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Resistance Training in Untrained Individuals: Impact of Light Repetition Ranges on Improvements in Fat Free Mass

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The hypertrophy range (8-12 repetitions at 70-85% one-repetition maximum (1RM)) has long been considered the optimal resistance training protocol for the development of fat-free mass (FFM). Recent investigations have hypothesized that lighter repetition zones (over 12 repetitions and less than 67% 1RM) are as effective as heavier loads for the development of FFM. The purpose of this investigation was to determine whether local muscular endurance workouts could sustain and further increase FFM following a program emphasizing the hypertrophy zone. Methods: Healthy, untrained subjects (36 men and 27 women, ages 23 ± 3) completed 96 resistance training workouts. After baseline testing (T1), testing of body composition (dual-energy x-ray absorptiometry (Lunar Prodigy, Madison, WI)) and performance occurred after every 32 workouts (at T2, T3, and T4). In the first block of 32 workouts, 2 of every 3 workouts emphasized the hypertrophy zone and 1/3 emphasized the strength zone (3-7 repetitions at 83 to 93% 1RM). Of the last 32 workouts, 28% of the workouts were in the hypertrophy zone, 47% in the strength zone, and 1/4 in the local muscular endurance zone. Results: FFM significantly increased from T1 (49.8 ± 10.0 kg) until T3 (52.6 ± 10.5 kg), at which point it significantly decreased to T4 (52.2 ± 10.7 kg). Squat strength and bone mineral density significantly increased, but vertical jump power production did not continue to increase between T3 and T4. Discussion: This investigation suggests that replacing hypertrophy-zone workouts with endurance zone workouts prevents further increases in FFM and results in a loss of FFM previously gained.

Resistance Training in Untrained Individuals: Impact of Light Repetition Ranges on Improvements in Fat Free Mass

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Resistance Training in Untrained Individuals

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Acknowledgements

My recent dissertation defense provided the opportunity to personally express my sincere appreciation to those that contributed to my career and time at the University of Connecticut. Any attempt to express those sentiments here would pale in comparison to my verbal statements and I would prefer to allow the words I have spoken to represent themselves. These written remarks are therefore brief. Every sentence represents a small portion of the appreciation I have for those who have brought me to where I am today.

Dr. Carl M. Maresh

In his time as Department Head, Dr. Carl Maresh provided professional, level-headed, and constructive leadership at every turn. In any meeting or conversation, he was careful to consider how each decision would impact members of the faculty, staff, department, and administration at large. His attentive insight into each individual's interests was reflected in his deep consideration for others during his decision-making process. His egalitarian leadership provided individuals of all backgrounds - regardless of race, creed, sex, or other identifier – opportunities to advance beyond their own capabilities. Dr. Maresh exercised patience and careful deliberation when conflict arose and put the interests of the department ahead of his own. He navigated incredible obstacles and seized challenging opportunities to bring this department to the top of its field. It is not surprising that so many, including myself, are grateful to Dr. Maresh for all he has done. Dr. Maresh: I wish you a calm and rewarding road ahead.

Dr. William J. Kraemer

Whether at conferences, my contacts, or otherwise, I have learned about graduate programs in a variety of fields across the world. I have learned that many programs emphasize only coursework; that many train students to become little more than laboratory technicians (and often only with one type of technology); and that many advisors bury their students with work without regard for whether the nature of that work is varied and demanding enough to broaden the student's experience, continually develop their skills, and produce a vibrant *curriculum vitae*.

Some students are fortunate to have a personal relationship with their advisor - perhaps an advisor that shares beer with them. As fortunate as these students are, however, that is a relationship of friendship; it is not a relationship of appreciable depth, not one with a true sense of familial concern, not one that allows them to speak candidly with students about the core of who they are in a manner that, while rough, is necessary for their continued development. Most importantly, most advisors – through no fault of their own – truly have no concept of how to prepare students for the professional world.

In short, I have heard of only one program able to navigate the challenges of student advising. Using an approach that I have neither seen nor heard replicated elsewhere, Dr. Kraemer trains students to appreciate all aspects of becoming a fully-fledged, informed, and productive professionals in this field. Without hesitation, there could not be a graduate program in the country that compares to Dr. Kraemer's approach.

To describe this approach (albeit inadequately), Dr. Kraemer teaches his students to see the larger picture, to be efficient in all work, and to focus on the most important details. This is not to say that classes or technical skills are unimportant; instead, succeeding in classes becomes just one small component of an ever-changing array of demands and challenges that have real-world implications to grants, papers, and research projects. After only a few months, students are doing far more – and performing at a far higher level - than their peers at other institutions. They are involved simultaneously in multiple projects that challenge them to learn a diverse array of skills. They learn every aspect of professional life, from writing a manuscript or grant proposal to running an investigation. They even begin to understand subjects such as navigating administrative tension – things most advisors wouldn't consider discussing with a student.

Working with Dr. Kraemer taught me about maintaining momentum, constantly developing the next grant or paper or talk, never seeing any one project (most especially not one's own thesis or dissertation) as its own defining endpoint. On the other hand, Dr. Kraemer taught me the difficult lesson that working on projects that promote my own career – publishing papers, running my own investigations, developing my own CV – was the best method at my disposal for enhancing the interests of the team as a whole. I have learned to prioritize in a manner that you cannot find in a time management book, to recognize when a time-consuming project that may *seem* important – and that people around you might believe is important - will not provide the best long-term benefit to the team (and I have learned how to communicate that to a team). I have learned that refusing to accept less urgent outside responsibilities – regardless of where they come from - is sometimes the most responsible thing one can do, and that there are times when completing the responsibilities assigned to me takes precedence over disappointing others. Perhaps more importantly, I have learned how to effectively manage people I am responsible for (truly a skill set that had to be learned from scratch) and to transition from a personality as an academic and thinker to someone who can also perform. People typically do not have an appreciation for the lessons I have learned until they are well into their professional years - if ever. If I find success in my career, I will be able to track much of it to my time with Dr. Kraemer. Dr. Kraemer: our work together is unfinished and I look forward to further collaboration.

Shawn D. Flanagan

Throughout my life, I have been fortunate to meet people from all over the world, of all ages, backgrounds, and stations of life. Perhaps more importantly, I have met highly successful people who pride themselves on their ability to get things done. Among all of these individuals, one person stands apart in his tenacity, his drive, and his relentless productivity. This is a person of impeccable character and integrity. His extraordinary personal successes speak for themselves; that is why I can claim with complete objectivity that Shawn Flanagan is – and remains – one of the most impressive people I have had the pleasure to meet. Shawn: I look forward to the road ahead.

Advisory Committee

To my committee, as I hope you know from my recent comments, I value every moment you spent on both my dissertation and on developing your personal relationship with me. Dr. Denegar, I have appreciated the opportunity to work with you on the analysis of a number of studies in my time here. Thank you for our candid discussions and your open door. Dr. Joseph, thank you for staying with this project even as we were forced to switched from the electroencephalogram. I look forward to collaborating with you on both my original dissertation topic and on electrophysiology investigations in the future. Dr. Volek, thank you for your patience, your understanding, and for providing me with the opportunity to work on this investigation. I am grateful to all of you for your patience and the positive impact you have had on my development and my career.

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Chapter 1: Introduction

Ample evidence suggests a classic pattern of adaptations to resistance training in untrained individuals. The early phase (about 6 weeks) of resistance exercise training is predominantly characterized by neurological adaptations, improved strength, and comparatively little hypertrophy (Sale, 1988). Increases in skeletal muscle hypertrophy begin to emerge only as training progresses (Kraemer, 2008). Thus strength is somewhat independent of hypertrophy at the onset of resistance training, whereas fat free mass (FFM) itself requires more time to increase.

Increased FFM with resistance training has been described in several investigations of training in the absence of energy restriction. These increases have been demonstrated in investigations of up to 3 months (Ryan et al., 1995, Abe et al., 2003, Tsuzuku et al., 2007, Prestes et al., 2009) and 6 months (Byrne and Wilmore, 2001, Binder et al., 2005, Nickols-Richardson et al., 2007, Hanson et al., 2009, Kirk et al., 2009, Rabelo et al., 2011). Progressive resistance training is important, however: in one 6-month investigation, FFM only increased at the 3-month time point. After that point, subjects were permitted to lower volume and train at will in an unsupervised context. Thus although the increases in FFM were maintained at 6 months, no further increases in FFM were seen (Schmitz et al., 2003). This suggests that resistance training without caloric restriction increases FFM, but only when performed progressively.

