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Original Research

Influence of Baseline Muscle Strength and Size Measures on Training Adaptations in Resistance-trained Men

GERALD T. MANGINE†[1], ADAM M. GONZALEZ†[2], JEREMY R. TOWNSEND†[3], ADAM J. WELLS†[4], KYLE S. BEYER†[4], AMELIA A. MIRAMONTI†[4], NICHOLAS A. RATAMESS‡[5], JEFFREY R. STOUT‡[4], and JAY R. HOFFMAN‡[4]

[1]Exercise Science and Sport Management, Kennesaw State University, Kennesaw, GA, USA; [2]Health Professions, Hofstra University, Hempstead, NY, USA; [3]Exercise and Nutrition Science, Lipscomb University, Nashville, TN, USA; [4]Institute of Exercise Physiology and Wellness, University of Central Florida, Orlando, FL, USA; [5]Health & Exercise Science, The College of New Jersey, Ewing, NJ, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 11(4): 198-213, 2018. The influence of baseline strength or muscle size on adaptations to training is not well-understood. Comparisons between novice and advanced lifters, and between stronger and weaker experienced-lifters, have produced conflicting results. This study examined the effect of baseline muscle strength and size on subsequent adaptations in resistance-trained individuals following a traditional high-volume, short-rest resistance training protocol. Fourteen resistance-trained men (24.0±2.7 y; 90.1±11.7 kg; 169.9±29.0 cm) completed pre-training (PRE) ultrasound measurements of muscle cross-sectional area (CSA) in the rectus femoris (RF), vastus lateralis (VL), pectoralis major, and triceps brachii (TRI) prior to strength assessments (e.g., one-repetition maximum strength bench press and back-squat). Post-training (POST) assessments were completed following 8-wks (4 d·wk^{-1}) of resistance training. Comparisons were made between stronger (STR) and weaker (WKR) participants, and between larger (LGR) and smaller (SMR) participants, based upon PRE-muscle strength and size, respectively. When groups were based on upper-body strength, repeated measures analysis of variance indicated a significant group x time interaction where greater improvements in bench press strength were observed in WKR (12.5±8.6%, p = 0.013) compared to STR (1.3±5.4%, p=0.546). Within this comparison, STR also possessed more resistance training experience than WKR (mean difference=3.1 y, p=0.002). No other differences in experience or adaptations to training were observed. These data suggest that following a short-duration training program (8-weeks), baseline size and strength have little impact on performance gains in resistance-trained individuals who possess similar years of experience. However, when training experience is different, baseline strength may affect adaptations.

KEY WORDS: Hypertrophy, strength adaptations, resistance training experience, short-duration resistance training

INTRODUCTION

It is well acknowledged that appropriately designed resistance training programs can stimulate significant improvements in muscle strength and size (5, 21, 33). Currently, the magnitude of these adaptations appear to be dependent upon individual training status and the specific characteristics of the training program (e.g., training volume load, rest intervals, etc.). In novice or minimally trained individuals, most training designs are effective for stimulating large adaptations. However, training experience and a high level of strength may reduce the potential for adaptations to training (5-7, 21, 33). This is attributed to a reduced reliance on neurological adaptations that facilitate a more efficient and effective recruitment of muscle; an effect that is more commonly associated with novice or detrained lifters (28, 30, 39). Neurological adaptations occur relatively early in the novel training program, and further strength improvements are primarily the result of muscle adaptation (28, 30, 39). Though it is plausible that periodic adjustments to the stimulus (i.e., changes to programming variables) may assist in continuing neurological adaptations, years of training will likely minimize the quantity of novel training options. Thus, the neurological contribution to strength improvements in individuals who possess several years of resistance training experience may be small or negligible. These individuals may need to focus their programming towards stimulating muscle hypertrophy to augment their strength. However, the ability to sustain increases in muscle cross-sectional area from a specific training stimulus may also be limited.

Skeletal muscle growth is believed to be the consequence of both mechanical and metabolic stresses introduced during resistance training (13, 14, 27, 28, 42). Mechanical stress results from the tension created when activated muscle moves through a range of motion against an external force (1, 42), while metabolic stress may occur from energy depletion of activated muscle fibers (14, 33). These stresses cause varying degrees of muscle damage, resulting in a recovery process that culminates with an adaptation of muscle fibers becoming desensitized to the aggravating stimulus (3, 10, 41). As a result, experienced, resistance trained individuals may become resistant to further adaptation, and require a different training strategy to stimulate further improvement. Currently, recommendations exist for improving muscle strength and size in resistance-trained individuals (5, 21, 33), but they do not account for the potential influence of existing strength and size on adaptations.

