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Predictors in Strength Gains in Untrained Men Over 9 Months of Training

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Predictors in strength gains in untrained men over 9 months of training

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CHAPTER ONE

INTRODUCTION

The baseline strength of resistance untrained individuals is determined by several genetic factors. Of these genetic factors, several exist that are not trainable such as number of muscle fibers, muscular attachment sites, body dimensions and joint leverages (8). Other genetic factors such as neural efficiency and quality of muscular protein (4) (19) also play a role in baseline strength, but can be further enhanced through environmental factors such as resistance training. Additional environmental factors such as employment type and nutrition may also have an impact on baseline strength as those individuals that perform heavy manual labor may already exhibit informal resistance training adaptations much as those individuals lacking proper nutrition may display limited strength as compared to their baseline potential under proper nutritional conditions (2).

For untrained individuals participating in a resistance training program for the first time, the type of program utilized may impact both the rate of gain and total strength gains that can be made. Much has been written about the most effective methods of eliciting strength gains with exercise selection, volume of work, intensity of load, and rest period between reps and sets being key variables of interest (11)(6)(1). It has been shown that a non-linear periodized model of strength training is superior to both a linear periodized model and a single set model in the maximization of strength gains for untrained individuals (11)(16)(9)(12)(17). Within the non-linear model, it has also been shown that free-weight barbell exercises utilizing multi-joint movements that closely mimic human movement encountered during daily living and sport (i.e. squat and bench press) to have greater overall human performance benefits than do single joint exercises (i.e. leg extension, arm curl) (1), particularly those involving fixed path machines (1)(3)(5).

For the untrained individual, it is known that strength gains experienced over the first five to eight weeks of resistance training are primarily neurological in nature (4)(14)(18) while gains experienced over the following year are dominated by increases in muscular cross sectional area resulting from muscular hypertrophy (4). Subjects embarking on a resistance training program for the first time can expect to achieve strength gains of about 40% (15)(1) and can expect the largest amount of their gains to be achieved at the beginning of the program. While the exact timeline for shifts in strength gain potential with training is not clear, it is known that individuals have a continuing decreased capability to make appreciable strength gains with training experience as the individual genetic limit is approached (1)(15). It is for this reason that an untrained individual can expect to make strength gains of 40% while a trained individual can only expect 16% gains and an elite trained individual can only expect a further 2% gain (15)(1).

Statement of Problem

The purpose of this study is to compare strength changes over time in men from an untrained state and determine if there are significant differences between relatively "low" and relatively "high" gainers over the course of a 9 month non-linear periodized resistance training program in the squat and bench press exercises.

CHAPTER TWO

REVIEW OF LITERATURE

The human body has a remarkable ability to adapt to the environmental stresses placed upon it. It is well documented within the literature that strength levels are one such adaptable human aspect and that resistance training leads to overall gains in strength (1). In addition to understanding that humans get stronger with training, it is also understood how these gains in strength progress over time and what factors, both fixed and trainable, contribute both to baseline strength levels and to adaptation to resistance training programs. This review will focus on these factors that determine baseline levels of strength, the means of enhancing strength, and how the trajectory of expected strength gains will progress, all for the untrained male. An understanding of these parameters will help shed light on the question at hand: what factors account for differences in strength between stronger and weaker untrained males both at baseline and after consistent training experience.

Physiological adaptations to resistance training resulting in increased strength

For the untrained young adult male, increases in strength are neurological in nature, related to increases in the size of the relevant muscle fibers (muscular hypertrophy), or a combination of the two (21)(31)(8). Gains achieved by a more efficient use of the nervous system appear to come in several forms. Multiple studies have suggested resistance training as a means to increase the neural drive coming from the higher neural centers resulting in a greater ability to create force. Proposed mechanisms for this higher level of force production with training are either an increased ability to recruit higher threshold motor units, an ability to increase the firing rate of already recruited motor units, or a combination of the two (8). Another proposed neural mechanism by which strength increases occur is decreased co-contraction of antagonist muscle groups with training. Studies involving the use of surface electrode electromyography have shown that resistance training can lead to decreased activation in the muscles capable of resisting desired concentric movement leading to a net increase in force production (8)(12). Yet a third neural adaptation capable of increasing strength is efficiency gained through a learning of the movement. Through repeated practice of a strength movement, the human body is often capable of detecting leverages and biomechanical positions that result in overall improved technique which in turn leads to an increased expression of strength (25)(30)(22). In support of strength gains that are purely neurological in nature, studies have shown that unilateral strength training can result in increased strength of the non-trained contralateral limb. Since the contralateral limb has gained strength without a direct mechanical training stimulus, the cause of the strength gains point to neurological in nature (28)(8).

A single session of heavy resistance exercise results in a net increase of myofibrillar protein synthesis of the trained muscles. As training becomes chronic, consistent increases in synthesis manifests itself as muscular hypertrophy: both an increase in myofibrillar area and myofibrillar number (8)(32). The myofibril contains the contractile units of the muscle and therefore adding more myofibrils in parallel (increased cross-sectional area) results in an increased capability of the muscle to produce force (16). This is supported by several studies including research conducted by MacDougall *et al,* in which untrained young men increased the muscle fiber area in their triceps brachii by 33% and 27% in Type II and Type I fiber respectively after six months of resistance training (20). In addition to the myofibrils increasing in size, changes affecting the quality of the myosin heavy chain occur as early as within the initial 2-4 workouts (32) showing that changes in protein occur rather quickly to a resistance training stimulus.

Factors contributing to strength gains in untrained populations

From the literature, it is clear that initial strength gains are neurological in nature followed by further strength gains resulting from muscular hypertrophy with a probable third set of gains coming again from neural factors (8). What is currently unclear is the length of time these periods persist. In the classic study by Moritani and deVries, it was found that neural mechanisms are the cause of strength gains experienced over the first 4 weeks of an 8 week resistance training program. After weeks 4-6, further strength gains were attributed to muscular hypertrophy (21). Since this study, subsequent research has been conceptually supportive, but inconclusive regarding timelines. Staron *et al.* for example, found that untrained subjects only started experiencing muscular hypertrophy after 6 weeks of resistance training, yet strength gains became visible after just 2 weeks (31, 32). Yet a third study by Staron, Karapondo, and Kraemer showed that hypertrophy still had not persisted in untrained subjects, even after 6 weeks of heavy resistance training (32). Once hypertrophy starts to contribute to overall gains in strength, it appears to be only a finite adaptational resource as according to Deschanes and Kraemer, significant hypertrophic responses may only persist for about a year. Because strength gains do tend to continue past this point, it is likely that another round of gains attributed to neural factors takes place (8).

