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Supervision during resistance training positively influences muscular adaptations in resistance-trained individuals

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Abstract

The purpose of this study was to compare the effects of supervised versus unsupervised resistance training (RT) on measures of muscle strength and hypertrophy in resistance-trained individuals. Thirty-six young men and women were randomly assigned to one of two experimental, parallel groups to complete an 8-week RT program: One group received direct supervision for their RT sessions (SUP); the other group performed the same RT program in an unsupervised manner (UNSUP). Program variables were kept constant between groups. We obtained pre- and post-study assessments of body composition via multi-frequency bioelectrical impedance analysis, muscle thickness of the upper and lower limbs via ultrasound, 1 repetition maximum (RM) in the back squat and bench press, isometric knee extension strength, and vertical jump height. Results showed the SUP group achieved superior increases in muscle thickness for the triceps brachii, all sites of the rectus femoris, and the proximal region of the vastus lateralis. Squat 1RM was greater for SUP; bench press 1RM was similar between conditions. The UNSUP group had a greater number of dropouts compared to SUP (7 vs. 2, respectively). In conclusion, our findings suggest that supervised RT promotes greater muscular adaptations and enhances exercise adherence in young, resistance-trained individuals.

KEYWORDS: intensity of effort, adherence, resistance exercise; hypertrophy; strength

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Introduction

Resistance training (RT) studies commonly investigate how different exercise variables that comprise training programs (e.g., sets, load, frequency, etc.) influence muscular development (1). When performed under researchers’ supervision, the RT protocols used in these studies essentially resemble those carried out by personal trainers with their respective clients — i.e., the trainer oversees and encourages the trainee during every set of every session. However, most people do not train this way in the real world. If research findings are to be used as a guidepost for training recommendations (2), this disconnect between research and ecological settings must be considered, raising the question: Do supervised training studies provide realistic insight for those who do not train under supervision?

There are several reasons why supervised training may elicit more favorable muscular adaptations than unsupervised training. First, of all the commonly manipulated RT variables, intensity of effort (as determined by proximity to muscular failure) is considered critical to producing robust muscular and strength development (3). General recommendations indicate that resistance-trained individuals achieve the best results when sets are carried out within ~2 repetitions of failure (4). To this end, the psychological support provided by supervision may intensify trainees’ efforts (5). Second, exercise technique has been proposed to influence stress on the target muscle(s), which could be exploited to augment muscular development (6). Under supervision, a trainee’s exercise technique can be monitored and coached on a repetition-by-repetition basis to emphasize the target muscle(s). If these proposed mediators are important determinants of RT efficacy, then supervised RT should elicit more favorable adaptations than unsupervised RT.

Despite a seemingly sound rationale, a recent meta-analysis reported that supervised RT conferred only small benefits on performance and physical function compared to training without supervision, with minimal impact on measures of body composition (5). It should be noted that only 2 of the 12 included studies in the meta-analysis investigated the topic in resistance-trained individuals (i.e., at least 1 year of consistent RT experience), limiting the ability to draw inferences in this population. Moreover, all studies that assessed changes in body composition employed indirect methods of measurement (e.g., dual energy absorptiometry, bioelectrical impedance analysis, air displacement plethysmography, and skinfolds). While these modalities provide gross estimates of muscle adaptations, they lack the precision to detect more subtle

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hypertrophic alterations over time compared to site-specific measures (7). Thus, considerable gaps exist in the current literature regarding the effects of supervision on muscular adaptations.

The purpose of this study was to compare the effects of supervised versus unsupervised RT on measures of muscle strength, explosive movement, and site-specific hypertrophy in resistance-trained individuals performing the same exercise program over an 8-week study period. We hypothesized that supervision would result in greater muscular adaptations.

Materials and Methods

Participants

We recruited 45 male and female volunteers from a university population. This sample size was justified by *a priori* precision analysis for the minimum detectable change at the 68% level ($MDC_{68\%}$; i.e., 1SD, which is conservative in that it requires a larger sample to produce a narrow interval) for mid-thigh thickness (i.e., $SEM \times \sqrt{2} = 2.93\ mm$), such that the compatibility interval (CI) of the between-group effect would be approximately ± $MDC_{68\%}$. Based on data from previous research (8), along with their sampling distributions, Monte Carlo simulation was used to generate 90% CI widths for 5000 random samples of each sample size. To ensure a conservative estimate, as literature values may not be extrapolatable, the sum of each simulated sample size’s 90% CI’s mean *and* standard deviation was used, and the smallest sample that exceeded $MDC_{68\%}$ was chosen; that is, 18 participants per group (1:1 allocation ratio). Additional participants were recruited to account for the possibility of dropouts.