Experienced, resistance trained individuals are typically stronger than untrained adults of similar body mass (2). Their greater levels of strength may be the consequence of possessing greater muscle mass, being capable of recruiting a greater percentage of muscle fibers at a given load, or both (18, 19). These physical advantages, especially when associated with training experience, appear to limit adaptation. For example, greater improvements in knee extension strength (20.9% vs. 5.6%) and size (3.9% vs. –1.8%) were reported in a group of physically active adults with no resistance-training experience compared to a group of stronger, experienced power lifters and bodybuilders, respectively, following 21-weeks of resistance training (2). Although the training protocols were different, strength and training history clearly affected adaptations. Similarly, greater strength and power have been reported in professional rugby players with more resistance-training experience (>3 years) compared to those with limited experience (less than 3 years) (7). After one year of training, however, the strength and power differences that existed at baseline were no longer present. While strength and power at baseline may explain differences in the rate of improvement in these athletes, it is debatable. It is possible that the scope or focus (intentional or not) of training for the more experienced athletes (elite, first-division national rugby league players) and those with less experience (sub-elite, second-division national rugby league players) did not match. Indeed, a 10-yr follow-up to the previous investigation indicated that the greatest improvements in strength & power occurred during the first four years of training (16.6 – 19.3%) compared to the last six years (2.5 – 5.6%) (6). The authors hypothesized that during their early career, the focus of training for the sub-elite athletes was to gain comparable (to elite players) strength and power. Once achieved, however, their focus shifted to maintaining strength, power, and improving sports-specific skills. Thus, it remains unclear whether a physiological benefit or disadvantage exists for experienced individuals with greater strength or muscle mass.

To the best of our knowledge, only one study has examined the effect of baseline strength on training adaptations within an experienced resistance-trained population (11). Cormie et al. (2010) investigated the effect of 10-weeks of ballistic training on several physiological and performance measures in stronger versus weaker resistance-trained males. They reported a greater effect on peak vertical jump power in stronger participants ($\eta^2 = 1.60$) compared to their weaker counterparts ($\eta^2 = 0.95$) but observed no group differences or changes in muscle strength and size. However, it is not clear whether the training program (i.e., jump squats only, 3 training sessions per week) was consistent with the participants' normal training habits and the training loads (i.e., jump squats at 0 – 30% 1RM) may have been too low for stimulating strength gains or hypertrophy (5, 21, 33). It is possible that these results do not reflect the adaptations that would occur in a resistance-trained population following a more traditional training scheme. Therefore, the purpose of this investigation was to determine the effect of baseline strength and muscle size on adaptations in these measures following 8-weeks of a high-volume, short-rest resistance training paradigm in experienced, resistance trained individuals. Our hypothesis was that the adaptations in muscle strength and size for weaker or smaller participants would be greater than those experienced by stronger or larger participants.

METHODS

Participants

Following an explanation of all procedures, risks and benefits, fourteen physically-active, resistance-trained men (24.0 ± 2.7 y; 90.1 ± 11.7 kg; 169.9 ± 29.0 cm) provided their informed consent to participate in the study. The participants had been part of a larger training investigation (24) and data from that study was used to determine an appropriate sample size. Using G*Power (v. 3.1.9.2, Kiel, Germany), it was determined that a minimum of 8 participants was necessary to determine statistical significance ($p < 0.05$) using the average effect size value for all ultrasound measures of muscle size (partial eta squared = 0.30) and $\beta = 0.80$ for a between-within repeated measures analysis of variance (ANOVA). Further, our sample size ($n = 14$) closely resembled that of the only previous investigation ($n = 16$) (11) to examine the effect of baseline strength on training adaptations. All participants were free of any physical limitations (determined by medical and athletic history questionnaire and PAR-Q) and had been regularly participating (at the time of recruitment) in resistance training for a minimum of 2 years (5.7 ± 2.2 y). This investigation was approved by the New England Institutional Review Board.

Protocol

Participants completed 8-weeks of a high-volume, moderate-intensity training program. Prior to the actual training intervention, all participants were required to complete a 2-week preparatory training program followed by pre-training (PRE) assessments of body composition, muscle morphology and strength. Following 8-weeks of resistance training (POST), the same assessments performed at PRE, were repeated. To examine the effect of baseline strength on training adaptations, participants were split into two equal groups based upon being stronger (STR) or weaker (WKR) than the entire group's median score in the bench press (BP) and back squat (SQ) exercises at PRE. Similarly, the effect of baseline muscle size on training adaptations was determined by splitting the participants into two equal groups based upon being larger (LGR) or smaller (SMR) than the entire group's median score for upper-body (i.e., the sum of cross-sectional area [CSA] of the *m. pectoralis major* and *m. triceps brachii*) and lower-body (i.e., the sum of CSA of the *m. rectus femoris* and *m. vastus lateralis*) muscle size at PRE. Consequently, separate comparisons were made between STR and WKR based upon upper- and lower-body strength, as well as between LGR and SMR based upon upper- and lower-body muscle size. Descriptive characteristics of each group are presented in Table 1.

Table 1. Group characteristics based on upper- and lower-body muscle strength and size at PRE.