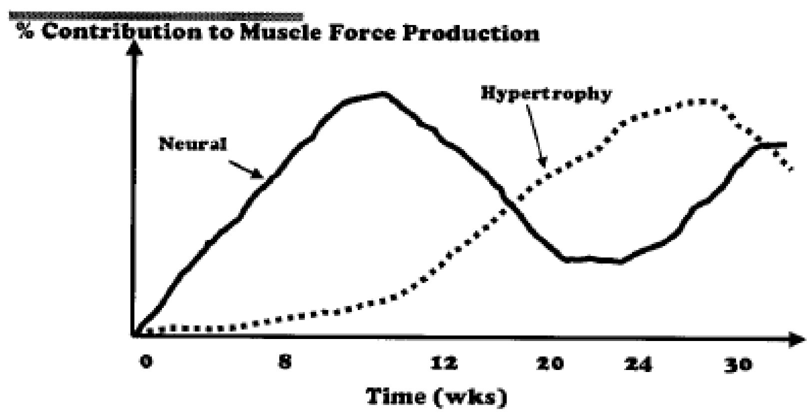

Fig 2.1 The balance of neural and hypertrophic factors contributing to strength gains in the untrained

In addition to understanding the mechanisms by which strength improves in the untrained individual, it is also understood to some extent the gains an individual should expect when beginning a well designed non-linear resistance training program. A review of 100 studies yielded that untrained individuals can expect gains of about 40%, while moderately resistance trained individuals can expect gains of 20% (22) (1). It is also understood to some extent the time course of expected gains in strength across time with the majority of gains taking place in the initial phase of training with significant gains contributing for over a year, but at a lesser rate. As training age continues, appreciable gains occur to a lesser and lesser extent as the genetic ceiling is approached (9)(8). While this trajectory is understood in the literature, the timeframe for these gains is not, however; unpublished research from our laboratory shows the most appreciable gains occurring in the first three months.

Adaptations based on training paradigm

Non-linear periodized resistance training programs have been shown to maximize strength gains in untrained individuals versus linear periodized (24) and single set models (10)(18)(17). Furthermore, the utilization of multi-joint, free-weight barbell exercises such as squat and bench press within a non-linear program have been shown to result in better strength and power gains in human movements relevant to activities of daily living and sport than do programs that focus on single joint movements and/or fixed-path variable resistance movements (9)(1)(4). It has been demonstrated that beginners can make gains in strength employing loads as light as 45-50% 1RM but more experienced lifters must use at least 80% of 1RM to make further neurological gains (1). Studies have additionally shown that gains in strength due to the neurological factors described above are maximized when both the eccentric and concentric portions of the lift are performed (7).

Possible causes for strength discrepancies within an untrained population

Of all factors influencing gains in strength, genetic factors must be considered first and foremost. As with all human endeavors that involve innate abilities such as writing skill and artistic acumen, strength, or the ability to create force is largely dictated by genetic disposition. Those who possess naturally high baseline levels of strength probably rate above average in one or more of the following categories when compared with other untrained persons: nervous system efficiency, muscular cross-sectional area in an untrained state (number of muscle fibers), biomechanical advantages such as structuring of bone, joint leverages and insertion points of muscles (14). These non-trainable factors support the notion that individuals who start out stronger tend to stay stronger, all else being equal.

While there are certainly innate factors that impact both an individual's baseline strength level as well as their ability to adapt to a training stimulus, there also exist additional variables, that when combined with resistance exercise can influence the overall gain in strength. One such major factor is diet. Studies have shown that the amount of calories consumed, the type of nutrients consumed, and the timing of nutrient intake can all play a role in influencing strength gains (2)(33). First and foremost, the body must have enough calories to meet metabolic demand. The human body is capable of using fat, carbohydrate, and protein as fuel with a preference towards the former two (23). In instances where the body cannot meet its metabolic fuel demands through fat and carbohydrate intake and stores, it will utilize protein, and in some instances this protein will come from or be at the expense of muscle protein (2)(23). Since strength is determined in part by the cross-sectional area of utilized muscle, reduced muscle resulting from decreased protein availability may result in reduced strength or a reduced strength potential. On the other hand, strength increases resulting from muscular hypertrophy results from an increase in the number of contractile units through both an increase in myofibrillar area and number; both coming from a relative increase in protein synthesis (8). In order to maximize this phenomenon, sufficient nutrients must be available to make this positive protein balance possible (2).

Along with caloric intake, source of calories is another factor influencing strength gains. Protein has been shown to individually activate multiple signaling pathways resulting in the long-term up-regulation of protein synthesis resulting in muscular hypertrophy (35). Protein availability is crucial to maximize muscular adaptations that take place during resistance training. While we know from the work of Tipton and Wolfe that the protein needs of the individual athlete are based on training regimen and habitual nutrient intake (34), there is much debate as to the actual amount of protein various athletes need to maximize training adaptations. According to Lemon, athletes may benefit from consuming ~2g of protein per kg of body mass per day during periods of intense training (19) while other researchers have suggested consuming the same amount as recommended for the general population (~1g of protein per kg of body mass per day) (2). Currently, this is a subject of great debate.

A third dietary factor directly influencing adaptation to resistance training is the timing of nutrient intake. An increase in muscle protein results from a positive protein balance: the amount of protein being synthesized exceeds the amount of protein being catabolized. During a rested and/or fasted state, the protein balance is negative as breakdown exceeds synthesis. Following exercise, even in a fasted state this balance shifts in favor of synthesis, but to truly maximize synthesis, research has shown that dietary protein must be readily available for the muscle. This is supported by several studies including one by Tipton *et al.* in which those subjects ingesting a combination of carbohydrate and protein immediately before or after resistance training led to greater amino acid availability to muscle and a greater overall protein synthesis than the control group (33). Karlsson *et al.* showed greater and longer levels of protein synthesis following resistance training when subjects consumed branch chain amino acids (BCAAs) versus a placebo (15).

While dietary factors are certainly a major contributor to maximizing adaptations to resistance exercise, they are not the only ones to be considered. Other significant contributors to overall strength gains may include sleep and overall stress levels. While anecdotal evidence supports the claim that sufficient sleep is necessary to reap the recovery and remodeling benefits of resistance training, not much literature has been published on adaptations to strength training with chronic sleep loss. Of the limited literature available on the acute effect of sleep loss on strength, the results were mixed, with one study showing a loss in maximal torque after 24 hours of sleep deprivation and another showing no significant decrease in weightlifting performance after 24 hours of sleep deprivation (5)(6). While anecdotal evidence also supports the claim that high levels of psychological stress and anxiety may mitigate adaptations to strength training, further research must be conducted to either support or refute this claim. In conjunction with stress and anxiety, other environmental factors such as circadian rhythms and daily training time may influence gains in strength. Of the limited literature published on this topic, Sediak showed a discrepancy in peak knee extensor torque and EMG based on training time at baseline that tended to resolve itself with time specific training (26) but in a subsequent study failed to show significant differences in muscular hypertrophy with training at different times (27). More research is necessary before the influence of training times and circadian rhythms can be understood.

While the above factors are all individually or in combination capable of explaining discrepancies in strength, even within a given population such as untrained young adult males, sometimes the appearance of discrepancy can be explained by classification factors. These factors can show a significant discrepancy, but not truly be representative of the adaptation that is actually occurring. Ultimately, it is one's set of genetic factors (number of muscle fibers, muscle attachments, etc.), combined with environmental circumstances (physical demands of job, nutrition, sleep, etc) that determine strength levels.

One such environmental factor is previous training experience. Studies conducted in our laboratory classify subjects as untrained if they have not resistance trained within the past year. This categorizes those individuals who have never experienced weight training the same as those with weight training experience, just not recent experience. A fair amount of research has been published on resistance detraining adaptations over the short term in several populations with significant, but not total losses in strength occurring from both reduced muscular hypertrophy and decreased neural efficiencies (3)(13)(11)(31), but only a couple of studies have looked at long term detraining (6 months to a year). Staron *et al* showed that previously untrained women who resistance trained for 20 weeks and detrained for 30-32 weeks lost significant, but not all of the strength and hypertrophy gains they had made over the 20 week resistance training program. Staron proposed that the continued increase in strength over baseline levels was attributable to both residual hypertrophic and neural gains from the original 20 weeks of training citing hypertrophy and "muscle memory"; although it could not be determined the percentage each factor contributed to the remaining strength increase (31).