To qualify for inclusion in the study, the participants were required to be: (a) between the ages of 18-40 years; (b) free from existing cardiorespiratory or musculoskeletal disorders; (c) self-reported as free from consumption of anabolic steroids or any other illegal agents known to increase muscle size currently and for the previous year; and, (d) considered as resistance-trained, defined as consistently lifting weights at least 3 times per week (on most weeks) for at least 1 year. Participants were asked to refrain from the use of muscle-building supplements (e.g., creatine) throughout the course of the study period.

Participants were randomly assigned to 1 of 2 experimental, parallel groups: a group that received direct one-on-one supervision for their RT sessions (SUP: *n* = 22) or a group that performed the same RT program in an unsupervised manner (UNSUP: *n* = 23). Randomization

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was carried out using block randomization stratified by sex, with two participants per block, in R software (9).

Approval for the study was obtained from the college’s Institutional Review Board. Informed consent was obtained from all participants prior to beginning the study. The methods for this study were preregistered prior to recruitment (https://osf.io/96zxw).

Resistance Training Procedures

The RT protocol targeted the major muscle groups of the upper and lower body using the following exercises: front lat pulldown, machine shoulder press, machine chest press, cable triceps pushdown, supinated dumbbell biceps curl, plate-loaded leg press, machine leg extension, and machine lying leg curl. Participants performed (in SUP) or were instructed to perform (in UNSUP) 3 sets of 8-12 RM for each exercise with 2 minutes rest between sets. In SUP, participants were verbally encouraged to carry out all sets to volitional failure (i.e., the point where an individual felt that he/she could no longer complete an additional repetition); those in UNSUP were instructed to carry out all sets to volitional failure. We included primarily machine-based exercises so that unsupervised participants could safely train without the need for a spotter, thus helping to facilitate the ability of participants to train until volitional failure. The cadence of repetitions was prescribed to be performed in a controlled fashion, with a concentric action of approximately 1 second and an eccentric action of approximately 2 seconds. Loads were prescribed to be progressively adjusted to maintain the target repetition range. The training was carried out on 3 non-consecutive days per week for 8 weeks. All training (both SUP and UNSUP) was performed in the same facility, using similar equipment, to minimize additional sources of variance. Participants in SUP were provided verbal encouragement and, when applicable, feedback on performance-related matters during training.

Prior to training, participants underwent a 10RM testing session to determine individual initial training loads for each exercise. The RM testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (10). During this testing session, participants were instructed how to perform each exercise in the manner specified in the protocol. Thereafter, the SUP group was directly supervised during each training session by members of the research staff. Alternatively, the UNSUP group was provided with a template of the prescribed RT program and performed sessions on their own after receiving initial instructions on how to carry out the training protocol. To determine adherence, participants in

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UNSUP signed into a log sheet prior to each session in the college gym. The research staff charted the repetitions and load for each set in the SUP group; the UNSUP group charted their own routines (exercises, sets, and load) and uploaded the information to a Google Docs file on a weekly basis for review by the lead researcher. Participants were required to complete >85% of training sessions to remain in the study.

Dietary Adherence

To avoid potential dietary confounding of results, participants were advised to maintain their customary nutritional regimen and to avoid taking any supplements purported to build muscle. Dietary adherence was assessed by self-reported food records using MyFitnessPal.com (http://www.myfitnesspal.com), which were collected twice during the study: 1 week before the first training session (i.e., baseline) and during the final week of the training protocol. We tracked 5 days of food intake during each period, including at least 1 weekend day. Participants were instructed on how to properly record all food items and their respective portion sizes consumed for the designated period of interest. Each item of food was individually entered into the program, and the program provided the total energy consumption, as well as the amount of energy derived from proteins, fats, and carbohydrates for each time period analyzed.

Measurements

The following measurements were conducted pre- and post-study in separate testing sessions. Participants reported to the lab having refrained from any strenuous exercise for at least 48 hours prior to baseline testing and at least 48 hours prior to testing at the conclusion of the study. Anthropometric and muscle thickness assessments were performed first in the session, followed by measures of muscle strength. Each strength assessment was separated by at least a 10-minute rest period to ensure complete recovery.

*Anthropometry***:** Participants were told to refrain from eating for 12 hours prior to anthropometric testing, eliminate alcohol consumption for 24 hours, and void their bladder immediately before the test. Participants’ heights were measured using a stadiometer connected to a calibrated Detecto Physician Scale (Cardinal Scale Manufacturing Company**,** Webb City, MO).