	Upper-body		Lower-body	
Strength comparisons	WKR	STR	WKR	STR
Age (y)	23.1 ± 2.9	24.2 ± 2.8*	21.7 ± 1.6	25.6 ± 2.3*
Training experience (y)	4.3 ± 1.8	7.4 ± 1.0*	5.1 ± 2.5	6.6 ± 1.5
Height (cm)	177.6 ± 3.6	177.7 ± 4.7	178.1 ± 3.1	177.2 ± 5.0
Weight (kg)	84.8 ± 8.1	92.8 ± 14.9	84.1 ± 9.4	93.6 ± 13.6
Muscle size comparisons	SMR	LGR	SMR	LGR
Age (y)	23.2 ± 2.7	24 ± 3.1	22.9 ± 2.8	24.3 ± 2.9
Training experience (y)	5.1 ± 2.5	6.6 ± 1.5	5.7 ± 2.4	6.0 ± 2.0
Height (cm)	176 ± 1.7	179.3 ± 5.0	178.1 ± 3.2	177.2 ± 4.9
Weight (kg)	81.5 ± 6.0	96.2 ± 12.8*	86.9 ± 8.0	90.7 ± 15.9

* = Significant ($p < 0.05$) difference between groups.

Strength testing: Strength was assessed in BP and SQ. All participants completed standardized warm-up and testing procedures as previously described (20). Briefly, a warm-up set of 5 – 10 repetitions was performed for each exercise using 40 – 60% of the participant's perceived one-repetition maximum (1-RM). After a 1-minute rest period, the participants performed a set of 2 – 3 repetitions at 60 – 80% of their perceived 1-RM. Subsequently, 3 – 5 maximal trials (1-repetition sets) were performed to determine the 1-RM. Rest periods between maximal attempts were 2 – 3 minutes in length. For the bench press, any trials that involved excessive arching of the back or bouncing of the weight were discarded. For the back squat, a successful attempt required the participant to descend to the "parallel" position, where the greater trochanter of the femur was aligned with the knee. All strength testing was completed under the supervision of a certified strength and conditioning specialist (CSCS).

Morphologic assessments: Initially, height (±0.1 cm) and body mass (±0.1 kg) were determined using a Health-o-meter Professional scale (Model 500 KL, Pelstar, Alsip, IL, USA). Non-invasive skeletal muscle ultrasound was used to monitor changes in the size of specific muscles using previously describe procedures (24). Briefly, a 12 MHz linear probe scanning head (General Electric LOGIQ P5, Wauwatosa, WI, USA) was used to collect images of the rectus femoris (RF), vastus lateralis (VL), pectoralis major (PM), and triceps brachii (TRI). The same investigator identified all anatomical locations of interest using standardized landmarks on the participant's dominant side for the purpose of measuring muscle cross-sectional area (CSA; ±0.1cm^2). For all images, the extended field of view mode (Gain = 50 dB; Image Depth = 5cm) was used to capture two consecutive panoramic images of the muscular regions of interest. After image collection, the ultrasound data were transferred to a personal computer and analyzed by the same investigator using Image J (National Institutes of Health, Bethesda, MD, USA, version 1.45s). The averaged values from both images within a specific region were used for statistical analysis. Using these procedures, measures of reliability had been determined for assessing the RF ($ICC_{3,K}$ = 0.88, $SEM_{3,K}$ = 1.78, MD = 4.60cm^2), VL ($ICC_{3,K}$ = 0.99, $SEM_{3,K}$ = 1.11, MD = 3.05cm^2), PM ($ICC_{3,K}$ = 0.98, $SEM_{3,K}$ = 2.86, MD = 7.84cm^2), and TB ($ICC_{3,K}$ = 0.97, $SEM_{3,K}$ = 1.28, MD = 3.50cm^2) were determined on ten active, resistance-trained men (25.3 ± 2.0y; 90.8 ± 6.8kg; 180.3 ± 7.1cm).

Training intervention: The details of the high-volume, short rest training protocol (4 sets of 10 – 12 repetition maximums, 1-min rest intervals between sets) have been described elsewhere (24). Briefly, all participants were required to complete at least 28 resistance training sessions (~90%) of their training program (4 sessions · wk^{-1}) which included six, upper- and lower-body exercises during each session. Each training session began with a standardized warm-up followed by several, multi-joint, core exercises (e.g., bench press, incline press, shoulder press, back squat, deadlift, leg press, etc.) and single-joint, assistance exercises (e.g., dumbbell flys, dumbbell lateral raise, biceps curls, and overhead triceps extensions). Further, the participants were instructed to avoid participating in any supplementary resistance training sessions for the duration of the study. All sessions were completed under the direct supervision of CSCS.

Nutrient intake and dietary analysis: Throughout the entire study, participants were instructed to maintain their normal dietary-intake habits. Additionally, post-exercise nutrition was standardized by providing ~235 mL of chocolate milk (170 calories; 2.5g Fat; 29g Carbohydrate; 9g protein) or Lactaid® (150 calories; 2.5g Fat; 24g Carbohydrate; 8g protein) to each participant immediately following each workout. Nevertheless, to monitor kilocalorie and macronutrient intake, 3-day food diaries were collected during the first and last week of the training intervention. For statistical analysis, total caloric, macronutrient (protein, carbohydrate, and fat), and branched chain amino acid (leucine, isoleucine, and valine) intake were analyzed relative to body mass.