While initial changes in strength and muscle mass follow a stereotyped response, the repetitions performed and the load used (expressed as 1RM) influence the pattern and nature of these adaptations. A one-repetition maximum (1RM) is a reflection of strength and corresponds to the maximal load an individual can use to perform an exercise one time. Maximal strength improves in beginners lifting as little as 45% 1RM, but optimal strength improvements are seen with heavier loads roughly corresponding to a 3-7 repetition zone (83 to 93% 1RM) (Fleck and Kraemer, 2004). Skeletal muscle hypertrophy is optimized with a load roughly corresponding to an 8-12 repetition zone (8-12 repetitions performed at a load of 70 to 85% 1RM) (Kraemer et al., 1996). Local muscular endurance is emphasized at lighter loads (or 67% 1RM) with repetitions over 12 (Stone and Coulter, 1994). Thus adaptations to exercise are specific to the loads and repetition ranges used, with hypertrophy optimized in an 8-12 repetition *hypertrophy zone* (corresponding to 70 to 85% 1RM).

The importance of the hypertrophy zone can be demonstrated by comparing repetition zones in investigations with caloric restriction. Alongside the expected decreases in fat mass, FFM typically decreases in response to caloric restriction if no resistance training is performed (Stiegler and Cunliffe, 2006). Resistance training workouts that focus on the hypertrophy zone, however, have been shown to maintain FFM in investigations of less than 3 months (Geliebter et al., 1997, Kraemer et al., 1997, Bryner et al., 1999, Kraemer et al., 1999, Kraemer et al., 2007, Campbell et al., 2009) and to increase FFM at 6 months (Hunter et al., 2008). By comparison, a number of investigations that used lighter loads (or the endurance zone) have seen decreases in FFM despite resistance training (Gornall and Villani, 1996, Wadden et al., 1997, Doi et al., 2001). In one example, FFM deceased when the appropriate 70-80% resistance was used, but only for 6-8 repetitions performed per set (Donnelly et al., 1991). Although some of these lighter-load investigations maintained FFM despite dieting (Svendsen et al., 1993, Kempen et al., 1995, Marks et al., 1995), none have displayed a significant increase. It is also interesting to note specificity at the other end of the spectrum as well: an investigation performed with high-impact training (outside of the hypertrophy zone) also did not significantly increase FFM, even when bone mineral density (BMD) significantly increased (Winters-Stone et al., 2011). Thus FFM adaptations to training appear specific to the repetition zone performed, with hypertrophy-zone workouts beneficial to FFM even during energy restriction.

In contrast to the concept of repetition ranges, some have argued that lighter loads performed at high intensity may provide the same benefits to strength, hypertrophy, and muscle protein synthesis as the heavier repetition zones classically prescribed (Mitchell et al., 2012). To examine this hypothesis, subjects in the current investigation trained primarily with hypertrophy-zone workouts, then transitioned primarily to endurance workouts. The purpose of the investigation was to determine whether lighter loads (12+ repetition zone) could sustain and further promote increases in FFM that had been previously developed using the traditional hypertrophy zone. Findings indicate that despite continued training and emphasis on the heavy strength zone (3-6 repetitions), the change in emphasis from the hypertrophy zone to endurance zone decreased FFM.

Chapter 2: Review of Literature

The enhancements that resistance exercise provides to physical performance, health, and appearance are a function of adaptations within the diverse physiological systems in the body, including the nervous, endocrine, muscular systems (Ratamess and American College of Sports Medicine., 2011). Among these adaptations, skeletal muscle hypertrophy serves as either a prominent or primary determinant of the outward improvements to performance, health, and appearance that individuals seek with resistance training (Fleck and Kraemer, 2004). Muscle mass is therefore a primary outcome of interest for both resistance exercise programs and investigations.

Despite its important outcome measure, however, muscle mass is not necessarily easy to determine. The assessment of muscle mass using magnetic resonance imaging or computerized tomography is cost-prohibitive for many purposes, and many institutions do not have access to both ultrasound technology and the precise, well-trained technicians required to accurately assess muscle mass. The traditional and widely available measures of body composition (including hydrostatic weighing, skinfolds, air-displacement plethysmography, bioelectrical impedance, and dual-energy x-ray absorptiometry (DEXA)) cannot themselves directly measure muscle mass. Instead, these technologies rely on the quantification of - and differentiation between - fat mass and fat-free mass (FFM) (Kraemer et al., 2012). FFM is itself comprised of all lean tissue (including bone and organs), with skeletal muscle comprising approximately 35% of FFM in women and 45% in men (Abe et al., 2012). While indirect, it is assumed (both within the field of exercise physiology and within the literature) that marked changes in FFM can be attributed to changes in muscle mass. Although this assumption has some weaknesses (including the possibility of improvements in bone mineral density (BMD)), it has provided a somewhat consistent basis for evaluating changes in FFM across time.

The diverse components of FFM are metabolically demanding, and therefore drive the preponderance of metabolic activity at rest (Seidell et al., 1992, Muller et al., 2002). As a result, FFM plays an overwhelming role in determining resting metabolic rate (Deriaz et al., 1992, Sparti et al., 1997), with lesser contributions from demographic (Freake and Oppenheimer, 1995) or genetic profiles (Astrup et al., 1999). As discussed below, FFM is often compromised by energy restriction during weight loss. In and of itself, this has led to an interest in the potential for exercise to influence FFM and perhaps metabolic rate; thus most of the studies concerning FFM and exercise interventions involve energy-restricting diets.

In this review, we discuss the physiological relationship between diet, exercise, and FFM. The evidence for increases in FFM with resistance training is described and a differentiation is made between resistance training and endurance training (which appears to have little effect on FFM). We conclude with a discussion of how properly programmed resistance exercise not only increases FFM, but can attenuate decreases in FFM due to energy restriction.

2.1. Influence of Energy-Restricted Diets on FFM

2.1.1. Energy Restriction and FFM Losses

Although not the focus of this review, it is important to highlight the difference between changes in FFM due to diet and those due to exercise alone. Specifically, a negative energy balance is conducive to fat loss, but energy restriction typically has deleterious effects on FFM and resting metabolic rate (Menozzi et al., 2000, Stiegler and Cunliffe, 2006). This has been demonstrated with several different dietary interventions, including low-carbohydrate diets, low-calorie, and low-fat diets.

For 23 women with obesity, a 12 week low-carbohydrate diet was superior to a low-fat diet for decreases in body mass. Those who performed endurance exercise demonstrated greater decreases in fat mass over those who did not. Resting metabolic rate significantly decreased for all groups, as did FFM (-2.0 ± 1.7 kg) (Racette et al., 1995).

In a separate investigation, a low-carbohydrate diet resulted in greater fat loss than a low-fat diet (6.20 ± 0.67 compared to 3.23 ± 0.67 kg) in 40 women who were overweight. Both groups exhibited a decrease in resting metabolic rate. Once again, FFM significantly decreased in both groups (-3.34 and -1.94 kg, respectively) (Brehm et al., 2005).

Further, in a 16-20 week program with 49 subjects, a low-calorie diet was superior to a low-fat diet for body fat reduction, but resulted in similar decreases to FFM and resting metabolic rate (Schlundt et al., 1993). Thus the loss of FFM with dieting is consistent found in low-fat, low-carbohydrate, or low-carbohydrate dietary interventions.

Some dietary interventions have not decreased FFM. In a multi-center investigation with 398 individuals who were overweight, subjects completed a 6-month diet reducing fat to 10% of energy intake. Fat mass significantly decreased in both the complex carbohydrate and simple carbohydrate groups, and FFM did not change (Saris et al., 2000). This investigation focused on composition of the diet, however, and not on energy restriction. Thus the majority of the literature base supports that weight loss from energy-restricted diets reduces FFM in addition to fat mass.

2.1.2. Macronutrient Ratios, Energy Restriction, and FFM

Although historical investigations have focused on low-fat or low-calorie interventions, the unique properties of fat, protein, and carbohydrates have stimulated recent interest in their differential impact on FFM changes with diet. For example, carbohydrate-rich meals stimulate insulin secretion and fat deposition, while high-protein acts to counterbalance such activities while stimulating protein synthesis (particularly with leucine) (Layman and Baum, 2004). A few investigations that have examined the impact of protein supplementation are discussed below.