The concept of muscle memory can be operationally defined as the residual learned effect to a motor task; in this case a measure of strength such as the squat and bench press. As afore mentioned, some gains in strength as a result of resistance training come from the body's ability to discover through trial and error and perhaps instruction, movement and leverage efficiencies as well as decreased antagonist muscle co-activation. As the Staron paper discussed, it is likely that a portion of this learning can be retained, even after detraining for a significant period of time (at least 32 weeks) (31). In agreement with Staron was the previously published Berger study in which untrained males were trained for 6 weeks, detrained for a year, and then retested. Remarkably, Berger discovered that these subjects retained 50% of their strength gains through the detraining period.

Conclusion

Non-linear periodized resistance training utilizing free weight exercises such as the squat and bench press have been shown to maximize strength gains in untrained individuals. The causes for these gains in strength are primarily related to changes in neurological factors and increases in muscle cross-sectional area (muscular hypertrophy). Although both are vital to maximizing strength gains, the timing of their contribution differs greatly as neurological factors are responsible for gains over the first several weeks with hypertrophy taking over for up to a year followed by more gains related to neurological factors. While the literature is clear on the order in which these gains take place, there is much debate as to the length of time each factor is the major contributor for.

Even within a given homogenous population such as untrained young adult men, some individuals will gain more strength relative to others and this can be attributed to several different factors. Those subjects who posses a relatively more efficient nervous system and/or greater amounts of relevant muscle fiber at baseline will tend to remain stronger in a trained state as will those subjects who enjoy other genetic advantages such as more optimal structuring of bone, joint leverages and insertion points of muscles, as well as a relatively better ability to master technique.

Furthermore, it is possible the appearance of discrepancies in baseline strength occur when in reality none are actually present. This is possibly due to the ways in which we classify or test subjects. Studies that classify subjects with previous training experience as untrained using the reasoning that a significant length of time (a minimum of one year in the case of our laboratory) has passed since their last bout of resistance training exercise may be creating a misleadingly high baseline strength estimate as at least two studies have shown that after significant periods of detraining, "muscle memory" and some level of hypertrophy still exist above baseline levels. Since each individual has finite adaptational resources (sometimes referred to as a genetic window), if strength gains are measured by finding the net gain in strength between baseline and any other time point after training, that subject will be at an unfair disadvantage because they have already used a portion of their adaptational resources by baseline testing. In all fairness, this argument relies on the underlying assumption that subjects detrained past one year (particularly as the detraining period gets longer) still maintain some level of neurological and hypertrophic gains. While the literature does point to a confirmation of this assumption, much more research must be done before a conclusion can be reached.

Similarly to the classification issue is the testing familiarization issue. For reasons of practicality, sometimes studies are conducted with one or two familiarization sessions. If these exercises are complex movements such as the squat and the bench press, these subjects may learn the movement well enough to complete a safe test, but may not be able to display a similar level of technical mastery of the exercise as that of a trained or detrained individuals (29)(22)(31). Other subjects who are considered untrained but in fact are detrained (as classified above) already have at least some level of familiarity with the exercise and through a level of "muscle memory" may be able to produce an artificially high and disadvantageous baseline measurement. While the literature shows that technical mastery of complex movements (such as the squat) is not possible in one or two familiarization sessions (30)(31), more studies examining the long term maintenance of muscle memory through periods of detraining must be conducted before we can conclusively say that subjects who are detrained are at a disadvantage when compared with truly untrained individuals when monitoring for increases in strength over the course of a resistance training study.

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CHAPTER THREE

METHODS

Experimental Approach to the Problem

This study used a single group of untrained men who were going to initiate a resistance training program. This study examined the pattern of changes in strength in the bench press and squat in untrained men over a 9 month period of training using a non-linear periodization model and a split versus the mean between men who made higher versus lower gains in the 1RM in these lifts. We examined these changes at baseline and every 3 months over the course of a nine month non-linear resistance training program with the purpose of determining how both large and small gainers (as determined by percentage increase in each exercise over the course of the study) progress in relation to each other. We had three major questions: "When do the largest gains in these two major lifts occur?", "Are there significant differences between "high gainers" and "low gainers" at any point over 9 months of training" and "Are strength gains taking place at the same time frame for these two groups?" Since most training studies do start with untrained individuals, we wanted to examine with this training status as an initial study into these questions.

Subjects

Subjects were 33 healthy men 18-35 years of age who were classified as untrained (no regular resistance exercise training for at least the previous 12 months). The characteristics of these subjects are presented in Tables 3.1 and 3.2. After having the risks and benefits of the explained to them, each subject signed an informed consent form that was approved by the University of Connecticut Institutional Review Board (See Appendix A) as a part of a larger study. Subjects were considered untrained based on the fact that none had participated in a resistance training program for the last 12 months. There were no significant differences between groups.

Table 3.1 Characteristics of the experimental subjects (Mean±SD) for Squat

	Low Gainers	High Gainers	Total Group
Age (Yrs)	23.60 ± 3.11	23.65 ± 6.01	23.63 ± 3.22
Height (cm)	176.19 ± 6.49	177.29 ± 6.01	176.77 ± 6.14
Body Mass (kg)	79.73 ± 16.7	82.62 ± 16.67	81.26 ± 16.41
Baseline Weekly Activity (METS)	2551 ± 2530	2419 ± 2558	2481 ± 2504

Table 3.2 Characteristics of the experimental subjects (Mean±SD) for Bench Press

	Low Gainers	High Gainers	Total Group
Age (Yrs)	23.00 ± 3.00	24.18 ± 3.49	23.63 ± 3.22
Height (cm)	176.66 ± 5.87	176.87 ± 6.55	176.77 ± 6.14
Body Mass (kg)	79.95 ± 13.1	82.42 ± 19.28	81.26 ± 16.41
Baseline Weekly Activity (METS)	2760 ± 3060	2202 ± 2504	2481 ±2504

1 Repetition Maximum (1RM) Test Controls

Subjects were asked to refrain from any physical exercise for at least two days prior to 1RM testing. At their initial test, subjects were asked to arrive with a diet log recording food and drink intake for the previous 24 hours. At each subsequent test they would again follow this diet. Furthermore, subjects were asked to perform all tests in the same footwear and style of clothing. Prior to beginning the test, subjects were weighed in and tested for hydration. Subjects were asked to maintain the same foot placement for squat and same grip for bench press from test to test. By subject, each test was scheduled for approximately the same time of day.

Non-Linear Resistance Training Controls

This particular study was part of a larger study examining the effects of different protein type supplementation on non-linear resistance training exercise performance and body composition. For this reason, each subject ingested a supplement daily containing whey protein, soy protein, or a carbohydrate control. Supplement could be ingested any time of day, except on training days when the supplement was consumed immediately after resistance training. Supplement compliance protocols were in place. A one way ANCOVA was used to show there were no significant differences in percentage strength increase due to supplement when controlling for baseline strength (Squat $F(2,28)=.517$, $p=.602$, Bench $F(2,28)=.405$, $p=.671$). Subjects were asked to maintain close to their original body mass over the course of the study. The mean (kg ± SD) gain in body mass over the course of the study was 2.26 ± 3.08. Compliance measures were taken to ensure weight maintenance and dietary counseling was provided to both maintain body mass and control the proportion of macronutrient intake. Subjects were asked to maintain their previous level of activity throughout the study.