Statistical Analysis
Initially, an independent t-test was performed at PRE to determine whether differences existed between groups (i.e., STR vs. WKR and LGR vs. SMR) for upper- and lower-body measures in terms of their training experience, muscle strength, and muscle size. A two-way (group x time) analysis of variance with repeated measures was used to assess the differences between STR and WKR, as well as between LGR and SMR, on adaptations in muscle strength and size following 8-wks of resistance training. In the event of a significant F-ratio, paired samples t-tests were performed to assess significant changes occurring in each group separately. A criterion alpha level of $p \leq 0.05$ was used to determine statistical significance. All data were reported as mean ± standard deviation. Statistical Software (V. 21.0, SPSS Inc., Chicago, IL) was used for all analyses.

RESULTS

Significant ($p < 0.05$) differences were observed between groups based on strength at PRE. When participants were grouped based on upper-body strength, it resulted in STR being older (mean difference = 1.1 y, $p = 0.049$) and possessing more resistance training experience (mean difference = 3.1 y, $p = 0.002$), greater BP strength (mean difference = 32.1 kg), and greater PM CSA (mean difference = 18.3 cm^2) than WKR. When strength groups were based on lower-body strength, STR was older (mean difference = 3.9 y, $p = 0.033$) and possessed greater SQ strength (mean difference = 30.4 kg) and RF CSA (mean difference = 3.2 cm^2) than WKR. Descriptive and performance differences between groups based on strength at PRE, are presented in Tables 1 and 2, respectively.

Significant ($p < 0.05$) differences were observed between groups based on muscle size at PRE. When participants were grouped based on upper-body muscle size, it resulted in LGR possessing more body mass (mean difference = 14.7 kg, $p = 0.026$), greater BP strength (mean difference = 19.9 kg), and greater PM CSA (mean difference = 24.4 cm2) compared to SMR. When muscle size groups were based on lower-body measures, LGR possessed greater VL CSA (mean difference = 10.1 cm2) compared to SMR. Descriptive and performance differences between groups based on muscle size at PRE, are presented in Tables 1 and 3, respectively.

Training adaptation comparisons: Changes in muscle strength and size when groups were based on upper- and lower-body muscle strength and muscle size at PRE, are presented in Tables 2 and 3, respectively. When participants were grouped based on upper-body strength, a significant group x time interaction was observed where a greater improvement in BP was observed in WKR (12.5 ± 8.6%, $p = 0.013$) compared to STR (1.3 ± 5.4%, $p = 0.546$). The changes in BP strength when groups were based on BP at PRE, are illustrated in Figure 1. No other significant group x time interactions were observed for any measure of muscle strength or size.

Table 2. Muscle strength and size comparisons when groups were defined by baseline upper- and lower-body strength.

				At Baseline		Group x Time	
		PRE	**POST**	**t**	**p-value**	**F**	**p-value**
Upper-body strength							
Bench Press (kg)	WKR	88.4 ± 6.7	99.7 ± 13.3	-6.10	<0.001	5.75	0.034
	STR	120.6 ± 12.2	122.1 ± 13.8				
Pectoralis Major (cm^2)	WKR	66.3 ± 10.3	68.2 ± 12.1	-2.39	0.034	0.12	0.734
	STR	84.6 ± 17.5	86.0 ± 16.4				
Triceps Brachii (cm^2)	WKR	8.4 ± 2.9	9.9 ± 3.3	-1.16	0.268	0.62	0.446
	STR	11.4 ± 6.3	13.5 ± 7.0				
Lower-body strength							
Back Squat (kg)	WKR	124.9 ± 14.7	145.1 ± 15.7	-3.69	0.003	0.53	0.480
	STR	155.3 ± 16.1	170.6 ± 17.5				
Rectus Femoris (cm^2)	WKR	15.1 ± 1.6	15.3 ± 2.0	-2.44	0.031	0.21	0.657
	STR	18.2 ± 3.0	18.2 ± 2.8				
Vastus Lateralis (cm^2)	WKR	37.8 ± 5.6	38.1 ± 4.9	-0.61	0.552	1.86	0.198
	STR	40.2 ± 8.6	42.3 ± 8.2				

Table 3. Muscle strength and size comparisons when groups were defined by baseline upper- and lower-body muscle size.