In a 10-week investigation of 24 women who were overweight, those on a diet that emphasized protein lost a higher proportion of mass from fat mass than those on a diet that emphasized carbohydrates (with losses in FFM of -0.88 ± 0.33 compared to -1.21 ± 0.58) (Layman et al., 2003). A separate 12-week dietary intervention examined 57 subjects who were overweight with slight hyperinsulinemia; FFM was better maintained in a high-protein than a standard protein diet in women, with comparable decreases in fat loss for all subjects. FFM losses for the standard diet were in men (−1.9 ± 2.1) and women (−1.5 ± 0.3); for the high-protein diet, they were in men (−2.5 ± 2.8) and women (−0.1 ± 0.3) (Farnsworth et al., 2003). Thus protein content during caloric restriction is important for prioritizing the loss of fat mass instead of FFM.

The form of protein also appears to play an important role in its protective effect on FFM during energy restriction. In a 12-week study, 38 male policemen (28-40 yr) who were overweight completed a hypocaloric diet. They were assigned to a diet only group, a resistance training with added casein group, or resistance exercise with added whey group. The resistance training occurred 4 days per week, with 1 muscle group per day. Exercises were performed on cybex machines for 30 minutes (no other details provided). "Maximal effort" (8-10 RM) was assessed at 1, 4, 8, and 12 weeks. Body fat change was significantly greater in the casein (-7.0 ± 2.1) and whey (-4.2 ± 9) groups than in diet alone (-2.5 ± 0.5). FFM increased significantly more in the casein (4.1 ± 1.4) and whey groups (2.0 ± 0.7) than the diet alone group (0.4 ± 0.4) (Demling and DeSanti, 2000). Investigations such as these underscore the importance of the protein composition of diet, rather than the caloric content alone.

2.2. Can Endurance Training Increase FFM?

It is likely that high-power and high-force activities (heavy resistance exercise, sprinting, and explosive jumping), which recruit (and stimulate the hypertrophy of) higher-threshold, Type II motor units, would be most effective for increasing FFM. It has therefore been suggested that resistance exercise would be more beneficial than aerobic exercise for improving FFM and thereby improving resting metabolic rate (Walberg, 1989). The effectiveness of endurance exercise for increasing FFM has been assessed in several investigations.

One short-term investigation confirmed that endurance exercise did not appear to influence FFM or resting metabolic rate. Twelve weeks of cycling at 40% VO_2max (maximal oxygen consumption) failed to change resting metabolic rate or body composition in 21 pre-menopausal women with obesity (van Aggel-Leijssen et al., 2001).

Over the course of a separate 16-month investigation, 31 men and 43 women engaged in endurance exercise 5 days per week. The exercise protocol started with 60%

of heart rate reserve (about 55% VO_2max) for 20 minutes and progressed to 75% (about 70% VO_2max) for 45 from 6 months onward. FFM did not increase significantly (non significant -0.2 kg decrease in men and 0.9 kg increase in women) and only men demonstrated a significant decrease in fat mass (-4.8 kg) (Donnelly et al., 2003, Kirk et al., 2003).

Further, one 18-month investigation compared brisk, intermittent walking (2 x 15-minute sessions per day, 5 days per week) to continuous exercise (60-75% VO_2max for 30 minutes, 3 days per week) in 22 sedentary women with obesity. FFM did not change in either group (intermittent: -0.07 kg; continuous: 0.4 kg) and body fat significantly decreased only in the continuous group (-2.1 kg) (Donnelly et al., 2000).

In contrast to these investigations, Wilmore observed increased FFM with endurance exercise. In a multi-center investigation, 557 subjects between 16 and 65 yr engaged in a cycling program 3 times per week for 20 weeks. The intensity began at 55% of VO_2max for 30 minutes and progressed to 75% for 50 minutes in the final 6 weeks. FFM significantly increased by 0.5 ± 0.1 kg, body fat decreased by -0.7 ± 0.1 kg, and resting metabolic rate did not change (Wilmore et al., 1999). The sample size of this investigation likely allowed for the detection of these modest increases in FFM.

2.3. Can Endurance Training Prevent Diet-Induced Losses in FFM?

Many investigations have examined low-intensity endurance exercise or low-intensity resistance activities that are unlikely to generate appreciable changes to muscle hypertrophy. Decreases in RMR have been detected with long-term low-intensity aerobic exercise (Van Aggel-Leijssen et al., 2002), while an investigation of progressive endurance training demonstrated no differences (Wilmore et al., 1999).

Even when resistance exercise is performed, its impact on FFM may be unpredictable when combined with endurance exercise. Byrne and Wilmore demonstrated that resting metabolic rate increased in a resistance training-only group, but decreased in a combined resistance training and walking group (despite increases in FFM) (Byrne and Wilmore, 2001).

A one-year investigation of 121 men who were overweight compared diet alone to a walking/jogging intervention. The exercise group covered 10.0 ± 5.6 miles per week. Loss of fat mass was greater in the dieting group, but the diet group lost -1.2 kg FFM and -149 kcal per day in RMR (Frey-Hewitt et al., 1990).

One investigation did contrast with these findings. During a 3-month investigation, a dieting group displayed a decrease in RMR (-247 kcal per day). At the same time, the group that jogged 3 to 5 days per week increased RMR by 202 kcal per day. These changes appeared to correspond to changes in FFM (Schwartz et al., 1990). On the whole, however, these investigations suggest that while resistance exercise may sustain FFM during energy restriction, endurance exercise is less likely to do so. Longer-term investigations into well-designed resistance training programs may yield more convincing evidence in either direction.

2.4. Can Resistance Training Increase FFM?

Few investigations have examined training-induced changes in FFM without energy restriction. Schmitz et al conducted a 10-month investigation with a 15-week resistance training class (2 days per week) followed by four months of unsupervised training. Sixty women between 30 and 50 yr of age completed 3 sets of 9 exercises twice a week using 8-10 repetitions during the class. At the conclusion of the course, subjects were instructed to train for 6 months on their own, performing the 9 exercises at a load equal to or higher than that used in class for a minimum of 2 sets (50% of women continued to complete 3 sets). Participants used free weights to complete bench press, shoulder press, and bicep curls, and tricep extension. Cybex machines were used to complete lat pulldowns, squats, leg presses, leg extensions, and hamstring curls. Progression of weight did not occur until subjects completed 3 sets of 10 repetitions at two separate workouts; at that point, the weight was increased by "the smallest possible increment". With this higher load, subjects who were able to complete 8 repetitions on the first set of an exercise followed by 6 repetitions on the next could continue to use this heavier weight; if not, the weight was decreased back to the load of the previous workout for the final set. At the end of the 15-week course, FFM increased significantly more (0.89 kg) and fat mass also decreased significantly more (-0.98 kg) in the trained group. No further improvements were made following the course but the improvements were sustained (Schmitz et al., 2003). It is likely that the unsupervised program did not provide sufficient stimulation for continued improvements thereafter.

A 22-week investigation of 50 individuals who were sedentary (23 men and 27 women, with 3 men and 6 women serving as controls) compared a resistance exercise group to a control group. Exercise on Keiser pneumatic machines was performed 3 days per week. The first 10 weeks was comprised of knee extensions, with the first set of 5 reps at 50% 1RM, the next set of 5 reps at 5RM (85% 1RM initial set), the 3rd set of 5-7 reps at 5RM with weights lowered, and finally the 4th and 5th sets at 15 and 20 RM. For the second 12 weeks, the intensity and programming remained similar, but the exercises were whole-body; knee extensions, rows (seated), hamstring curls, crunches, and alternating leg presses. FFM increased significantly in both men (1.1 kg) and women (0.4 kg) (Hanson et al., 2009).

In a 6-month investigation, 22 participants (16 men, 6 women) were assigned to a resistance-training group and 17 (11 men, 6 women) to a control group. The resistance training occurred 3 days per week on Paramount equipment. It consisted of 1 set within the subject's 3-6 repetition maximum zone (or at about 85-90% 1RM). Exercises were performed with a 2 second concentric and 4 second eccentric phase. When 6 repetitions were successfully performed, 2.25 kg was added. FFM increased significantly more in the resistance-training group (1.5 kg) than in the control group (-0.3 kg). Resting metabolic rate increased 7.4 ± 8.7% only in the resistance group. Fat mass increased in the control group (2.3 ± 0.6 kg) but not the training group (0.9 ± 0.6 kg) (Kirk et al., 2009). Although improvements were seen in FFM, they were slight for a 6-month study, which may be attributed to the low volume and load of this protocol.