Table 3.3 Supplement breakdown by group for squat

	Supplement				
Gainer Group	A	B	C	Total N	Group Baseline Strength (Mean ± SD)
High	8	4	5	17	76.60 ± 14.94
Low	4	6	5	15	98.79 ± 14.95

Table 3.4 Supplement breakdown by group for bench press

	Supplement				
Gainer Group	A	B	C	Total N	Group Baseline Strength (Mean ± SD)

High	7	6	4	17	50.80 ± 10.60
Low	5	4	6	15	75.00 ± 16.68

Non-Linear Resistance Training Protocol

Subjects trained for 32 consecutive weeks in planned free-weight non-linear resistance training workouts with a focus on the squat and bench press exercises. All workouts were conducted under the individual supervision of trained strength and conditioning specialists and conducted in accordance with non-linear training protocols as described by Kraemer and Fleck in Optimizing Strength Training: Designing Nonlinear Periodization Workouts (11). An example participant workout is shown in table 3.5.

Table 3.5- Sample week of non-linear periodized workouts

	DATE			
Day 1	Week X	3-5 reps	180 s. rest	Notes:
	set 1	set 2	set 3	
Walking DB Lunge				
Seated row				
Incline bench				Subject Reports No Complaints Upon Exit: (Subj Initial/Date): __________
RDLs				
DB Shoulder press				
MB Push Press Throw				
Push-ups (Max Reps)				Trainer Initial/Date (Supplement): _________

	DATE			
Day 2	Week X	8-10 reps	180 s. rest	Notes:
	set 1	set 2	set 3	
Squat				
Close-grip bench				
Pulldown				Subject Reports No Complaints Upon Exit: (Subj Initial/Date): __________
Plate raise				
Bicep curl				
Pushups (Max Reps)				
DB Step Ups				Trainer Initial/Date (Supplement): _________

	DATE			
Day 3	Week X	10 reps	120 s. rest	Notes:
	set 1	set 2	set 3	
In-Place DB lunge				
Bench				Subject Reports No Complaints Upon Exit: (Subj Initial/Date): __________
Pulldown				
Push press				
Upright row				
Pushups (Max Reps)				Trainer Initial/Date (Supplement): _________

1 Repetition Maximum (1RM) Test Procedure

The testing protocol was performed per prior methods already described by Kraemer et al. (10). Subjects were briefly familiarized with the proper squatting and bench press technique using a Smith machine (Life Fitness: Schiller Park, IL). In order to eliminate differences in skills we utilized a Smith machine testing format and subjects trained with free weights and Smith machine sets so as to eliminate any learning effects. Once technique was deemed acceptable, separate but consecutive 1RM tests were performed; squat followed by bench press. Subjects warmed up with 5 minutes of cycle ergometer exercise followed by a series of dynamic stretches; no static stretches were used in the warm-up protocol. For both the squat and the bench press, two warm up sets were done: the first at 50% of estimated 1RM for 8-10 repetitions, the second at 80% of estimated 1RM for 2-5 repetitions. Four to five maximal trials were completed to determine the 1RM. For the squat exercise, the subject descended to the femur parallel position and ascended to the starting position upon a verbal signal from the tester. For the bench press, the subject brought the bar down to his chest and immediately pressed the bar to the starting position. Subjects were asked to maintain the same foot placement for squat and same grip for bench press from test to test and this was verified by standardizing measurements. The 1RM tests were performed at baseline and then in subsequent 3 month intervals (3, 6, and 9 months).

Statistical Analyses

Data are presented as means ± SE unless otherwise specified. Significance was set at or below an alpha of 0.05. We separated the subjects into two groups for both squat and bench press: those who made above average gains (High Gainers) and those who made below average gains (Low Gainers). Subjects with incomplete testing data were removed from analysis. Of 33 subjects, 3 Low Gainers in squat became High Gainers in bench and 4 High Gainers in squat became Low Gainers in bench. T-tests verified statistically significant differences between groups in strength change for both squat and bench press.

Data were analyzed for normality; log10 transformations were only necessary for variables used in regression analysis. After accounting for baseline strength in both squat and bench press, both volume (sets x reps x load) and intensity (peak load each week) were eliminated in stepwise regression indicating no additional variance was explained by these variables beyond starting (PRE) 1RM. This is likely because the same weight training program produced the same volume with the exception of the intensity component; the differences in intensity appeared to arise from differences in initial strength. As these factors did not influence prediction, they were excluded from further analysis.

A mixed Factorial 2 x 4 (Performance Group x Time Point) ANOVA was performed to examine one-repetition maximum for both squat and bench press. All conditions for sphericity and homogeneity of variance were met. Multiple pairwise comparisons were performed with Tukey (which were robust against the more conservative Bonferroni corrections).

In addition to dividing subjects by group, all subjects were collectively analyzed to estimate the association between baseline strength and improvement in performance for both squat and bench press. Pearson product moment correlation coefficients were calculated for percentage incrase in force production at 3, 6, and 9 months.

CHAPTER FOUR

RESULTS

For both squat and bench press, those individuals belonging to the “High Gainer” group gained strength across every time point throughout the study (p=0.000 for all pairwise comparisons in squat, p≤0.005 for all pairwise comparison in bench). In the “Low Gainer” group, however; no differences were seen between 6 and 9 month testing (mean difference between the 6 and 9 month for squat 1RMs is -4.119 ± 2.146 kg, p=0.064; for bench 1RMs is -2.540 ± 1.380 kg, p=0.075) possibly indicating a plateauing phenomenon.

Significant differences in squat 1RM strength between the two groups existed only at baseline. The low gainer group started stronger (mean difference in starting 1RM between low and high performers is equal to 22.543 ± 5.133 kg, p=0.000). While no significant differences were seen at any time point, the mean difference between the two groups became smaller over time (mean difference at 9 month testing between low and high performers is 0.919 ± 7.075 kg, p=0.897).

There was a significant difference between the rate of change between baseline and 3 month testing between the two groups for both squat (F(1,31)=8.789, p=0.006) and bench press (F(1,31)=5.309, p=0.028), but not between any other time points. Thus, as may be seen in figures 4.1 and 4.2, while the rate of change was higher overall in the

"High Gainer" group, this can be attributed to a higher rate of gain only in the first three months.

Those subjects belonging to the "Low Gainer" group were consistently and significantly stronger at every time point for bench press, $p \leq 0.02$. The mean difference between the groups started at 24.833 ± 4.535 kg (p=0.000) and decreased to 15.775 ± 6.064 (p=0.014) by 9 month testing.

As shown in table 4.1, percent gain in performance was inversely related to baseline strength. The strength of this relationship increased over the course of 9 months, indicating that 53% of the variation in percent strength increase could be attributed to baseline strength for both squat and 40% for bench press by the end of the study.