Assessment of body mass, fat mass, total body muscle mass, and body water content were carried out using an InBody 770 multi-frequency bioelectrical impedance analysis (MF-BIA) unit (Biospace Co. Ltd., Seoul, Korea). As per the manufacturer's instructions, the

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participants’ palms and soles were cleaned with an electrolyte tissue prior to each measurement. The participants then stood on the MF-BIA unit, placing the soles of their feet on the electrodes. The instrument derived the participants’ body masses; age and sex were manually entered into the display by the researcher. The participants then grasped the unit's handles, ensuring that each hand's palm and fingers made direct contact with the electrodes, and extended and abducted their arms approximately 20°. The unit analyzed body composition while the participants remained as motionless as possible.

Muscle Thickness (MT): Ultrasound imaging was used to obtain measurements of MT. A trained, blinded ultrasound technician performed all testing using a B-mode ultrasound imaging unit (Model E1, SonoScape, Co., Ltd, Shenzhen, China). The technician applied a water-soluble transmission gel (Aquasonic 100 Ultrasound Transmission gel, Parker Laboratories Inc., Fairfield, NJ) to each measurement site, and a 4-12 MHz linear array ultrasound probe was placed either parallel or perpendicular to the tissue interface without depressing the skin. When the quality of the image was deemed to be satisfactory, the technician saved the image to a hard drive and obtained MT dimensions by measuring the distance from the subcutaneous adipose tissue-muscle interface to either the aponeurosis or the muscle-bone interface. Measurements of 4 different muscle groups were taken on the right side of the body: (1) elbow flexors, (2) elbow extensors, (3) mid-thigh (a composite of the rectus femoris and vastus intermedius), and (4) lateral thigh (a composite of the vastus lateralis and vastus intermedius). For the anterior and posterior upper arm, measurements were obtained at 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula; mid- and lateral thigh measurements were obtained at 30%, 50%, and 70% between the lateral condyle of the femur and greater trochanter. To ensure that swelling in the muscles from training did not obscure MT results, images were obtained at least 48 hours after each participant’s last RT session. This is consistent with research showing that acute increases in MT return to baseline within 48 hours following a RT session (11) and that muscle damage is minimal after repeated exposure to the same exercise stimulus over time (12) (13). To further ensure the accuracy of measurements, 3 images were obtained for each site and then averaged to obtain a final value. The test-retest intraclass correlation coefficients (ICC) from our lab for MT measurements are excellent (>0.94) with coefficients of variation (CV) of ≤3.3%.

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Countermovement Jump (CMJ): The CMJ was used as a proxy measure of explosive lower body performance. Participants were instructed on the proper performance of the CMJ. Performance was carried out as follows: participants began by assuming a shoulder-width stance with the body upright and hands on hips. When ready for the movement, they descended into a semi-squat position and then forcefully reversed direction, jumping as high as possible before landing with both feet on the ground.

Assessment of jump performance was carried out using a Just Jump mat (Probotics, Huntsville, AL), which was attached to a hand-held computer that recorded airtime and thereby ascertained the jump height. The participant stood on the mat and performed 3 maximal-effort countermovement jumps with a 1-minute rest period between each trial. The highest jump was recorded as the final value.

Dynamic Muscle Strength: Upper and lower body strength was assessed in the bench press ($1RM_{BENCH}$) and the back squat ($1RM_{SQUAT}$), respectively. All testing sessions were supervised by two research assistants to achieve a consensus for success on each attempt. Repetition maximum testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (10). In brief, participants performed a general warm-up prior to testing consisting of light cardiovascular exercise lasting approximately 5-10 minutes. Next, a specific warm-up set of the given exercise of 5 repetitions was performed at ~50% 1RM followed by one to two sets of 2-3 repetitions at a load corresponding to ~60-80% 1RM. Participants then performed sets of 1 repetition of increasing weight for 1RM determination. Three to 5 minutes rest was given between each successive attempt. All 1RM determinations were made within 5 attempts.

Testing for the $1RM_{BENCH}$ was carried out on a Smith machine (Life Fitness, Westport, CT). A successful performance was determined as follows: Participants assumed a supine position on the bench with a five-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor) and grasped the bar at a comfortable distance and width. Participants received assistance removing the barbell from the rack (if desired), brought the weight down until it touched the chest without bouncing, and then executed a full lock-out without assistance. The test-retest ICC from our lab for the Smith machine bench press is 0.996 with a CV of 2.0%.