Across a 24-week training period, 154 women (67.1 +/- 5.9 yr) were placed into either a control group or a progressive resistance-training group. Resistance training was performed 3 days per week with 3 sets of: 12 repetitions at 60% 1RM weeks 1-4; 10 repetitions at 70% 1RM weeks 5-8; and 8 repetitions at 80% 1RM remaining 16 weeks. The chest press, lat pulldown, knee extension, hamstring curl, leg press, hip abduction exercise, shoulder abduction exercise (with dumbbells), and toe raises were performed on plate loaded machines (Righetto Fitness Equipment). Sit-ups and trunk extensions were also performed. The resistance training group significantly increased FFM (from 36.4 ± 4.0 to 37.1 ± 4.2 kg), while the control group did not (Rabelo et al., 2011).

2.5. Can Resistance Exercise Prevent Diet-Induced Losses in FFM?

In this section, investigations are divided between those with appropriate programming for Type II motor unit hypertrophy and gains in FFM, and those without. Appropriate loads are defined broadly, counting anything within a 6-12 repetition maximum (RM) zone. To be defined as appropriate, the investigators also had to use loads that corresponded to roughly 70 to 85% maximal strength (or one-repetition maximum 1RM)), a range has been shown to emphasize improvements in skeletal muscle hypertrophy. Further, the investigation also had to incorporate more than one set of each exercise, which is also important for developing hypertrophy (Baechle et al., 2000).

2.5.1. Resistance Training, Appropriate Programming: Up to 3 Months

Twenty-two men and 20 women on an energy-restricted diet consumed a high-fiber supplement alone or consumed the supplement while completing an 8-week exercise intervention. The exercise intervention included both endurance and resistance exercise 3 days per week. For the endurance exercise portion, subjects walked or ran for 30 minutes at an intensity that increased across the investigation. The resistance exercise was non-linear, with between 1-3 sets and 3-12 repetitions depending on the repetition zone focus (e.g. 3 sets 6-8, 3 sets 8-10, 1-2 sets of 10-12). It included free weight (bench press (flat), bench press (incline), squat, calf raise, shoulder press, sit-ups/weighted sit-ups, deadlifts, upright row) and cable (lateral pull down and seated row) exercises. Body fat percentage significantly decreased in both the non-exercise (men: -1.4%; -1.9%) and exercise (men: -2.9%; women: -2.8%) groups. FFM did not significantly change in either the non-exercise (men: -0.1 kg; women: 0.4 kg) or exercise (men: 0.6 kg; women: 0.4 kg) groups (Kraemer et al., 2007).

In an 8-week investigation, 25 men and 40 women (19-48 yr) with moderate obesity were assigned to three groups: a diet-only group; a diet with endurance exercise group; and a diet with resistance training group. Exercise was performed 3 days per week. The endurance exercise group completed 30 minutes of exercising, rotating from lower body cycling for 8 minutes to upper body cycling, and back to lower body cycling again. This was completed at 55% of $V0_2$max and above 70% of heart rate max. For the resistance exercise, subjects performed all repetitions in at a slow cadence, with 5 seconds to both the eccentric and concentric components. Subjects performed 2 sets of 6 repetitions, followed by a third set to failure. If subjects were able to perform more than 8 repetitions on the 3rd set, the resistance was increased at the following session. The Nautilus machines used included 8 stations: leg extension, hamstring curl, chest press, lat pullover, lateral raise, curls, tricep extension, and leg press. FFM decreased in all groups, but decreased significantly less in the resistance-trained group (-2.7 ± 2.1, -2.3 ± 2.4, and -1.1 ± 2.3 kg, respectively). Fat loss was comparable across the three groups (-6.8 ± 2.6, -7.2 ± 3.0, and -6.7 ± 2.8 kg). There were no significant changes in resting metabolic rate (Geliebter et al., 1997).

Over the course of a 12-week study, 31 premenopausal women completed one of three interventions: diet only, diet with endurance exercise (3 days per week), and diet with endurance and resistance exercise (3 days per week). The endurance exercise consisted of cross-training with a heart rate between 70-80% functional capacity, starting with 30 minutes and progressing to 50 minutes. The resistance exercise program alternated between heavy (5-7) and moderate (8-10) repetition zones and progressed from 1 to 3 sets over time. Exercises included the squat (Tru-Squat machine) and Nautilus exercises (shoulder press, bench press, lat pulldown, row (seated), sit-up, a lower back exercise, leg press, hamstring curl, calf raise, and curls. FFM did not change significantly, but fat mass decreased in all groups except for control (-5.8, -8.0, and -4.3%, respectively) (Kraemer et al., 1997).

During a 12-week intervention, men were divided into 4 groups, including control (C, n=6), diet only (D, n=8), endurance training with diet (DEt, n=11), and endurance and resistance training with diet (DEtRt, n=10) groups. Training occurred 3 days per week. The endurance training progressed from 30 to 50 minutes of cross training over the course of the investigation at 70-80% of functional capacity. Subjects then performed a non-linear resistance-training program, alternating between including heavy (5-7RM) and moderate (8-10RM) days, and progressing from 1 to 3 sets. Exercise performed on Tru-Squat and Nautilus equipment included shoulder press, bench press, lat pull-down, rows (seated), sit-ups, lower back exercise, leg press, hamstring curls, calf raises, and curls. Fat mass did not change in C (-0.80 kg) but significantly decreased in the D (-6.68 kg), DEt (-7.00 kg), and DEtRt (-9.57) groups. FFM did not significantly change in the C group (0.45 kg) and was maintained in the DEtRt group (-0.33 kg). FFM significantly decreased in the D (-2.96 kg) and DEt (-2.00 kg) groups (Kraemer et al., 1999).

Using an extremely low calorie (800 calories per day) liquid diet, 17 women and 3 men with obesity participated in either an endurance or resistance training program for 12 weeks. The endurance-training program was completed 4 days per week, starting with

20 minutes and reaching 50-60 minutes by the end of the investigation (self-paced exertion). The resistance exercise group performed a 10-station circuit training machine workout 3 days per week with 4 lower body and 6 upper body exercises. The intensity progressed from 1 set of 15 repetitions to 2 sets of 8-12 by the 2nd week. A 3rd set was added at 6 weeks and a 4th set at 9 weeks. Progression occurred if subjects could execute more than 12 repetitions at a given load. Fat mass was similar between the two groups (-12.8 and -14.5 kg, respectively). FFM decreased significantly in the endurance group but not the resistance group (-4.0 and -0.9 kg), while resting metabolic rate decreased in the endurance group and increased in the resistance group (-210.7 and 63.3 kcal/day) (Bryner et al., 1999).

One 3 month study examined 69 women with obesity using 4 interventions: diet-only (D, n=26), diet with endurance training (DEt, n=16), diet with resistance training (DRt, n=18), and diet with both endurance and resistance training (DEtRt n=9). Both exercise groups trained 4 days per week. The endurance training progressed from 20 mins to 60 minutes. For the majority of the investigation, the intensity was 70% of heart rate reserve in the endurance-training group and 3 sets of 6-8 repetitions at 80% 1RM for the resistance-training group. The resistance-training group used Universal equipment; although specific exercises were not named, strength tests were taken on the bench press, lat pull-down, knee extension, and hamstring curl equipment. All groups displayed significant decreases in fat mass (D (-16.1 ± 5.1), DEt (-16.6 ± 3.6), DRt (-16.1 ± 4.1), and DRtEt (-18.0 ± 4.3 kg)), but these losses were not significantly different between groups. FFM also significantly decreased in all groups (D (-4.7 ± 4.3), DEt (-4.8 ± 2.4), DRt (-4.7 ± 4.6), and DRtEt (-4.1 ± 3.5 kg)), but the changes were again not significantly different between groups (Donnelly et al., 1991).