Table 4.1 Percent gain in performance in relation to baseline strength

	Percent Increase		
	3 months	6 months	9 months
Baseline Squat	r^2=0.26, p=0.003	r^2=0.50, p=0.000	r^2=0.53, p=0.000
Baseline Bench	r^2=0.20, p=0.010	r^2=0.36, p=0.000	r^2=0.40, p=0.000

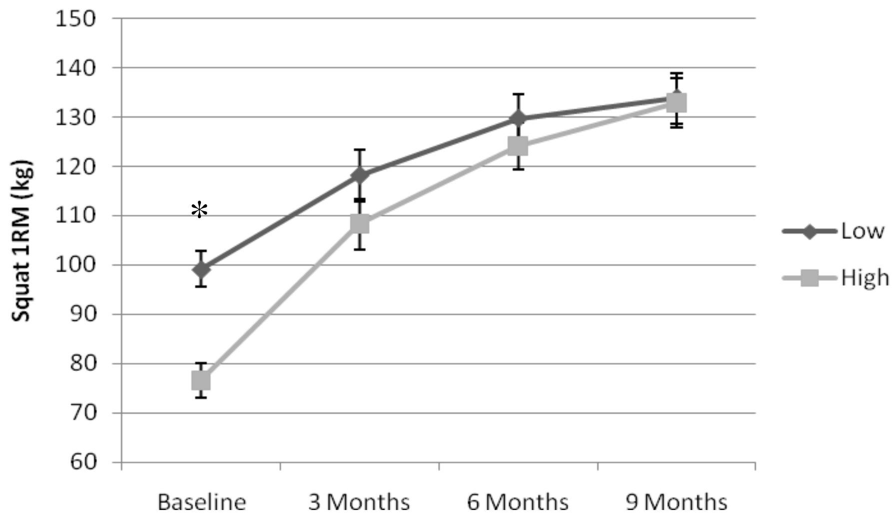

Fig. 4.1 Comparisons of gains in 1RM squat performance across time for both "Low" and "High" gainer groups. There was a significant time by performance group interaction for squat (F(3,93)=13.130, p=0.000). The rate of change differed between the groups only between baseline and 3 month testing.

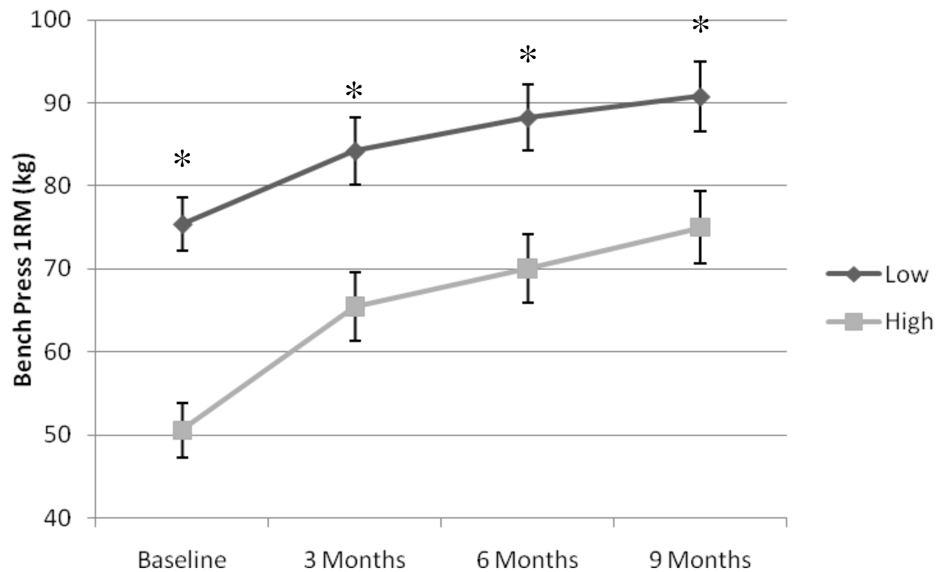

Fig. 4.2 Comparisons of gains in 1RM bench performance across time for both "Low" and "High" gainer groups. There was a significant time by performance group interaction for bench press F(3,93)=5.245, p=0.002). The rate of change differed between the groups only between baseline and 3 month testing.

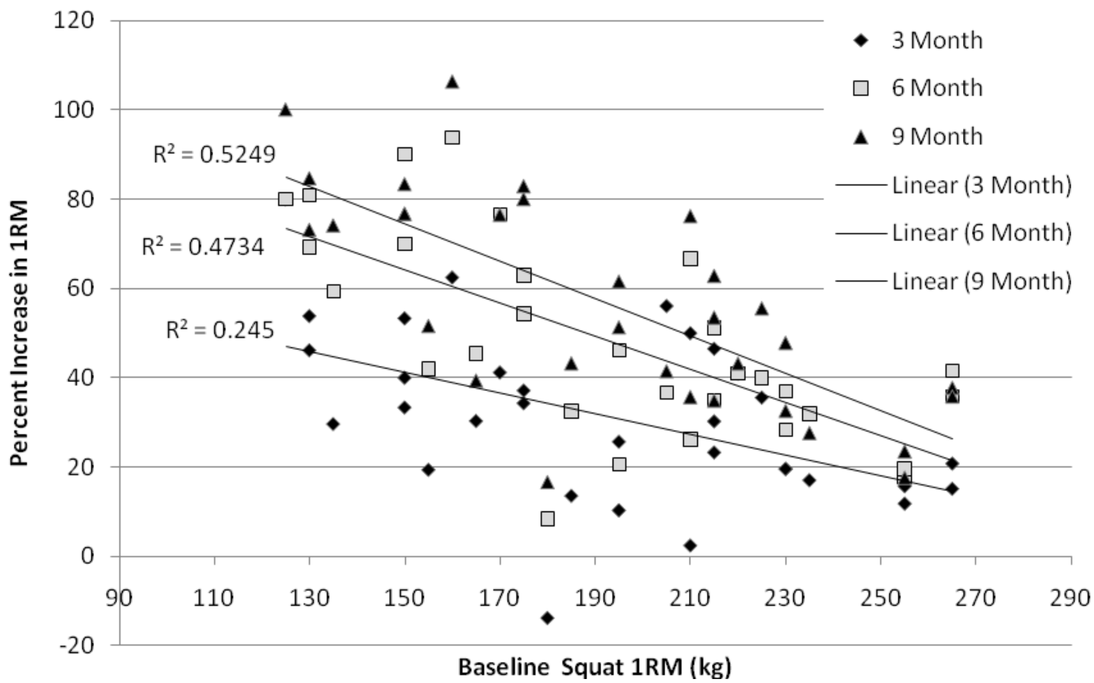

Fig 4.3 Correlations between baseline strength and percent increase in strength over 3, 6, and 9 months for squat