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Testing for $1RM_{SQUAT}$ was carried out on a Smith machine (Life Fitness, Westport, CT). Participants were required to reach parallel (i.e., upper thigh in line with the floor) in the $1RM_{SQUAT}$ for the attempt to be considered successful; confirmation of squat depth was obtained by a research assistant positioned laterally to the participant to ensure accuracy. The ICC from our lab for the Smith machine squat is 0.953 with a CV of 2.8%.

Isometric Knee Extension Strength: Isometric knee extension strength assessment was carried out using dynamometry testing (Biodex System 4; Biodex Medical Systems, Inc. Shirley, NY, USA). After familiarization with the dynamometer and protocol, participants were seated in the chair and performed unilateral isometric actions of the knee extensors on their dominant limbs.

During each trial, participants sat with their backs flush against the seat back pad and maintained a hip joint angle of 85 degrees with the center of the lateral femoral condyle aligned with the axis of rotation of the dynamometer. The dynamometer arm length was adjusted to allow the shin pad to be secured with straps proximal to the medial malleoli. Participants were strapped across the ipsilateral thigh, hips, and torso to help prevent extraneous movement during the performance and were instructed to hold onto handles for greater stability. Testing was carried out at 110° of knee flexion (0° equates to full knee extension)

Each maximum voluntary contraction trial lasted 5 seconds, followed by 30 seconds rest, for a total of 4 trials. Participants were verbally encouraged to produce maximal force throughout each bout. The highest peak net extension moment from the 4 trials was used for analysis.

Blinding

To minimize the potential for bias, we incorporated two levels of blinding into the design and analysis of this study. First, the principal investigator, who obtained the measurements of the primary outcome (MT), was blinded to group allocation; second, the statistician performed blinded analyses.

Statistical Analysis

Our primary analyses assessed the effects of supervision relative to no supervision using linear regression with pre-intervention score and sex included as nuisance parameters (14). All models were fit using ordinary least squares and residuals were qualitatively examined for structure and heteroscedasticity; normality was not checked since the CIs were calculated nonparametrically via the bootstrap, in accordance with our pre-registration. We computed 90%

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CIs of the adjusted effects using the bias-corrected and accelerated bootstrap with 5000 replicates. Importantly, these primary analyses were per protocol.

Since there were several dropouts (nine total across the two groups), we also performed intention-to-treat (ITT) analyses. ITT ensures that participants are analyzed as randomized, meaning all randomized participants are included in the analysis, even if they did not complete the intervention to which they were assigned. There were two issues we needed to analytically resolve: (1) one participant’s triceps brachii MT, one participant’s rectus femoris MT (70%), and one participant’s vastus lateralis MT (70%) were not viewable at baseline; (2) participants who dropped out of the study did not have post-intervention values. We imputed these missing values using Bayesian linear regression models and Multivariate Imputation using Chained Equations in the mice package in R (15). The data were not missing completely at random (MCAR). Thus, we assumed the data were missing at random (MAR) for our imputation models. Pre-intervention models (#1 above) were constructed using the participant’s sex and the pre-intervention muscle thickness of a statistically related muscle (i.e., biceps brachii to inform triceps brachii; rectus femoris at 50% to inform 70%; vastus lateralis at 50% to inform 70%). Post-intervention models were constructed using pre-intervention scores, group, and sex. For the rectus femoris and vastus lateralis, we also included post-intervention scores from adjacent measurement sites. We used the bootImpute (16) to calculate 90% CIs using 2000 bootstrap replicates and 10 imputations per bootstrap replicate.

We drew inferences via an estimation approach (8). That is, we did not wish to binarize the presence of an effect or no effect; rather, we sought to draw inferences about the magnitude and uncertainty of the effects, whether they be close to zero or otherwise. To evaluate the robustness of our findings, sensitivity analyses were performed on the primary outcome measures to detect the presence of outliers or individuals that may have inflated or attenuated the observed effects and their uncertainty—participants who strongly influence the outcomes would affect the point estimate (in either direction) and increase the standard error due to the increase in heterogeneity. To accomplish this, we performed leave-one-out analyses, in which each participant was removed from the analysis, and the analysis was repeated as if that participant was not in the study. This process was repeated for all participants that completed the study, and the resulting effects and their standard errors were examined qualitatively.

Secondary analyses were performed on the nutrition data. Nutrition data were analyzed similarly to the muscle thickness and strength data, using multiple regression with group dummy-coded and pre-intervention nutrition scores as covariates of no interest. The results of these secondary analyses are presented using mean adjusted effects and their standard errors.