2.5.2. Resistance Training, Appropriate Programming: Over 3 Months

In 19 women with moderate obesity, 20 weeks of resistance training alone was compared to resistance training with a concurrent walking program. The group that performed walking with resistance exercise began the investigation walked for 20 minutes 3 times per week, starting at 50% VO_2max and progressing to 40 minutes at 70% VO_2max. The resistance-training program (completed by all but the control group) consisted of an upper-body/lower-body split routine completed 4 days per week. Exercises were completed on Schnell or Nautilus machines. The upper-body days consisted of a chest press (standing), chest fly (inclined), row (lying down), dips (assisted), shoulder press, lateral raises, tricep kick-backs, and crunches. The lower-body days consisted of a leg press, leg extension, hamstring curl, lat pulldown, pull-ups (assisted), curls (barbell), and crunches. Participants performed 3 sets of 10-12 repetitions for the first 6 weeks; thereafter, subjects performed "three sets of 10-12RM, 8-10RM, and 6-8RM, respectively" (we cautiously interpret this to signify that each set became progressively heavier, but this may apply to different macrocycles or have some other significance). At the conclusion of the program, the resistance training-only group had a significant 1.9 kg increase in FFM and a non-significant 0.1 increase in fat mass.

The resistance training with walking group also had a significant 1.9 kg increase in FFM as well as a non-significant -0.2 decrease in fat mass. Finally, the control group gained a non-significant 0.5 kg of FFM and a non-significant 0.5 kg of fat. Resting metabolic rate increased by 44 kcal/day in the resistance-only group but decreased by -53 kcal/day in the combined group. The authors hypothesized that this decrease was due acclimation to heat (Byrne and Wilmore, 2001).

A 16-week investigation compared the effects of resistance training in women with obesity (n=7) to women without obesity (n=8). The postmenopausal women, ages 50-69 yr, all completed resistance training 3 days per week; the women with obesity also followed a hypocaloric diet. Trainees completed 14 exercises primarily on Keiser variable-resistance pneumatic machines. These included 1 set of leg presses, chest presses, hamstring curls, lat pull-downs, leg extensions, shoulder press, leg adductor and abductor exercises, exercises for the upper back, triceps, lower back, and upper abdomen, curls (with dumbbells), and lower abdominal exercise on the floor. A second set was completed only for the leg press, hamstring curl, and leg extension. The first 3-4 repetitions were performed in the 5RM zone (about 90% of 3RM); resistance was then reduced so the subjects could complete a total of 15 repetitions per set. Resting metabolic rate did not change. The women with obesity lost fat mass by design, whereas the investigation was designed to prevent the women without obesity from doing so. FFM significantly increased in both the women with (0.5 kg) and women with (1.1 kg) obesity (Ryan et al., 1995).

2.5.3. Resistance Training, Inappropriate Programming: Up to 3 Months

In an investigation with prepackaged food, 20 women were randomized to either a diet-only or diet with resistance exercise group over a short period of 4 weeks. The resistance exercise program consisted of 3 sets of 10 repetitions on the bench press, lat pulldown, leg extension, leg press, shoulder press, hamstring curl, triceps extension using free weights and a universal machine. Progression was 2.5 kg if 10 repetitions were successfully performed for 3 sets. Subjects also performed back, abdominal, and step-up exercises at 20-repetition maximum. Fat mass (-4.04 and -3.53 kg), FFM (-1.35 and -1.85), and resting metabolic rate (-32.96 and -15.8 kJ/hr) decreased similarly in both groups (Gornall and Villani, 1996). These findings are most likely due to the short time frame of the investigation as well as its programming.

One 8-week investigation of 20 women with obesity compared diet alone to diet combined with exercise. The exercise program was performed 3 days per week and alternated between aerobic dancing and circuit resistance training. FFM (-1.6 ± 0.3 and -1.3 ± 0.5 kg) and sleeping metabolic rate (-10% in both groups) declined to a similar degree in both groups. Decreases in fat mass, however, was more pronounced in the exercise group (-5.5 ± 0.8 and -7.8 ± 0.8 kg) (Kempen et al., 1995).

A 12-week intervention assigned postmenopausal women who were overweight to control (C, n=20), diet-only (D, n=50), and diet with both endurance and resistance exercise (DEtRt, n=49) groups. The endurance training consisted of cross training at an intensity of 70% VO2max, progressing from 30 minutes to 55 minutes. The circuit resistance training (Ultra Rehab Aps equipment) consisted of 7-15 repetitions with sets progressing from 2 to 3 at 65% 1RM. Exercises included the leg press, leg flexor exercise (likely a hamstring curl), calf exercise, abdominal leg raise, back exercise, pull-down, dips, row, hip adductors, and abdominal exercise. Fat mass decreased significantly more for DEtRt than D; C: 0.5 ± 1.3; D: -7.8 ± 2.5; DEtRt: -9.6 ± 2.7. FFM in the DEtRt groups was also significantly higher than D (C: 0.6 ±1.3; D: -1.2 ± 1.3; DEtRt: 0.0 ± 1.7. Resting metabolic rate did not change, but it did increase relative to body mass for the DEtRt group (Svendsen et al., 1993). Thus even with a program that would not be considered intense enough to stimulate significant hypertrophy, resistance training does appear to prevent losses in FFM with dieting.

During a 12-week program in 17 men who were overweight, all men participated in an energy-restricted diet (-17% intake) and what would best be classified as resistance activity. One group consumed no post-exercise supplement, whereas the other group consumed a protein supplement. The daily training program consisted of 10-15 repetitions (it appears that 1 set was performed). The load began at 3 kg and progressed to 5 kg by the end of the study for all exercises. The exercises included "shoulder presses, bent rowing, squatting, twisting, standing dumbbell lifting, butterflies, bent lateral raises, lateral rowing, dumbbell frontcurling, one arm dumbbell rowing, dumbbell side-curling, triceps kickbacks, and French presses." Changes in fat mass (-2.1 and -2.5 kg) and FFM (-2.0 and -1.8 kg) were similar, but FFM and resting metabolic rate only changed significantly in the protein supplemented group (0.8 and 5.5 J•(kg • min)$^{-1}$) (Doi et al., 2001).

2.5.4. Resistance Training, Inappropriate Programming: Over 3 Months

In 29 men with obesity, one 16-week intervention compared three interventions: diet alone, diet with endurance exercise, or diet with resistance exercise. The endurance exercise program consisted of 5 days per week of a participant-selected modality that progressed from 20 minutes to 60 minutes (at 50 to 85% heart rate maximum) over the course of the investigation. The resistance-training program was a typical Nautilus program: 1 set of 8-12 repetitions to failure on Nautilus machines. Progression to heavier loads occurred with subjects could perform 12 repetitions of an exercise. Exercises included leg extension, hamstring curls, lat pullovers, bench press, shoulder press, triceps extension, curls, and sit-ups. Fat decreases were similar among the three groups (-8.5 ± 2.9; -9.7 ± 4.6; and -10.8 ± 3.5 kg, respectively). The diet-only group lost -2.5 kg of muscle mass, while the exercise groups had non-significant increases (0.3 ± 1.0 and 0.2 ± 2.2, respectively) as measured by magnetic resonance imaging (Rice et al., 1999). When the same investigation was completed in 38 premenopausal women, fat loss (-7.5 ± 4.6, -7.3 ± 5.4, and -8.5 ± 2.3 kg, respectively) and losses to skeletal muscle (-1.1 ± 0.8, -0.6 ± 1.1, and -0.4 ± 1.1 kg) were comparable (Janssen et al., 2002).

Another investigation examined 44 women (20-49 yr) who were overweight and sedentary over 20-weeks. Subjects were divided into 4 groups: control (C); diet only (D); diet with endurance training (DEt); diet with resistance training (DRt); and diet with both cycling and resistance training (DEtRt). All exercise groups trained 3 days per week. For the endurance protocol, subjects performed interval training on a stationary cycle at 70-85% of their HR max, progressing from 12 minutes to about 30 minutes a session by the end of the investigation.

The resistance training protocol used a Lifecircuit electromagnetic circuit routine. The protocol consisted of 8 exercises: leg extension, hamstring curl, row (seated), chest press, abdominal exercise, curls, and tricep extensions. The DRt group performed 2 sets of 12 repetitions; the DEtRt group performed 1 set of 12 repetitions. Maximal strength was tested for each exercise at each session prior to exercise. The training itself was set at or below 50% of the testing 1RM. Subjects performed 12 repetitions per set: 3 ramping up to 50% and 3 ramping down from 50%. The ramping intensities corresponded to approximately 35%, 40%, 45% of 1RM. The eccentric load was set 20-40% higher than the concentric load, suggesting the maximum eccentric intensity may have reached 70% 1RM.