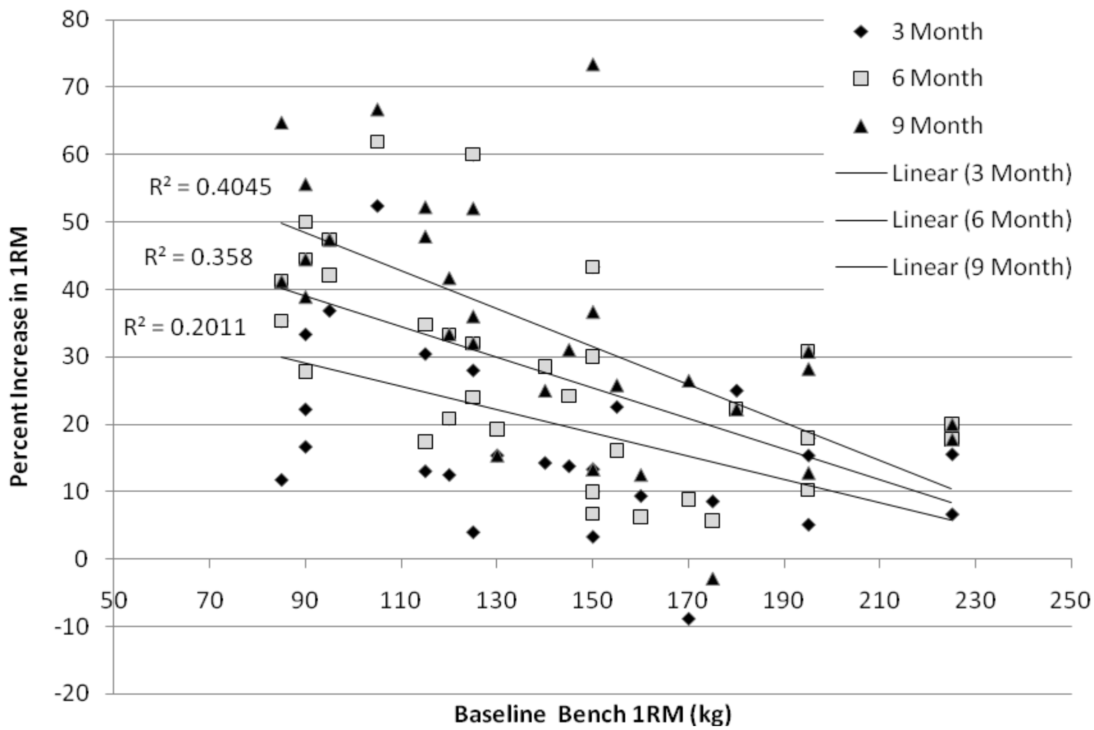

Fig 4.4 Correlations between baseline strength and percent increase in strength over 3, 6, and 9 months for bench press

CHAPTER FIVE

DISCUSSION

The purpose of this study was to compare the strength gains of "High Gainers" versus "Low Gainers" resistance untrained men over the course of a 9 month training protocol as measured by squat and bench press. Our focus was to track the rate of strength gain these two groups made in relation to each other over the course of 9 months and the relationship between baseline strength and 9 month testing strength should one exist.

The primary finding of this study is that those individuals that started weaker in both squat and bench press tended to gain more strength than did those individuals that started stronger. This can be seen by group in Figs 4.1. and 4.2 as well as by individual in Figs 4.3 and 4.4. Furthermore, significant differences in squat strength between groups existed onky at baseline and were eliminated by 3 month testing. As Figs 4.1 and 4.2 shows, between group differences in strength for both squat and bench press lessened with time over the course of the study. On average, "low gainers" started the study about 25 kg stronger than "high gainers" in both squat and bench press. By the end of the 32 weeks, "low gainers" were only 1 kg stronger on average than "high gainers" in squat and only 16 kg stronger in bench press. What figures 4.1. and 4.2 show is that while both groups start at distinct levels of strength, with training experience they trend towards becoming one indistinguishable group.

As mentioned earlier, there are several genetic factors that determine strength levels; some are fixed and others are malleable due to environmental factors (8)(4)(19). As Tables 3.1 and 3.2 exhibit, the characteristics of both subject groups (for both bench and squat) are homogenous in comparison to each other, and very close to the characteristics of the average American male with both the heights and weights of the subject mean being very close to the national 50th percentile for age group (13). The similarities between groups and the closeness to normalcy in combination with converging strength profiles at the conclusion of 9 months suggest a single population or group with baseline strength discrepancies possibly explained by trainable genetic factors manifested by previous environmental conditions.

It has been established in the literature that humans have finite adaptational resources as it pertains to strength and this genetic window of opportunity gets progressively smaller with resistance training experience (7)(15)(1). This is why an untrained individual can expect a 40% gain in strength from a well designed resistance training program whereas a trained individual can only expect a 16% gain and an elite trained individual a 2% gain (15). It is possible in this study that the "Low Gainer" group had already utilized a portion of their adaptational window through environmental factors. This is supported by the fact that "Low Gainers" were the stronger group at baseline and throughout the study for both squat and bench.

In further support of this proposed explanation is the trajectory of gains both groups made in relation to each other, particularly in the first 3 months of the study and the last 3 months. It was the initial 3 months of the study in which the rate of strength gain differed most between groups for both squat and bench press. For the squat, the only time point with significant differences in strength between groups was baseline. It has been shown that the initial phases of a resistance training program offer the greatest opportunities for strength gain with 10% increases of strength not being uncommon after 2 weeks of hard training (7). If the “Low Gainers” group had utilized some of their adaptational resources through environmental factors pre-baseline, it is likely they would have not re-experienced the same magnitude of beginners gains and therefore not made as large overall gains in the first 3 months of training. This concept of previous utilization of environmental factors in the “Low Gainers” group may also explain the lack of significant gains made by this group over the final 3 months of training. The plateauing phenomenon seen by “Low Gainers” is supported in the literature by the concept of decreased gains with training experience until a plateau is reached as the genetic limit is approached (7, 15)(15). As Figs 4.1 and 4.2 show, both groups appear to be making less gains with time as expected, but it is the “Low Gainers” group that is plateauing faster, perhaps because pre-baseline factors have them closer to their genetic limit.

It is possible that individuals in the “Low Gainers” group tended to have utilized some of their adaptational resources pre-baseline due to environmental factors. Of these factors, previous training experience as well as job type and lifestyle all possibly further affected by nutritional intake may have played a part (18) (BERGER) (2). While one of the inclusion criteria for participation in the study was untrained status, our lab classifies untrained as not having participated in resistance training for the previous 12 months. It is possible that both residual neurological and hypertrophic related adaptations from prior training experience account for the increased level of strength displayed by the "Low Gainers" group at baseline. This is directly supported by research conducted by Staron *et al.* in which untrained female subjects were trained for a period of 20 weeks and then detrained for the following 6 months (18). Staron determined that while significant decreases in both strength and muscular cross sectional area took place as a result of detraining, neither strength nor cross sectional area returned to baseline measures. This is in partial agreement with Berger *et al.* who trained men for 6 weeks and then detrained them for a year and found that 50% of the previous strength gain was retained through the period of detraining (Berger). Both works support the notion that detrained individuals do not return to baseline levels of strength, even after minimum periods of 6 months or a year. In addition to formal resistance training experience, resistance training adaptations may have occurred pre-baseline due to the physical demands of work (i.e. physical labor such as construction) or lifestyle (active versus sedentary, type of physical activities).

The major limitation of this study is a lack of insight into subject pre-baseline strength training experience. Furthermore, while subjects filled out a questionnaire quantifying their current physical activity (Table 3.1 and 3.2), this questionnaire did not account for past experiences nor was it focused on activities that could directly or indirectly result in strength training adaptations in this population. In addition, subjects were asked to continue with their pre-baseline level of physical activity over the course of the study, so differences inherent to these activities as well as their duration and intensity could have influenced strength gains.

In conclusion, the data from this study suggest that members of a homogenous population of young untrained males will tend to trend towards similar levels of strength at the end of longer term training regardless of their baseline strength levels. This study is also in agreement with previous work that shows a plateauing of strength gains with training experience and supports the overall concept of a finite genetic window of strength adaptation (7)(15).

Practical Applications

The findings of this study may be useful for the strength and conditioning practitioner when setting expectations, planning resistance training goals, and evaluating training programming efficacy for novice young adult males. The major finding of this study is that although individuals within this specific population may start a resistance training program with different levels of strength, over time these discrepancies tend to trend towards zero. When the major finding of this study is combined with previously established curves of strength gains over time (also confirmed in this study) (14)(15), practitioners should be able to use these tools to accurately predict strength gains over time for their clients, as well as assess the quality and efficiency of their training program post-training.