				At Baseline		Group x Time	
		PRE	**POST**	**t**	**p-value**	**F**	**p-value**
Upper-body size							
Bench Press (kg)	SMR	94.6 ± 12.2	101.3 ± 12.8	-2.21	0.048	0.01	0.910
	LGR	114.4 ± 20.5	120.6 ± 16.8				
Pectoralis Major (cm^2)	SMR	63.2 ± 6.8	64.7 ± 7.6	-3.99	0.002	0.07	0.800
	LGR	87.7 ± 14.7	89.5 ± 13.5				
Triceps Brachii (cm^2)	SMR	8.0 ± 3.0	9.5 ± 3.6	-1.51	0.156	0.76	0.402
	LGR	11.8 ± 5.9	13.9 ± 6.6				
Lower-body size							
Back Squat (kg)	SMR	132.4 ± 21.5	152.7 ± 17.8	-1.36	0.198	0.53	0.480
	LGR	147.7 ± 20.4	163 ± 23.5				
Rectus Femoris (cm^2)	SMR	15.5 ± 2.3	16.1 ± 2.7	-1.58	0.140	3.38	0.091
	LGR	17.8 ± 3	17.4 ± 2.9				
Vastus Lateralis (cm^2)	SMR	33.9 ± 3.5	35.6 ± 3.7	-3.80	0.003	0.47	0.506
	LGR	44 ± 6.1	44.8 ± 6.3				

Table 4. Changes in dietary and nutritional intake following 8-wks of training in resistance-trained men.

		Upper-body		Lower-body	
		PRE	**POST**	**PRE**	**POST**
Strength comparisons					
Calories (kcal · kg-1)	WKR	30.8 ± 13.0	23.5 ± 4.1	27.3 ± 7.4	25.5 ± 5.0
	STR	32.9 ± 4.1	30.8 ± 5.7	33.8 ± 9.6	27.8 ± 6.7
Protein (g · kg-1)	WKR	1.64 ± 0.61	1.40 ± 0.54	1.76 ± 0.88	1.70 ± 0.57
	STR	1.94 ± 0.61	1.68 ± 0.33	1.80 ± 0.52	1.47 ± 0.42
Carbohydrate (g · kg-1)	WKR	2.97 ± 1.68	2.18 ± 0.45	2.76 ± 1.14	2.24 ± 0.88
	STR	3.67 ± 0.79	3.69 ± 0.96	3.56 ± 1.35	3.23 ± 1.05
Fat (g · kg-1)	WKR	1.29 ± 0.66	0.78 ± 0.25	0.82 ± 0.25	0.71 ± 0.14
	STR	1.10 ± 0.30	1.00 ± 0.42	1.35 ± 0.50*	0.97 ± 0.39
Leucine (g · kg-1)	WKR	0.07 ± 0.03	0.10 ± 0.10	0.10 ± 0.08	0.10 ± 0.10
	STR	0.13 ± 0.04*	0.10 ± 0.01	0.09 ± 0.03	0.10 ± 0.01
Isoleucine (g · kg-1)	WKR	0.04 ± 0.02	0.04 ± 0.03	0.06 ± 0.05	0.06 ± 0.05
	STR	0.08 ± 0.03*	0.06 ± 0.02	0.06 ± 0.02	0.05 ± 0.02
Valine (g · kg-1)	WKR	0.04 ± 0.02	0.04 ± 0.03	0.06 ± 0.05	0.06 ± 0.05
	STR	0.08 ± 0.03*	0.07 ± 0.02	0.06 ± 0.02	0.05 ± 0.02
Muscle size comparisons					
Calories (kcal · kg-1)	SMR	34.7 ± 13.8	25.4 ± 4.6	28.5 ± 5.1	27.2 ± 9.2
	LGR	29.9 ± 5.0	28.3 ± 7.0	34.0 ± 11.0	27.1 ± 3.9
Protein (g · kg-1)	SMR	1.99 ± 0.81	1.57 ± 0.66	1.59 ± 0.44	1.24 ± 0.55
	LGR	1.66 ± 0.43	1.52 ± 0.32	1.93 ± 0.68	1.74 ± 0.25
Carbohydrate (g · kg-1)	SMR	3.72 ± 1.65	2.58 ± 0.57	2.86 ± 0.75	3.42 ± 1.55
	LGR	3.05 ± 1.06	3.17 ± 1.30	3.62 ± 1.54	2.61 ± 0.55
Fat (g · kg-1)	SMR	1.20 ± 0.75	0.66 ± 0.11	1.19 ± 0.22	0.94 ± 0.32
	LGR	1.18 ± 0.31	1.05 ± 0.37	1.19 ± 0.64	0.86 ± 0.39
Leucine (g · kg-1)	SMR	0.10 ± 0.06	0.10 ± 0.10	0.10 ± 0.04	0.10 ± 0.01
	LGR	0.09 ± 0.04	0.10 ± 0.01	0.10 ± 0.05	0.10 ± 0.01
Isoleucine (g · kg-1)	SMR	0.06 ± 0.04	0.05 ± 0.04	0.06 ± 0.02	0.03 ± 0.03
	LGR	0.05 ± 0.02	0.05 ± 0.02	0.06 ± 0.03	0.06 ± 0.03
Valine (g · kg-1)	SMR	0.07 ± 0.04	0.06 ± 0.04	0.06 ± 0.02	0.04 ± 0.03
	LGR	0.06 ± 0.02	0.05 ± 0.02	0.06 ± 0.03	0.07 ± 0.03

* = Significantly ($p < 0.05$) different at PRE.