We had intended to analyze differences in volume load between conditions, but the training logs provided by UNSUP were not of sufficient quality to carry out analyses on a group level. All analyses were performed in R (version 4.2.2) (9).

Results

Of the 45 participants who initially agreed to participate in the study, 9 dropped out prior to completing the required number of training sessions (Fig 1). Thus, the final sample included 20 participants in SUP (men: n=14; women: n=6) and 16 participants in UNSUP (men: n=12; women: n=4). The overall sample could be classified as recreationally resistance-trained. Participants in SUP completed 96% of sessions and participants in UNSUP completed 92% of sessions. Table 1 shows descriptive data for each group both in the per-protocol analysis and the intention-to-treat analysis.

INSERT TABLE 1 ABOUT HERE

INSERT FIGURE 1 ABOUT HERE

Hypertrophy

Across MT and skeletal muscle mass outcomes, SUP generally outperformed UNSUP on average. Although most of the upper limits of the CIs encapsulated appreciable values favoring SUP, the CI’s lower limits are more outcome dependent. In some cases, such as for triceps brachii and rectus femoris MT, even the lower limit is compatible with a strong effect favoring SUP; however, in other muscles, such as the biceps brachii and vastus lateralis (50 and 70%), the lower limit weakly favors UNSUP, yielding somewhat uncertain inferences. All outcomes are depicted in Fig 2 and presented in Table 2.

INSERT TABLE 2 ABOUT HERE

INSERT FIGURE 2 ABOUT HERE

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Strength

On average, SUP outperformed UNSUP in the $1RM_{SQUAT}$, with an interval compatible with an appreciable effect in favor of SUP (~ 9 kg) ranging to equivalence (~ 0 kg). In contrast, $1RM_{BENCH}$ and isometric knee extension strength were equivocal and uncertain, respectively (Fig 3, Table 2).

INSERT FIGURE 3 ABOUT HERE

Explosive Performance

The countermovement jump favored UNSUP on average, but the data were also compatible with values favoring SUP, yielding uncertain inferences (Fig 3, Table 2).

Nutritional Data

Based on self-reported food records, nutritional intake was relatively similar between groups at baseline. However, during the final week of the study, UNSUP reported reducing overall energy intake via a reduction in carbohydrate and protein intake whereas SUP reported minimal change in macronutrient consumption (Supplemental Table S1).

Discussion

This study produced several notable findings that enhance our understanding of the effects of supervision during RT in young, recreationally trained men and women. For one, supervision generally promoted greater improvements in muscular strength- and hypertrophy-related measures, although these results were not universal across outcomes. In addition, attrition was markedly higher in the unsupervised compared to the supervised group, indicating that supervision had a positive influence on exercise adherence. In the succeeding paragraphs, we discuss the results in the context of previous literature on the topic as well as their practical implications.

Hypertrophy

To our knowledge, this is the first study to investigate site-specific measures of hypertrophy in supervised vs. unsupervised RT. Both groups increased muscle mass across the study period; however, measures of hypertrophy generally favored the supervised group. Specifically, MT changes in the triceps brachii and all regions of the mid-quadriceps were

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appreciably greater in supervised compared to unsupervised groups; increases in the proximal aspect of the lateral quadriceps favored SUP as well. Conversely, MT increases in biceps brachii and mid- and distal aspects of the lateral thigh were similar between conditions. Taken as a whole, the results suggest supervision has a positive effect on muscle development.

Estimates of total body muscle mass via MF-BIA indicated more favorable changes in SUP than in UNSUP. Specifically, supervision enhanced muscle accretion by 0.54 kg with a relatively tight $CI_{90\%}$ (0.05 to 0.98 kg). It should be noted that although MF-BIA shows good agreement with dual-energy x-ray absorptiometry for measuring muscle development (17), these modalities provide only gross estimates of changes in this outcome and thus results should be interpreted somewhat cautiously (18). That said, the MF-BIA results obtained in our study generally coincide with the greater site-specific changes derived from ultrasound, lending credence to their validity.

To our knowledge, only one previous study compared changes in body composition in trained individuals under supervised vs. unsupervised conditions, with estimates obtained via skinfold measurements of fat-free mass (19). Although the results of the previous study did not show statistically significant between-group differences, absolute increases in fat-free mass favored the supervised group compared to those training without supervision (1.38 vs. 0.25 kg, respectively). Thus, these findings are generally consistent with those of the present study.