Appendix A

Consent Form for Participation in a Research Project

University of Connecticut

Principal Investigator: Jeff S. Volek and William J. Kraemer

Study Title: The effects of supplementation on responses to resistance exercise

Invitation to Participate

You are invited to participate in this study designed to examine the effects of dietary supplementation with protein versus carbohydrate on responses to resistance training. Resistance training is well known to result in increases in muscle size and strength, but the effects on other health related markers are not as well studied. This project will examine how diet and supplementation with protein and carbohydrate alter responses to 9 months of resistance training in healthy men and women.

Description of Procedures

This research study will take place at the University of Connecticut (UConn) in Storrs and will last approximately 9 months. For this study, you will be required to follow a specific diet and supplementation program and perform resistance training in our facility three times per week for a nine month period. This is specifically what will happen during the research study:

Screening Visit: You will initially be screened, which will include assessment of your medical, nutrition, dietary supplementation, menstrual, and exercise history. We will also determine your height, weight and blood pressure. This visit will take about 30 minutes. We are looking for men and women between 18 and 35 years of age who have not been regularly participating in a high intensity resistance training program. You will be excluded if any of the conditions below are true:

Exclusion Criteria:
1) You have partipated in a resistance training program within the last year.
2) Your body weight is more than 320 pounds.
3) Your blood pressure is more than 150/95.
4) You have diabetes.
5) You regularly use tobacco products.
6) You take cholesterol lowering or blood pressure medications.

7) Your have lost or gained more than 7 pounds in the last 3 months.
8) You are taking anti-inflammatory medication (aspirin, NSAIDs).
9) You consume alcohol more than 3 drinks/day or 18/week.
10) You are pregnant or intend to become pregnant during the 9 mo study period.
11) You have an abnormal menstrual phase.
12) You have an allergy to whey or soy protein.

If you qualify based on the screening visit, we will schedule you for testing. There are a series of tests we will conduct before you start the diet and training portion of the study in order to determine your baseline fitness level. These tests are listed below followed by a brief description of the procedures we will use. We should be able to complete all these tests in three separate visits, but we may need to schedule additional visits depending on your availability.

Testing Measures:
All these tests will be done at baseline and 9 mo of diet and training. In addition, some test will be performed at 3 and 6 months as indicated below. Thus, you will be tested on four separate occasions. We will be asking you to fast for about 12 hours overnight before coming to the laboratory for testing. This means no food or drink that contains calories (including coffee) but you should drink plenty of water. We want you to be well hydrated during all tests. You must also avoid alcohol and strenuous exercise for at least 36 hours prior to coming to the laboratory for testing.

Body weight will be measured on a digital scale.

Body composition (fat, lean, and bone weight) will be determined at four times (baseline, 3, 6, and 9 months) using a machine that will expose you to a small amount of X-ray radiation. You will lie quietly on a table while a scanning arm passes over your body from head to toe. You must remain still for about 5 min during this test. A certified X-ray technician will perform the scan. We will also measure the amount of water in your body by placing two electrodes on your arm and leg while you are comfortably lying down. These tests will take about 1 hour.

Muscle shape will be determined with an ultrasound machine at four times (baseline, 3, 6, and 9 months). We will place a small probe on your upper leg in order to capture various images of the underlying muscle and fat tissues. This test will take about 30 minutes.

Resting Blood pressure will be measured at four times (baseline, 3, 6, and 9 months) by putting a cuff around your arm while you are comfortably seated. Resting blood pressure will take about 15 minutes. We will also attach a monitor that you will wear for an entire day during which time blood pressure and heart rate will be electronically recorded. This will give us an indication of your average blood pressure during the day.

Physical performance will be measured at four times (baseline, 3, 6, and 9 months) by having you lift the most weight in a bench press and squat exercise. Following a standardized warm-up, you will be given multiple attempts to lift as much weight as possible in good form on a specialized machine in our laboratory. Using these same movements, we will assess isometric maximal strength. For this test, you will press up against an immovable bar as hard as possible while we measure your force output. Muscle power will be assessed in the same movements (squat and bench press). We will load the bar with 30% of your previously determined maximum and ask you to perform the movement in an explosive manner to generate as much power as possible. We will also assess your power by having you jump as high as possible off a force platform while you keep your hands on your waist. These tests will take about 1 hour.

Metabolic rate will be determined twice (baseline and 9 months) early in the morning after you have been lying down on a table for 30 minutes. A ventilated canopy will be placed over your head so we can collect your expired breath for about 20 minutes. The expired breath that is collected will be analyzed for oxygen and carbon dioxide content so that we can calculate the amount of energy (kcal) you are burning. During the test you will be required to rest quietly and breath normally but you will not be allowed to fall asleep. We will also ask you to collect your urine in a container for a 24-hour period starting on the morning of the visit for resting metabolic rate testing. This test allows us to determine how many calories you burn during the day while at rest. This test will take about 1 hour.

Blood will be taken from a vein in your arm to assess resting levels of several health related markers (lipids, hormones, etc.). The amount will be equal to about ½ cup. Thus, over the four visits at baseline, 3, 6, and 9 months we will collect 2 cups of blood total. We will be freezing a portion of your blood that may be used at a later point in time to analyze for specific genes affecting your response to the diet and exercise training. We will not share the results of the genetic analysis with you because they have no direct benefit to you. The blood draw will take about 20 min.

An ***Acute Resistance Exercise Test*** will be performed twice (baseline, 3, 6, and 9 months) to assess how your body responds to an exercise bout. For this test, we will put a flexible catheter into a vein in your arm so that we can draw blood before exercise, immediately after exercise, and 15, 30, and 60 min post-exercise. The total amount of blood during this test will be a little more than ½ cup. The exercise bout will consist of a warm up followed by 6 sets of 10 maximal repetitions of squat. This test will only be done at baseline and after 9 months of diet and training and will take 90 minutes. Thus, the total blood from these tests will be one cup. The total amount of blood collected during the whole study including the resting blood will be a little more than 3 cups.

Supplementation and Diet Assignment:

After baseline testing, you will also be randomly (like pulling a number out of a hat) placed into one of 3 groups. You may also request to be in a control group that only performs the testing described above but does not participate in the supplementation and resistance training.

1. Carbohydrate Supplementation + Resistance Training

2. Whey Protein Supplementation + Resistance Training
3. Soy Protein Supplementation + Resistance Training

Depending on your group assignment, you will be provided with a 2-week supply of the supplements and instructed to consume one serving per day with breakfast on non-training days and immediately after exercise on training days. Each serving contains about 190 kcal. Since it is critical you take the supplement every day, we will ask you to record the time you consumed the beverage each day on log sheets.

In addition to being randomized to a supplementation group, we will counsel you to follow a diet that is designed to meet your caloric needs and that contains a specific amount of protein that should remain constant over the 9 months. The diet will follow general diet guidelines (55-60% carbohydrates, 15-20% protein, and 25-30% fat) emphasizing restriction of saturated fat (<7%) and cholesterol (<300 mg/day). Counseling will focus on making healthy carbohydrate choices, encouraging whole-grain products, fruit and vegetable intake, and lean protein sources.
In order to help you with the diet and monitor compliance, we will ask you to complete a 5-day food record every month. You will be given a small scale to weigh food and specific instructions on how to complete the food logs. We will also ask you to attend regular nutrition meetings one time every two weeks. One of the meetings will be a group meeting and the other a one-on-one meeting with one of our study nutritionists. During the meetings, we will provide you with specific diet advice to help you follow the appropriate guidelines and enhance motivation. We will give you educational materials and counseling regarding the diet including specific lists of appropriate foods, recipes, and example meal plans to help you with the diet. To help with motivation and nutrient assessment, we will be providing you with a Personalized Digital Assistant (PDA) with Palm operating system that has nutrient analysis and graphing software. You will be asked to record the food you eat during a 5-day period each month of the study using the PDA. We will provide you with specific training to make sure you feel comfortable with the software and operation of the device.