Nutritional intake and dietary analysis: At PRE, STR (based on upper-body strength) consumed more leucine (mean difference = 0.06 g · kg^{-1}, $p = 0.005$), isoleucine (mean difference = 0.04 g · kg^{-1}, $p = 0.005$), and valine (mean difference = 0.04 g · kg^{-1}, $p = 0.005$) compared to WKR. Additionally, STR (based on lower-body strength) consumed more dietary fat at PRE (mean difference = 0.45 g · kg^{-1}, $p = 0.050$) compared to WKR. Over 8-wks of training, no group x time interactions (F = 0.003 – 3.452; p = 0.100 – 0.957) were observed for relative caloric intake, protein intake, carbohydrate intake, dietary fat intake, leucine intake, isoleucine intake, or valine intake in any grouping combination. Further, no main effects for time were observed (F = 0.224 – 5.314; p = 0.051 – 0.649). Changes in nutritional and dietary intake over 8-wks of training with respect to groups based on upper- and lower-body muscle strength and size at PRE, are presented in Table 4.

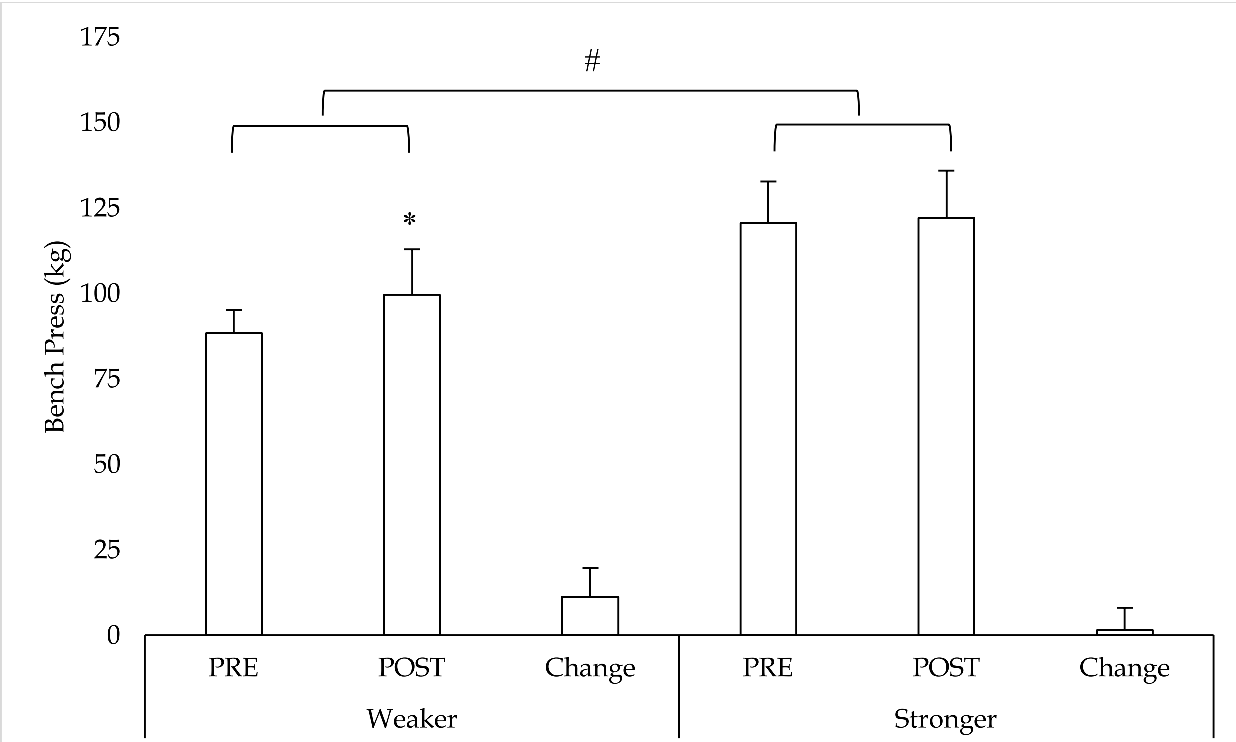

Figure 1. Changes in bench press strength in stronger versus weaker resistance-trained adults. * = Significantly ($p < 0.05$) different from PRE**,** # = Significantly ($p < 0.05$) different between groups