Strength

Both groups increased lower and upper body dynamic strength across the study period. The SUP group achieved greater increases in the $1RM_{SQUAT}$ compared to UNSUP (4.0 kg (-0.02, 9.2)), while similar increases between groups were observed in the $1RM_{BENCH}$. Previous research generally reports superior strength gains when resistance-trained participants train under supervised conditions. Coutts et al. (20) showed greater 3RM bench press and squat improvements in a supervised vs. unsupervised group after a 12-week RT program in a cohort of young, resistance-trained rugby league players. Similarly, Mazzetti et al. (19) showed supervision led to greater increases in 1RM bench press and squat strength compared to unsupervised training in a cohort of young, recreationally trained men. Discrepancies in upper body strength changes between previous studies and the present investigation might be attributed to the fact that we tested dynamic strength using a Smith machine, which limits degrees of freedom during movement. It is therefore possible that any technique-related improvements in

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the bench press obtained during training did not materially translate to testing on a Smith machine compared to free weight testing as employed in previous studies. Alternatively, the squat is a more complex movement pattern, where coordination remains high even with the restricted bar path in the Smith machine, perhaps explaining why differences were observed in lower body strength between conditions and not in the bench press. This hypothesis warrants further investigation.

Although isometric strength improvements favored UNSUP by 10 N·m, the magnitude of this effect is relatively small with a wide CI (−10 to 33 N·m). In general, the overall magnitudes of changes in isometric strength were considerably smaller than those assessed dynamically. This is consistent with research indicating a task-specificity to dynamic resistance training, whereby strength increases to a substantially greater magnitude when testing dynamically than statically (21). However, changes in isometric strength were particularly modest in this study. Although speculative, this result may be explained at least in part by the fact that testing was carried out at 110° of knee flexion. Evidence indicates that assessment at a given isometric joint angle influences the relationship with dynamic strength changes (22), and it is conceivable that a greater transfer of training may have occurred at lesser knee angles.

Explosive Performance

Changes in explosive lower body performance as determined by the countermovement jump modestly favored the UNSUP group, with the lower limit of the $CI_{90\%}$ suggesting a weak benefit for SUP and the upper limit indicating a moderate superiority for UNSUP. Prior research shows similar increases in vertical jump height between resistance-trained participants following a regimented RT program under supervised and unsupervised conditions (19) (20). It remains speculative as to whether ambiguities in changes in this outcome between previous studies and our investigation are attributed to differences in study design, participant characteristics, random chance, or a combination of these factors. A logical explanation for the finding remains elusive and its practical significance is unclear.

Adherence

There were a substantially greater number of dropouts in UNSUP (*n*=7) compared to SUP (*n*=2) across the 8-week training period. The findings are consistent with those of Coutts et

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al. (20), who reported that supervised participants completed more training sessions than unsupervised participants in a cohort of young resistance-trained rugby league players.

When speaking with participants after the study, several in the supervised group mentioned that supervision held them accountable to a regimented training schedule; in effect, the accountability motivated them to show up for the training session even when they might not have felt like attending. Participants in SUP also may have achieved greater motivation to train via the augmented feedback provided by the research assistants during training (23). Given that adherence is paramount to achieving the beneficial effects associated with RT, supervision would have added value for a segment of the recreationally trained population who may lack the motivation to train consistently.

Implications for Resistance Training Studies

These findings have several important implications for the design and interpretation of RT studies. First, supervision increases internal validity by improving adherence to the training regimen. This is accomplished through between-session means (attendance) and within-session means (following the program itself; e.g., exercises, repetitions, effort, etc.). Second, supervision decreases attrition, reducing the need to rely on imputation when performing ITT analysis. In turn, supervision may maximize the inferential benefits of randomization. Third, since supervision appears to augment muscular development, it may influence effect size estimates through several potential mechanisms: (1) if interventional effects are strictly additive, effect estimates should not be affected by supervision; (2) if interventional effects scale at all with main (or “time”) effects, supervised training should produce greater interventional effect estimates; (3) if supervised training creates a ceiling effect, it may diminish interventional effect estimates, and similarly, if unsupervised training creates a floor effect, it may diminish interventional effect estimates; (4) if supervised training can help homogenize a sample by decreasing sources of training variance, then supervised training should have greater power and better precision. Our study did not investigate points 1–3, which are second-order effects, but they are worth considering when designing future studies. However, our data do not support point #4 (i.e., dispersion models with a group term do not show evidence of appreciable systematic differences in the variance between groups), but this could partly be attributable to our efforts to homogenize training across groups (same facility, equipment, etc.). Finally, supervision’s superiority suggests that the raw, within-group effect sizes in RT studies cannot be readily extrapolated to unsupervised environments. From this standpoint, although supervision may increase internal validity, it may come at the expense of ecological validity. In essence, supervision may be better for assessing efficacy than effectiveness in regard to RT-induced muscular adaptations in recreationally trained individuals.