Although losses in fat mass were similar except in the control group (C: 0.7 ± 1.5; D: -3.4 ± 3.7; DEt: -4.7 ± 1.7; DRt: -4.2 ± 2.3; DEtRt: -5.7 ± 4.5 kg), percent body fat was only significantly lower than control with the DEtRt group (-4.6% ± 5.1). No significant differences were detected between the groups for FFM (C: 0.8 ± 1.5; D: -0.2 ± 1.7; DEt: 0.2 ± 1.4; DRt: 0.7 ± 3.0; DEtRt: 0.3 ± 4.1 kg) (Marks et al., 1995). Although significant differences may have been detected with larger sample sizes in each group, an improved training program would likely have yielder far more promising results in favor FFM with resistance exercise.

In a 48-week investigation, 128 women with obesity were assigned to a diet only (D), endurance training with diet (DEt), resistance training with diet (DRt), and endurance and resistance training with diet (DEtRt) groups. Exercise was performed 3 days per week. The DEt group performed moderate step aerobics, progressing from 12 minutes to 40 minutes. For the DEtRt group, endurance training consisted either of step aerobics, walking, or cycling. Resistance training occurred on Cybex or Universal Gym equipment. Exercises included the bench press, lat pull-down, chest fly, shoulder press, leg extension, hamstring curl, leg press, curls, tricep extensions, sit-ups, and back extensions. Participants progressed from 1 set 10-14 to 2 sets; load was increased if more than 14 repetitions were performed for 2 sets. Percent body fat decreased in all groups with no differences among groups. Resting energy expenditure fell in all groups, but decreased less in the DEt group than the ERt group (D: -106 ± 149; DEt: 20 ± 125; DRt: -46 ± 206; DEtRt: -7 ± 164). No significant differences were seen for changes in FFM (D: -2.8 ± 3.0 kg; DEt: -3.1 ± 2.7 kg; DRt: -3.2 ± 3.4 kg; DEtRt: -1.8 ± 3.9 kg) (Wadden et al., 1997).

2.6 Conclusions

As previously described, most investigations utilizing endurance exercise neither display improvements in FFM nor the ability to protect against diet-induced decreases in FFM. Throughout those investigations classified as *not* appropriately programmed (based on their load/repetition range and volume), none displayed significant increases in FFM and many displayed decreases in FFM across time with energy restriction. This was in stark contrast to those training protocols categorized as appropriate; for these, the majority displayed a significant increase in FFM in spite of energy restriction.

Based on the available evidence, properly programmed resistance training (at least two sets at a repetition maximum zone at 6-12 with an intensity of 70-85%) is effective not only for maintaining muscle mass during energy-restrictive diets, but also appears to increase FFM over time. Resistance training protocols that do not use the hypertrophy zone and endurance training are not likely to yield the same benefits to FFM.

Chapter 3: Methods

3.1. Experimental Approach

To examine the impact of decreased hypertrophy zone workouts, healthy men and women performed 96 resistance exercise sessions punctuated by testing at baseline (T1) and following their 32^{nd} (T2), 64^{th} (T3), and final 96^{th} (T4) workouts. Each 32-workout period emphasized a progressively smaller ratio of hypertrophy to endurance workouts. Changes to the resistance program were double-blind; neither subjects nor the training staff were informed that the emphasis of the workouts changed over time from hypertrophy to endurance. No subjects appeared to notice these changes and post-intervention interviews revealed that trainers were not aware of the changes over time.

3.2. Participants

For the purposes of this investigation, only subjects that completed the investigation (with T4 testing) were analyzed. Table 3.1 provides a baseline description of these subjects.

Table 3.1. Characteristics of Experimental Subjects S = Sex difference between men and women in line with expectations.

	Age (yr)	Height (cm)	Body Mass (kg)	Squat Strength (kg)
Men (n=36)	23 ± 3	176.8 ± 6.2 [s]	79.4 ± 14.9 [s]	87.0 ± 18.4 [s]
Women (n=27)	23 ± 3	163.9 ± 6.7 [s]	64.5 ± 12.3 [s]	46.3 ± 13.2 [s]

A physician screened potential subjects to exclude individuals whose medical history indicated an increased risk of injury due to participation. They were also excluded if their participation would introduce confounding factors (e.g. medical conditions sensitive to supplementation) or compromise the investigation for any similar reason. Subjects were excluded for participating in a resistance exercise program within the prior year. Included subjects continued their other recreational activity but abstained from exercise at an intensity that would conflict with the outcomes measures of training (e.g. training for or competing in marathons). For detailed information on recruitment process and attrition, see (Volek et al., 2013). All subjects signed an informed consent form approved by the Institutional Review Board at the University of Connecticut.

3.3. Dietary and Supplementation Protocol

As part of a separate experimental question, the subjects were also randomized in a double-blind fashion into three parallel nutritional supplementation groups. Each group supplemented either with carbohydrate (carb), whey protein (whey), or soy protein (soy); this supplementation did not influence the findings of the current experimental question.

Body mass was assessed weekly using a calibrated scale (Defender 5000, Ohaus, Florham Park, NJ) and all subjects met regularly with a registered dietician to ensure that body mass was maintained. Regardless of supplementation group, all subjects consumed between 1.0 and 1.2 g•body mass $(kg)^{-1}$ protein daily. Subjects were instructed to mix and consume a powdered packet with 240 mL of water each day (verified via supplementation logs, monthly unannounced urine samples for a para-aminobenzoic acid supplement additive, and direct observation of supplements by study staff immediately following each workout). The isocaloric supplements contained whey protein concentrate (~22 g•day^{-1}), soy isolate (~22 g•day^{-1}), or carbohydrate (maltodextrin) from an independent laboratory (Medallion Labs, Minneapolis, MN). For more detailed information on the dietary and supplementation protocol, please see (Volek et al., 2013).

3.4. Resistance Training Program

3.4.1. Overall Design of Training Program

Trained personnel supervised all workout sessions and were also responsible for regular communication with subjects to ensure training compliance. The training program consisted of 96 whole-body workouts using free weights and cable machines (infrequent exceptions included the occasional use of the hamstring machine and use of the leg press for calf exercise). Subjects were instructed to attend training sessions at a rate of 3 days per week; they could attend 2 days per week if scheduling issues arose, but were required to make up missing workouts.

The progressive resistance training program was designed to follow the fundamentals of a non-linear, periodized program (Kraemer and Fleck, 2007). This included repetition zones that emphasized strength (high load for 3-6 repetitions), hypertrophy (8-12 repetitions), and local muscular endurance (12-15 repetitions). Power exercises (high pull, medicine ball throws) at lighter loads (equivalent to 12-15 repetition intensity) would also be performed; these were performed with a smaller number of ballistic repetitions (often 3-5) to focus on power production. It is important to note that within the first 32 workouts, a single power exercise was often incorporated at the beginning of a given workout. By the end of the study, however, subjects performed a total of three workouts that consisted of only power exercises (instead of a power exercise performed in concert with a workout that otherwise emphasized hypertrophy or strength).

3.4.2. Changes in Training Program Emphasis over Time

Table 3.2. Example workouts from the beginning (workouts 1-3), midpoint (workouts 46-48), and end (workouts 94-96) of the investigation. All workouts consisted of 3 sets unless otherwise noted.