DISCUSSION

In experienced-lifters, the influence of existing strength or muscle size on the magnitude of training adaptations following short-duration resistance training programs are not well understood. Here, we examined adaptations in experienced lifters based on their strength and size prior to training. Participants with less upper-body strength experienced greater upper-body strength improvements compared to stronger participants. In contrast, no specific advantages were observed when existing lower-body strength and muscle size (upper- and lower-body) formed the basis of the comparison. Previously, greater changes in strength and muscle size have been reported in less experienced or novice lifters compared to experienced-lifters over the course of the same training duration (6). The more accelerated response in less experienced lifters is thought to be related to differences in strength or muscle size, their familiarity with the specific training stimulus, or both (5, 18, 27). In part, our data supports this contention as participants who were weaker in the upper-body also possessed less experience and achieved greater strength gains. However, no advantage was seen between stronger and weaker participants for developing upper-body muscle size. Among other group comparisons, no differences in training experience or adaptations were observed. These findings are consistent with previous comparisons between stronger and weaker, experienced lifters on adaptations following a 10-week ballistic training intervention (11). Thus, it appears that following short-duration (8 – 10 weeks) training interventions, baseline muscle size and strength of resistance-trained individuals may not influence subsequent short-term adaptations.

Training experience plays a critical role in exercise-induced training adaptations. The initial improvements in strength among novice lifters are primarily associated with neurological adaptations, which enhance the efficiency of muscle recruitment (13, 27, 28, 32). Although the early stages of muscle hypertrophy will also occur during this time, phenotypic changes in muscle size will not be apparent for a few weeks (28, 30, 39). In contrast, well-trained or advanced lifters are likely to have experienced a variety of neurological adaptations over several years of training and thus, improvements in strength are assumed to be primarily the consequence of hypertrophy (28, 30, 39). The findings of this investigation suggest that the factors that influence training adaptations in these individuals may be more complex. When training experience was comparable, we observed similar improvements between groups in muscle strength and size. However, when experience was different (i.e., participants with less upper-body strength possessed approximately 4.3 years of training experience compared to 7.4 years in stronger participants), the resultant adaptations were not uniform. This is interesting because all participants were considered to be experienced, well-trained lifters (i.e., inclusion criteria required greater than one year of training experience and be currently training) according to typical strength and conditioning standards (17).

Although current and historical (within the last 6 – 12 months) training practices and experience are commonly used to characterize training status, they do not account for quality. Further, it is difficult to make conclusive determinations on an individual's current status without detailed training logs or when select programming variables (e.g., rest interval durations, warm-up sets) are not recorded. As we have previously reported (24), we had inquired (via medical and athletic history questionnaire) about the participants' training habits prior to the study and found that they had all previously incorporated the exercises of the present investigation into their own training regimen and equally utilized comparable repetition ranges and rest intervals. As an additional control, we utilized a 2-week familiarization phase to ensure that the participants initiated the study in a similarly trained state. Nevertheless, weaker participants experienced greater improvements in bench press strength, without comparable improvements in muscle size. Current understanding suggests that this outcome would be indicative of neuromuscular adaptations (28, 30, 39), but this could not be determined based on our methodology. Though speculative, the novelty for our participants in being encouraged and motivated by a certified strength and conditioning specialist at all training sessions may have differentially impacted training effort (e.g., intensity selection and progression, completed training volume, compliance with prescribed rest intervals) (25, 34) and potentially, training adaptations. Alternatively, it is possible that concomitant changes in muscle size were missed due to our assessment of only two muscles in the upper- (pectoralis major and triceps brachii) and lower-body (rectus femoris and vastus lateralis).

Dietary intake may have also influenced the adaptations in bench press strength observed in weaker participants. While no differences were observed between groups in macronutrient intake, weaker participants reported consuming less branched-chain amino acids (BCAA) at the beginning of the training period compared to stronger participants, and comparable amounts at POST. The BCAAs are a trio of amino acids (i.e., leucine, isoleucine, and valine) that are distinctly metabolized in skeletal muscle and are known to have a stimulatory effect on muscle protein synthesis (8, 38). Although consumption of all essential amino acids is important for stimulating growth (26), since overall protein intake was comparable, it is possible that increased intake by weaker participants may have particularly affected strength gains. However, the point during training at which BCAA-intake became equal between groups could not be determined. It is possible that these data are only representative of the final two weeks of training. Therefore, we cannot make definitive conclusions on the influence of changes in BCAA intake on strength adaptations.

Aside from greater upper-body strength improvements in WKR, our main finding was that in experienced, resistance-trained men, baseline strength and muscle size do not affect adaptations following 8-wks of resistance training. Previously, Cormie and colleagues (11) examined the effect of baseline strength on changes in vertical jump performance, as well as muscle strength and size, following a 10-week ballistic training program. Although the authors reported a greater effect on peak vertical jump power development for stronger participants ($\eta^2 = 1.60$ vs. $\eta^2 = 0.95$), group differences were not significant and they occurred without concomitant changes in muscle strength or size. The improvements in vertical jump performance observed in Cormie's study (11) may have been the consequence of novel programming (i.e., performing jump squats only for 5 – 7 sets of 5 – 6 repetitions, 3 sessions per week), whereas the lack of strength gain or hypertrophy were likely the result of insufficient training intensity loads (i.e., 0 – 30% 1RM) for a resistance-trained population (5, 21, 33). In short, the observed outcomes were the consequence of training specificity. Improvements in vertical jump performance are not solely influenced by strength gain; they are also affected by technical skill (5, 16, 21, 33). Therefore, in conjunction with potential neural adaptations (28, 30, 39), the authors position that stronger individuals could produce more force at the beginning of the concentric, ballistic movement (9) and thus, were more capable of expressing and training greater power production, seems likely.