Limitations

This study had several limitations that should be acknowledged. First, the participants were a sample of young, recreationally resistance-trained men and women. Thus, results are not necessarily generalizable to other populations including children and adolescents, older adults, and novice trainees. It can be speculated that those new to training might have performed more poorly in UNSUP due to a lack of knowledge about RT performance, although resultant between-group differences might have been mitigated as a result of the possibly greater scope for adaptation in less well-trained individuals. Alternatively, highly trained individuals may have shown less disparity in results between conditions due to their discipline and experience. These hypotheses require further exploration. Second, although we did our best to instruct participants in the unsupervised group on proper performance prior to the onset of training, we cannot be sure to what extent they followed our instructions. Moreover, despite assessing adherence via training logs, we also cannot be certain that participants were truthful in their reporting. The detail of reporting in these logs varied considerably, and several of the unsupervised participants did not submit their logs. It is therefore possible that at least some of the unsupervised participants may have altered variables (e.g., volume, load, frequency, exercise selection, etc.) across the study period, which may have mediated results. Third, we only assessed site-specific muscle growth of the upper arm and quadriceps musculature. Thus, it is not clear whether participants may have experienced differential hypertrophy of other skeletal muscles. That said, assessment of changes in total body muscle mass via MF-BIA indicated greater growth for the supervised group, suggesting that supervision had a favorable overall effect on hypertrophy. Finally, although we instructed participants to follow their customary diet and attempted to monitor nutritional intake using food records, it remains questionable as to whether they followed instructions on a group level, which may have resulted in confounding of primary outcomes. Both groups displayed evidence of body recomposition (gains in muscle mass accompanied by reductions in body fat), suggesting that most of the participants were in an energy deficit during the study period. Self-reported energy intake did not appear to properly track with changes in body mass, particularly

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in UNSUP, calling into question the accuracy of the food logs as has been previously reported (25). Moreover, evidence indicates that an energy surplus is beneficial for maximizing muscular adaptations (24). Thus, results cannot necessarily be extrapolated to what might be achieved when different supervised conditions are combined with a hypertrophy-oriented nutritional protocol.

Conclusions

In conclusion, our study provides evidence that direct supervision elicits greater improvements in muscle strength and hypertrophy as well as enhancing exercise adherence in recreationally trained young men and women. Although speculative, it can be hypothesized that a combination of higher intensities of effort and better exercise technique achieved by supervision may be at least in part attributable to the superior muscular adaptations. The greater exercise adherence in the supervised group may be attributed to a combination of feelings of accountability as well as a heightened motivation to achieve better results.

From an applied standpoint, our findings suggest that supervision, such as that typically provided by personal trainers, promotes hypertrophic benefits for recreationally trained individuals independent of factors related to program design. In this regard, it can be speculated that training with a dedicated partner may also impart similar beneficial effects.

Our findings also suggest that research studies should employ supervised RT when investigating outcomes related to muscular adaptations in recreationally trained individuals. Supervision ensures that participants are training consistently with the study design, thus improving internal validity. Moreover, supervision helps to optimize RT-induced changes in strength and hypertrophy, providing better insights into the effects of the independent variable(s) of interest on study outcomes.

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Conflicts of Interest: *BJS serves on the scientific advisory board for Tonal Corporation, a manufacturer of fitness equipment. JPF provides consultancy services to strength training organizations which typically employ supervised strength training.*

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References

(1) Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc 2004 April 01;36(4):674-688.

(2) Wackerhage H, Schoenfeld BJ. Personalized, Evidence-Informed Training Plans and Exercise Prescriptions for Performance, Fitness and Health. Sports Med 2021 September 01;51(9):1805-1813.

(3) Schoenfeld B, Fisher J, Grgic J, Haun C, Helms E, Phillips S, et al. Resistance training recommendations to maximize muscle hypertrophy in an athletic population: Position stand of the IUSCA. IJSC 2021;16(1):1.

(4) Schoenfeld BJ, Grgic J. Does training to failure maximize muscle hypertrophy?. Strength Cond J 2019;41(5):108-113.

(5) Fisher J, Steele J, Wolf M, Korakakis PA, Smith D, Giessing J. The role of supervision in resistance training; an exploratory systematic review and meta-analysis. International Journal of Strength and Conditioning 2022;2(1).