Workout #	Repetitions	Rest (seconds)	Exercises
1	8-10	120	Squat Bench Press Lat Pull-down Upright Row Walking Lunge
2	6-7	180	Lunge Romanian Deadlifts Incline Bench Press Seated Row Dumbbell Shoulder Press
3	8-10	120	Squat Inverted Row Split Squats Upright Row Bench Press
46	4-6	180	Bench Press Squat Deadlift Lat Pull-down Sit-ups (20-25 reps)
47	13-15 (2 Sets)	90	Upright Row Arm Curls Split Squat Incline Bench Calf Exercise Lying Jackknife
48	8-10	120	Bench Press Squat Bent-Over Row Bicep Curls Upright Row Calf Exercise
94	8-10	120	Squat Seated Row Close-Grip Bench Press Hamstring Machine Bicep Curl Shoulder Press Push-Ups to fatigue
95	13-15	60	Lunge Bench Press Deadlift Deltoid Plate Raise Bicep Curl to Shoulder Press

			Weighted Crunches
96	3-5	180	Squat Bench Press Lat Pull-down Triceps Push-down (Cable) Abdominal Exercise Calf Exercise

Table 3.2 depicts workouts from different points in the investigation. The protocol for the first 32 workouts (from T1 to T2) largely reflected a classic resistance-training model: the loads used were heavy, with repetition ranges between 3 and 12 repetition zones (and no repetitions beyond 12). The initial emphasis (66% of workouts) was within the 8-12 'hypertrophy' range (primarily 8-10) and was accompanied by strength range for the remaining 34% of workouts (Table 3.3). Workouts emphasized functional movements (most often squat, deadlift, bench press, row, shoulder press, and latissimus pull-down).

Table 3.3. Percent of workouts performed for each Emphasis/Repetition Ranges over time. Subjects were provided with repetitions ranges on each given day (e.g. "3-5" or "5-7") that roughly corresponded to the strength, hypertrophy, and endurance ranges previously noted elsewhere (Fleck and Kraemer, 2004). There were 32 workouts in each time period. * For power workouts, a lighter weight was used, but fewer repetitions performed.

	Heavy (3-7 Reps)	Mod (8-12 Reps)	Light (12-15 Rep Load)
Time Period	Strength	Hypertrophy	Endurance or Power Only*
T1 to T2	34%	66%	0%
T2 to T3	38%	44%	19%
T3 to T4	47%	28%	25%

There was slightly more emphasis on strength in the period after T2. The major change from the first 32 workouts to the last was the replacement of the hypertrophy workouts with those that emphasized a lighter load (12-15 repetitions), predominantly for endurance (not power) training. Together, endurance workouts and power-only workouts increased from 0% to 25% of the workouts performed between T3 and T4.

The total volume of exercise performed is described in Table 3.4. To maintain the load component of volume (as heavier hypertrophy-zone workouts were replaced by lighter endurance-zone workouts), the number of strength workouts was slightly increased. The number of exercises performed per workout was also increased over time. Volume was significantly higher between T2 and T3 than the other two periods, in part due to endurance zone repetitions strongly increasing while hypertrophy zone workouts were in decline but still prominent.

Table 3.4. Total volume at each stage (load (lbs) x trepetitions). The period between T2 and T3 had significantly higher volume than the other two periods.

	T1 to T2	T2 to T3	T3 to T4
All Subjects (n=56)	327,654 ± 110,347	357,621 ± 118,023[1,3]	337,277 ± 141,752

3.5. Testing Battery

3.5.1. Body Composition

FFM as assessed with dual-energy x-ray absorptiometry (Lunar Prodigy, Madison, WI).

3.5.2. One-Repetition Maximum (1RM) Squat Strength Test

The one-repetition maximum (1RM) smith squat mass was assessed according to standard procedures as previously described (Dunn-Lewis et al., 2011, Volek et al., 2013). Briefly, subjects warmed up by performing smith squats at 50, 75, and 85 percent of their estimated 1RM. Subsequently, 4-5 trials were used to identify the heaviest load the individual could perform.

3.5.3. Vertical Jump Test

Subjects completed three non-consecutive maximal jumps on a smith machine with a load of 30% of their 1RM. Maximal power for the best attempt was measured using an integrated force plate (Fitness Technology 400, Australia) and linear transducer (Celesco, Chatsworth, CA) with Ballistic Measurement System software.

3.6. Statistical Analyses

Data are expressed as mean ± standard deviation except for mean differences (denoted MD), which are expressed as mean difference ± standard error. Significance in this investigation was established as $p \leq 0.05$. Data were examined and (when appropriate) corrected for assumptions of linear statistics using log10 transformations and by omitting subjects for any given variable on which they had missing or outlying data (over 3 standard deviations from the mean). All significant findings were separately analyzed by supplement to ensure that supplementation did not impact the primary questions in this investigation.

For the comparison of body composition, performance, and resting measures from T1 to T4, a one-factor mixed methods ANOVA was used: Testing Points (4: T1, T2, T3, T4) with repeated measures. Sex (2: male and female) was added as an additional factor where indicated. Fisher's LSD were employed for pairwise comparisons.

For predictive analyses, relationships identified using Pearson's correlations were further examined with stepwise regression. We describe in the results section that intrinsic differences between men and women in FFM, testosterone, and similar measures may cause spurious associations (for example, between testosterone, FFM, and height). Thus in addition to combined regression analyses, men and women were separately analyzed in some cases to cautiously suggest avenues to explore in future work.

Chapter 4: Results

4.1. Body Composition

4.1.1. Chronic Changes in Fat-Free Mass

FFM increased to a peak at the T3 time point (as shown in Table 4.1) and subsequently decreased significantly to T4.

Table 4.1. Fat-free mass (FFM) (kg) across the different time points. 1: significantly different from T1; 2: significantly different from T2; 3: significantly different from T3; 4: significantly different from T4.

	T1	T2	T3	T4	MD_{T4-T1}
All Subjects (n=62)	49.8 ± 10.0[2,3,4]	52.2 ± 10.7[1,3]	52.6 ± 10.5[1,2,4]	52.2 ± 10.7[1,3]	2.4 ± 0.2

4.1.2. Predictors of FFM

The change in FFM from one time point to the next ($\Delta FFM(T_n$ to $T_{n+1}))$ was positively correlated to the number of hypertrophy workouts performed during that time period (0.677) but negatively correlated to the strength (-0.582) and endurance (-0.689) workouts performed. Only the endurance workouts remained in a stepwise regression, accounting for 48% of the variance: $\Delta FFM(T_n$ to $T_{n+1})$ = 2.41 + -0.34 (# Endurance

Workouts). If the number of endurance workouts were removed for the analysis, 46% of the variance could be attributed to the number of hypertrophy workouts performed, and 2% to the number of strength workouts performed: $\Delta FFM(T_n \text{ to } T_{n+1}) = -8.4 + 0.34$ (# Hypertrophy Workouts) + 0.34 (# Strength Workouts). It should be reiterated that all subjects performed the same protocol, and were therefore assigned the same number of workouts of each type in each time period.

Several factors failed to predict the overall changes in FFM (from T1 to T4). These included squat strength, the relative intensity of at which individuals performed workouts within the prescribed parameters (defined as repetitions performed x % of 1RM used), or the time to complete workouts.

Table 4.2. Results for stepwise regression analysis of fat-free mass (FFM).

Time	Total R^2	Constant	β coefficient for Height	β coefficient for Squat	n
T1	90%	-61.97	0.57	0.21	63
T2	91%	-61.69	0.55	0.21	61
T3	91%	-58.21	0.53	0.20	63
T4	90%	-61.06	0.53	0.20	58

To determine the variables that might influence FFM, anthropometrics and other variables were entered into stepwise regression analysis (Table 4.2). Unfortunately, there were few meaningful findings; the results are therefore not useful to report except in general terms. Specifically, the predictors of FFM were intuitive: men (who happen to be taller, stronger, and have higher testosterone) have more FFM than women. Thus a regression among these variables significantly predicted that height, strength, and testosterone (data not shown) were related to FFM. Height and strength *did* significantly predict FFM in men and women when analyzed separately, but that finding did not provide meaningful insight to the current investigation. Further, it cannot be determined whether FFM predicts strength or whether those who are stronger may be more active (thereby increasing FFM).

4.1.3. Chronic Changes in BMD

In the absence of a non-training control group, it is not possible to definitely determine whether increases in BMD were due to training or to the age of the subjects (at 23 ± 3, subjects would just be reaching peak BMD). That being said, FFM is a measure of lean tissue other than muscle, including BMD. It is therefore important to confirm that BMD did not decrease alongside FFM.

As shown in Table 4.3, BMD at T4 was significantly higher than baseline in women (MD_{T4-T1}: 0.012 ± 0.004 g•cm^{-2}, p=0.000) and T2. This was also seen in men (MD_{T4-T1}: 0.007 ± 0.003, p = 0.045). The average increase in BMD was 0.8% in women and 0.5% in men. This translated to an average improvement in BMD t-score of 0.04 in women and 0.08 in men. (For reference purposes, the risk of fracture increases 1.5-3.0-fold with each standard deviation decrease (Cummings et al., 1993)). This indicates that BMD did not decrease with FFM.