In contrast to Cormie et al. (11), our participants were familiarized with the training protocol, which was designed to primarily stimulate hypertrophy with secondary increases in strength, yet no significant advantages were observed. It is likely that considering all participants were experienced lifters, the short duration of this study (8 weeks) was not sufficient to stimulate muscle adaptation. Another possible explanation may be related to the greater homogeneity of our sample. In our study, relative back squat strength for STR (1.68 ± 0.21 kg · body mass^{-1}) and WKR (1.51 ± 0.27 kg · body mass^{-1}) were more similar compared to the difference between stronger (1.97 ± 0.08 kg · body mass^{-1}) and weaker (1.32 ± 0.14 kg · body mass^{-1}) participants reported by Cormie et al. (11). Consequently, a larger training effect may have been necessary to observe significant differences. Future investigations might consider making comparisons between experienced participants that possess greater differences in muscle strength and size at baseline.

Results of this study indicate that baseline strength and muscle size do not appear to be influential of training adaptations in experienced lifters, but this may be limited to short-duration (8 – 10 weeks) training interventions. Experienced resistance trained athletes typically require longer training durations (i.e., 2 - 10 years) to stimulate small improvements (4-7, 21, 22, 33). For example, Baker and Newton (7) tracked strength changes in elite and sub-elite rugby players over a 4-year period and observed modest improvements in the stronger, more-experienced (>3 years of training experience), elite players (3.9%) compared to the weaker, less-experienced (< 3 years of training experience) sub-elite players (14.6%) during the first two years of training. Over the next two years (years 3 and 4) of training, however, both groups experienced statistically similar improvements. Moreover, the authors followed up with these players after ten years and found that the greatest improvements in strength and power occurred during the first four years of training (16.6 – 19.3%) compared to the last six years (2.5 – 5.6%) (6). Likewise, Hoffman et al. (22) reported greater strength improvements in division III football players heading into their second season (7.9 – 9.1%) compared to those observed between the players' 3rd and 4th seasons (~2.8%). Interestingly, the greatest improvements (11.3 – 12.2%) were seen between the 4th and 5th seasons (i.e., red-shirted players), though the authors speculated that the use of performance-enhancing drugs may have influenced adaptations over the players' final two seasons (i.e., year 4 and year 5). Others have also reported small (1.9 – 2.8%) and moderate (7.3 – 11.5%) improvements in lean body mass and strength, respectively, in highly-trained rugby players after 1 – 2 years of training (4). While larger improvements were seen in the present study, these improvements may be related to the specificity of the training program. That is, our program was designed to stimulate hypertrophy and strength, whereas athletes may train for these adaptations to compliment improvements in sport-specific performance. It is still unclear whether baseline strength or size are influential of adaptations to training that is designed specifically to stimulate their improvements over a longer (> 10 weeks) duration.

An individual's genetic predisposition for building muscle and gaining strength may also be an important consideration when predicting training adaptations. In the present study, individual gains in strength and muscle size ranged from 1.9 – 13.5% and 0.7 – 21.3%, respectively, depending on the specific measure. While a high degree of variability is common among participants in training studies (23, 36, 37), it may negatively affect a study's statistical analysis and data interpretations. The mechanisms responsible for producing these results within a homogenous sample are not well understood but are likely independent from the factors we considered (i.e., age, medical history, training experience, program familiarity, and nutritional intake). Although speculative, genetic factors involved in the muscle remodeling process may influence an individual's unique response to training. For instance, microRNAs (small non-coding RNA molecules) play an essential role in regulating muscle protein expression (15, 40) and they are differentially expressed in "responders" and "non-responders" following resistance training (12). Likewise, "extreme (hypertrophy) responders" possess more satellite cells prior to training and thus, experience a more robust proliferation response compared to "modest" and "non-responders" (29). Additionally, the expression of interleukin 15 (31) and genetic variation of its receptor (35) have been linked to the magnitude of training-induced hypertrophy. Although further discussion of the potential implications of these mechanisms on training adaptations is beyond the scope of this investigation, these data in conjunction with our results suggest that obtaining more detailed background information is important for studies that involve experienced lifters.

This study appears to be the first to examine the effect of baseline muscle strength and size on muscular adaptations following a high-volume, short rest (i.e., 10 – 12 RM, 1-min rest intervals) resistance training program in advanced lifters. While the program stimulated adaptations in all participants, only significantly greater improvements in upper body strength was observed in weaker, less-experienced participants. The remaining data indicated that neither baseline strength nor size appeared to significantly influence improvements during short-term training programs. Our results further suggest that training experience, even among trained individuals, may still influence adaptations to training.

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