficient stimulus for the subjects in this study to increase muscular hypertrophy of the lower extremity, especially since the subjects of the present study had 3 years and more resistance training experience. However, similar leg training frequencies and volumes to the 10-SET group were previously reported in a cohort of competitive bodybuilders (i.e., ~70% of respondents engaging in 1 session per week targeting the legs with ≥20 sets performed) (15). Therefore, the training stimulus for the legs, at least in the 10-SET group, was thought to be sufficient.

There are several limitations that should be taken into account when interpreting the results of this study. The duration of the intervention was relatively short which may have affected muscular hypertrophy adaptations. Another limitation was that further measures could have been collected throughout the intervention to allow for monitoring of fatigue, soreness, and muscular strength. Such measures may have enabled more definitive conclusions to be made. Also, there was an inconsistency between the DXA lean body mass and the muscle thickness measures, possibly due to large variations between individuals for the latter. For our study, the intrarater coefficient of variation for muscle thickness from a subset of subjects ranged from 2.6 to 7.0% compared with less than 5% in previous studies (1,7). This may have been averted if multiple measures were taken at different lengths of a muscle (e.g., 30, 50, and 70%), as described by Abe et al. (1) for the anterior thigh. Using this approach may have provided a greater representation of changes in muscle thickness for specific muscles compared with a measurement at only one length, as was performed in our study, especially since changes in thickness may not be evenly distributed along the length of a muscle (39). Furthermore, it is possible that changes in muscle thickness may have differed in the transverse plane (medial-lateral), which has been previously suggested (38).

It should be noted that the traditional GVT which originated in Germany and was used by weightlifters included squats and deadlifts, 2 exercises which were not included in our study. Squats and deadlifts are renowned as 2 of the best muscle mass-building exercises and results from our study should be interpreted in light of the omission of these exercises. Finally, although there were no statistical differences between groups for %1RM used at the 2 time points where this was assessed, the 5-SET group were training at a slightly greater %1RM than the 10-SET group during the final week. This may explain some of the greater gains found for the lower compared with the higher training volume group. However, it should not be ruled out that the majority of subjects in the 10-SET group may have been nonresponders to higher training volumes such as GVT. Future studies examining the effect of resistance training volume on muscle adaptations should endeavor to use larger sample sizes than used in our study to minimize the risk of trends that suggest that intervention groups at baseline may differ. Furthermore, further research is required in the area of responders vs. nonresponders in relation to resistance training volume.

Practical Applications

In conclusion, this is the first known study to examine the effect of a modified GVT intervention on muscle hypertrophy and strength. The results of our study suggest that the modified GVT program, or the 10 sets method, is no more effective than performing 5 sets per exercise for increasing muscle hypertrophy and strength. Based on the findings, it seems that performing 10 sets compared to 5 sets per exercise in a split-routine may result in a reduced training effect. Although GVT is claimed to be advantageous for increasing muscle hypertrophy compared with lower volume training programs, this view is not supported by the results of this study. For coaches, athletes, and trainers interested in resistance training programs targeting muscular hypertrophy, training volume is one of the many variables that need to be manipulated to enhance muscular hypertrophic effects. To maximize the training effects, 4–6 sets per resistance exercise is recommended as it appears that muscular hypertrophy will plateau beyond this range and may even regress due to overtraining. For individuals interested in increasing muscular strength, GVT should not be used due to relatively lower loads and reduced recovery between sets which may not provide a sufficient resistance training stimulus. Whether GVT is an effective technique for individuals targeting fat loss due to the associated high metabolic demands and potential elevations in lipolytic hormones remains to be determined and requires further study.

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