Table 4.3. BMD (g•cm^{-2}) with training across time in men and women. #: Significantly higher than baseline (T1). 2 = Significantly higher than T2.

	T1	T2	T3	T4	MD $_{T4-T1}$
Men (n=33)	1.272 ± 0.104	1.271 ± 0.097	1.276 ± 0.098	1.279 ± 0.094$^{\#2}$	0.007 ± 0.003
Women (n=24)	1.160 ± 0.060	1.161 ± 0.062	1.163 ± 0.061	1.170 ± 0062$^{\#2}$	0.012 ± 0.004

4.1.4. Predictors of BMD

For men and women combined, 43% of the variance in BMD at baseline was attributable to baseline squat strength; $BMD_{T1} = 1.05 + 0.003 \bullet Squat_{T1}$. Results for the other time points are displayed in Table 4.4 below.

Table 4.4. Results for stepwise regression analysis of bone mineral density (BMD).

Time	Total R^2	Constant	β coefficient for Squat	n
T1	43%	1.05	0.003	61
T2	50%	1.01	0.002	59
T3	51%	1.01	0.002	60
T4	45%	1.02	0.002	58

The change in strength between consecutive time points did not predict the change in BMD between consecutive time points. The number of strength (or any other) workouts also did not predict the change in BMD between consecutive time points. This may be related, in part, to the long period of time between the stimulation of bone and its final adaptations, changes that would not be detectable in the same ~3 month period.

4.1.5. Body Fat

There were no significant differences in body fat at any time (Table 4.5). No significant differences were detected.

Table 4.5. Fat mass (kg) over time. With careful monitoring of weight by Registered Dieticians, no significant differences were seen.

	T1	T2	T3	T4
All Subjects (n=63)	19.8 ± 10.4	19.4 ± 10.5	19.6 ± 11.0	19.6 ± 10.8

4.2. Performance

4.2.1. Chronic Changes in Squat Strength

As shown in Table 4.6, squat strength significantly increased ($p<0.002$) across all time points in men by an average of 45.6 ± 2.4 kg total (25.4 ± 2.1 kg from T1 to T2, 13.8 ± 1.4 kg to T3, and a final 6.5 ± 1.4 kg to T4). Women also grew stronger throughout the investigation, gaining 17.0 ± 2.6 kg on the squat from T1 to T2, 8.5 ± 1.7

kg to T3, and 6.4 ± 1.7 kg to T4, for a total strength increase of 31.8 ± 3.0 kg.

Table 4.6. Squat strength (kg) in men and women across time. * = Significantly different from all other time points.

	T1	T2	T3	T4	MD_{T4-T1}
Men (n=33)	87.6 ± 18.5 *	113.0 ± 21.4 *	126.8 ± 19.8 *	133.3 ± 20.0 *	45.6 ± 2.4
Women (n=24)	47.4 ± 13.1 *	65.0 ± 15.3 *	73.7 ± 15.4 *	80.2 ± 18.9 *	31.8 ± 3.0

4.2.2. Predictors of Squat Strength

Squat strength is highly related to FFM and displays the same significant relationships with height that FFM does in regression (creating difficulty in determining predictive relationships). For the change in squat strength, 21% of the variance was accounted for by Relative Intensity (Repetitions•%1RM) (12%) and the change in FFM_{T4-T1} (9%): $\Delta \text{Squat Strength}_{T4-T1} = 3.9 + 0.02 \bullet \text{Relative Intensity} + 2.8 \bullet \Delta FFM_{T4-T1}$, n=51.

4.2.3. Chronic Changes in Vertical Jump Power

Please see Table 4.7 for changes in vertical jump power. Vertical jump power significantly increased until T3, at which point it did not significantly change to T4.

Table 4.7. Vertical Jump Peak Power (W) across time.

	T1	T2	T3	T4
All Subjects	2700 ± 139[2,3,4]	3080 ± 139[1,3,4]	3266 ± 150[1,2]	3289 ± 149[1,2]

4.2.4. Predictors of Vertical Jump Power

At baseline, 76% of the variability in vertical jump power was attributed to FFM; Vertical Jump $Power_{T1}$= -803 + 79•FFM_{T1}. Please see Table 4.8 for regression equations at all time points.

Table 4.8. Results for stepwise regression analysis of vertical jump power.

Time	R^2	Constant	β coefficient for FFM	n
T1	76%	-803	79	47
T2	70%	-1227	85	57
T3	84%	-1294	91	54
T4	85%	-1208	90	56

Chapter 5: Discussion

5.1. FFM

The primary finding of the current investigation was that in response to a decreased number of hypertrophy zone workouts, FFM decreased at the end of the investigation (from T3 to T4). This was in spite of the fact that the same number of workouts was performed from T3 to T4, that the loads used progressively increased with the increased emphasis on strength days, and that the number of exercises performed each day increased. Although volume decreased at the end of the investigation, volume did not significantly predict changes in FFM. On the other hand, endurance zone workouts negatively predicted FFM while hypertrophy zone workouts positively predicted FFM.

We expected improvements in a novice population to be especially pronounced for the first few weeks - but also anticipate some continued improvements beyond that. The *deterioration* of progress is not an expected outcome or byproduct of a novice population. In an investigation of 55-80 yr men, for example, progressive resistance exercise increased strength and FFM at 6 and 12 months (Whiteford et al., 2010). The observation that the reduction in FFM corresponded to the reduced emphasis on the hypertrophy zone supports previous work of the specificity of adaptations to strength, hypertrophy, and endurance zones (Campos et al., 2002).

5.2. Strength and Power

It is interesting to note that strength continued to improve to T4 even when FFM decreased at T4. Although the number of hypertrophy workouts performed decreased, the strength workouts did not. Instead, there was a continued emphasis on strength workouts throughout the investigation, which increased in both frequency (34% from T1 to T2, up to 47% of workouts between T3 and T4) and intensity (more emphasis on the 3-5 repetition range than the 5-7 range over time). Thus strength appears to respond to strength zone workouts even when FFM decreases.

There were no significant differences in power production at the end of the investigation (T3 to T4) despite the inclusion of workouts dedicated to power. This coincided with the decreased FFM at that time, possibly compromising improvements in power output (in spite of the increased emphasis on strength and power-only workouts). The importance of skeletal muscle size for power production has been established in past work (Palmer et al., 2013). In support of this hypothesis, 76% of the variance in power was attributed to FFM at T1, while strength (which did continue to significantly increase) did not significantly predict resting power production. It is therefore possible that the decrease in FFM prohibited power from continuing to increase. Without a separate training group that did not change repetition zone emphasis, however, it is not possible to determine whether a significant increase should have occurred.

5.3. BMD

Our primary interest in BMD was to determine whether decreases in FFM also affected its development. BMD was significant higher at T4 than the beginning of the investigation. Although the number of strength workouts performed at each time period and the increases in strength at each time period did not predict changes in BMD, we did establish that resting BMD is related to strength. The improvements in BMD coincided with our emphasis on strength throughout the investigation, suggesting that strength is a primary stimulus for improvements in BMD. This is in agreement with previous indicating that heavier loads are superior to lighter loads for bone development during resistance training (Conroy et al., 1992) and is likely related to increased mechanical load translated into adaptations through mechanotransduction (Duncan and Turner, 1995). Thus in agreement with an investigation on BMD in women (Winters-Stone et al., 2011), we found BMD may increase in response to training that exerts force on bone – even in the absence of changes to FFM.

5.4. Summary

The primary purpose of the current investigation was to determine whether replacing hypertrophy workouts with endurance zone workouts would allow subjects to sustain or further improve FFM. In contrast to recent claims (Mitchell et al., 2012), this investigation suggests that replacing hypertrophy zone workouts with endurance zone workouts diminishes gains in FFM and may hamper power development. As the primary benefits of resistance exercise (performance, health, and appearance) are either directly controlled by or indirectly influenced by hypertrophy, replacing hypertrophy workouts resistance with those in the endurance range may hamper the progress an average person seeks to achieve with resistance training. Thus classical periodization models that include strength- and hypertrophy-zone training should be employed for most resistance training goals.

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