(6) Plüss M, Schellenberg F, Taylor WR, Lorenzetti S. Towards Subject-Specific Strength Training Design through Predictive Use of Musculoskeletal Models. Appl Bionics Biomech 2018 March 19;2018:9721079.

(7) Tavoian D, Ampomah K, Amano S, Law TD, Clark BC. Changes in DXA-derived lean mass and MRI-derived cross-sectional area of the thigh are modestly associated. Sci Rep 2019 July 11;9(1):10028-019.

(8) Schoenfeld BJ, Grgic J, Contreras B, Delcastillo K, Alto A, Haun CT, et al. To flex or rest: Does adding no-load isometric actions to the inter-set rest period in resistance training enhance muscular adaptations? Frontiers in Physiology 2019;doi: 10.3389/fphys.2019.01571.

(9) R: A language and environment for statistical computing. 2019; Available at: https://www.R-project.org/.

(10) Baechle TR, Earle RW editors. Essentials of Strength Training and Conditioning. 3rd ed. Champaign, IL: Human Kinetics; 2008.

(11) Ogasawara R, Thiebaud RS, Loenneke JP, Loftin M, Abe T. Time course for arm and chest muscle thickness changes following bench press training. Interventional Medicine and Applied Science 2012;4(4):217-220.

(12) Biazon TMPC, Ugrinowitsch C, Soligon SD, Oliveira RM, Bergamasco JG, Borghi-Silva A, et al. The Association Between Muscle Deoxygenation and Muscle Hypertrophy to Blood Flow Restricted Training Performed at High and Low Loads. Front Physiol 2019 April 17;10:446.

(13) Damas F, Phillips SM, Libardi CA, Vechin FC, Lixandrao ME, Jannig PR, et al. Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. J Physiol 2016 September 15;594(18):5209-5222.

(14) Vickers AJ, Altman DG. Statistics notes: Analysing controlled trials with baseline and follow up measurements. BMJ 2001 November 10;323(7321):1123-1124.

(15) van Buuren S, Groothuis-Oudshoorn K. mice: Multivariate Imputation by Chained Equations in R. Journal of Statistical Software 2011;45(3):1-67.

(16) Bartlett J. bootImpute: Bootstrap Inference for Multiple Imputation. R package version 1.2.0. 2021; Available at: https://CRAN.R-project.org/package=bootImpute.

(17) Ling CH, de Craen AJ, Slagboom PE, Gunn DA, Stokkel MP, Westendorp RG, et al. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. Clin Nutr 2011 October 01;30(5):610-615.

(18) Haun CT, Vann CG, Roberts BM, Vigotsky AD, Schoenfeld BJ, Roberts MD. A Critical Evaluation of the Biological Construct Skeletal Muscle Hypertrophy: Size Matters but So Does the Measurement. Front Physiol 2019 March 12;10:247.

(19) Mazzetti SA, Kraemer WJ, Volek JS, Duncan ND, Ratamess NA, Gómez AL, et al. The influence of direct supervision of resistance training on strength performance. Med Sci Sports Exerc 2000 June 01;32(6):1175-1184.

(20) Coutts AJ, Murphy AJ, Dascombe BJ. Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players. J Strength Cond Res 2004 May 01;18(2):316-323.

(21) Jones DA, Rutherford OM, Parker DF. Physiological changes in skeletal muscle as a result of strength training. *Q J Exp Physiol*. 1989;74(3):233-256. doi: 10.1113/expphysiol.1989.sp003268.

(22) Murphy AJ, Wilson GJ, Pryor JF, Newton RU. Isometric assessment of muscular function: the effect of joint angle. J Appl Biomech 1995;11(2):205-215.

(23) Weakley J, Till K, Sampson J, Banyard H, Leduc C, Wilson K, et al. The Effects of Augmented Feedback on Sprint, Jump, and Strength Adaptations in Rugby Union Players After a 4-Week Training Program. Int J Sports Physiol Perform 2019 August 29:1205-1211.

(24) Aragon AA, Schoenfeld BJ. Magnitude and Composition of the Energy Surplus for Maximizing Muscle Hypertrophy: Implications for Bodybuilding and Physique Athletes. Strength & Conditioning Journal 2020;42(5):79-86.

(25) Freedman LS, Commins JM, Moler JE, Arab L, Baer DJ, Kipnis V, et al. Pooled results from 5 validation studies of dietary self-report instruments using recovery biomarkers for energy and protein intake. Am J Epidemiol 2014 July 15;180(2):172-188.