Resistance Exercise Training:
All groups will perform resistance training. Training will occur three times per week. We will have designated times you can come to our facility in the Human Performance Laboratory. All sessions will be supervised by a certified personal trainer (CSCS). The program will include a variety of exercises to stimulate major muscle groups and provide variation. The entire workout will take approximately 1 hour.

<u>Risks and Inconveniences</u>

<u>Supplementation Protocol.</u> You should not be in this study if you have any major medical problems. If you are unsure, discuss your health history with the Principal Investigator. There are very few potential risks associated with the procedures used in this study. You should inform us if you have an allergy to soy or whey protein in case you are selected to be in one of these supplementation groups.

Blood Draws. Blood draws with a needle may cause discomfort at the puncture site and the development of a slight bruise. You may also experience lightheadedness or fainting during the blood draw. There is a slight risk of infection from these procedures. All possible precautions to avoid infection will be taken including use of sterile disposable needles, drapes and gauze and the practice of aseptic techniques during blood sampling. All blood samples will be obtained by trained people. You should refrain from giving blood during the course of the study.

Body Composition. You will be exposed to a very small amount of radiation by the scanner used to measure your body composition. Exposure to any amount of X-ray radiation, no matter how low, may cause abnormal changes in cells. However, the body continuously repairs these changes and the amount of radiation is very low in this study. The total exposure for a whole body scan is approximately 125 times less than the average radiation from a standard chest x-ray. Thus, the radiation levels are extremely low and the health risk minimal. We don't know what effect the radiation could have on an unborn baby so pregnant women should not be in this study. As a precaution we will ask women to take a urine pregnancy test before the scan. For the muscle shape measures, there are no known harmful effects from the use of ultrasound.

Resistance Training and Testing. Even though the resistance exercise program and testing protocols are designed to be safe, there is the risk that you may become injured. The researchers have an extensive experience in conducting short-term and long-term exercise studies, and they will do everything possible to reduce the chance of injury. Every effort will be made to make the study safe by proper supervision of proper technique during testing and exercise sessions. However, if you experience pain, unexpected discomfort, soreness, headache, loss of concentration, dizziness, vomiting, unusual fatigue or difficulty breathing you should immediately inform one of the supervising members of the research team, who will bring this to the attention of the principal investigators and the medical monitor. The performance of resistance exercise can entail a certain degree of risk from overexertion and/or accident. There are minimal risks for muscle strains or pulls of the exercised muscles. In very rare cases you can experience muscle spasms or tears. Some muscle soreness may be experienced 24 to 48 hours after exercise and this should completely subside with a few days and have no long-lasting effects. The risk of heart attack, although very small, does exist. The chance of any of these events occurring will be minimized by our screening, selection and monitoring procedures, and by the use of properly conducted research procedures. All the research team members are currently certified in CPR.

Urine Collection: There are no risks associated with the 24 hour urine collection, but this may be inconvenient for you. We will provide you a container that you will be asked to collect all your urine for entire day. You should keep the container refrigerated during the collection period.

Genetic Testing. It is not the purpose of this study to look for or provide you with any medical information or diagnoses relating to your present condition or any other disease or illness. Thus, we will not share the results of the genetic analysis with you. The risks associated with this study are mainly psychological and social. You might worry about having a possible genetic disorder. Although unlikely, there is a possibility that incidental findings might be made such as your risk for a certain disease. Your gene results could be used against you if some of these genes are ultimately shown to predict future disease. This could lead to discrimination, potential loss or difficulty in obtaining employment or insurance. For this reason, your DNA sample will be identified by a code number, and all other identifying information will be removed. The Principal Investigator will keep a code sheet which links the sample code number with your name locked separately and this will be destroyed after two years. This information will not be disclosed to third parties except with your permission.

Benefits

The results of this study will help to determine the role protein supplementation has on responses to weight training and general health, and therefore contribute to a better understanding of dietary recommendations to enhance health. You will be provided with a facility to train under supervised conditions for 9 months during the study. You will also learn your body composition and will most likely improve your fitness and health status.

Economic Considerations

If you complete all training and testing you will receive a stipend of $400 at the end of the study. The stipend will be prorated if you do not complete the study: $50 after completion of baseline testing, $100 after completion of 3 month testing, and $100 after completion of 6 month testing.

If you are selected for the control group that only performs testing (no training) you will receive $200 for completion of all testing sessions. The stipend will be prorated for those who do not complete the study: $25 after completion of baseline testing, $50 after completion of 3 month testing, and $50 after completion of 6 month testing.

Confidentiality

All the data collected will be kept for a minimum of five years and remain confidential and you will never be identified by name in any reporting of results. Further, the results will not be shared with any person outside the investigation without your consent. The results of this study will be kept in locked cabinets under the supervision of Dr. Volek and Dr. Kraemer. You should also know that the UConn Institutional Review Board (IRB) and the Office of Research Compliance may inspect study records as part of its auditing program, but these reviews will only focus on the researchers and not on your responses or involvement. The IRB is a group of people who review research studies to protect the rights and welfare of research participants.

Confidentiality of your genetic information will be of high priority to protect the DNA samples from falling into unauthorized possession. All blood samples for gene testing will be identified by a code number, and all other identifying information will be removed. The code number will be linked to the physiological data already obtained from you. The genetic information will be kept at a separate facility where the genetic testing will be done. This information will be kept electronically and/or in locked files. The code sheet which links your sample code number with your name will be kept in a locked file and office in a different location at the University of Connecticut. This information will be in hard copy form only and not electronic. The code sheet will be destroyed after two years. Your genetic information will not be disclosed to third parties except with your permission.

In Case of Illness or Injury

In the event you become sick or injured during the course of the research study, immediately notify the principal investigator or a member of the research team. If you require medical care for such sickness or injury, your care will be billed to you or to your insurance company in the same manner as your other medical needs are addressed.

If, however, you believe that your illness or injury directly resulted from the research procedures of this study, you may be eligible to file a claim with the State of Connecticut Office of Claims Commissioner. For a description of this process, contact the Office of Research Compliance at the University of Connecticut at 860-486-8802.

Voluntary Participation

You do not have to be in this study if you do not want to. If you agree to be in the study, but later change your mind, you may drop out at any time. There are no penalties or consequences of any kind if you decide that you do not want to participate.

Do You Have Any Questions?

Take as long as you like before you make a decision. We will be happy to answer any question you have about this study. If you have further questions about this project or if you have a research-related problem, you may contact the principal investigator, Jeff S. Volek at 860-486-6712. If you have any questions concerning your rights as a research subject, you may contact the University of Connecticut Institutional Review Board (IRB) at 860-486-8802.

Authorization:

I have read this form and decided that ________________________________ will
(name of subject)
participate in the project described above. Its general purposes, the particulars of involvement and possible hazards and inconveniences have been explained to my satisfaction. My signature also indicates that I have received a copy of this consent form.

____________________ ____________________ __________
Participant Signature: Print Name: Date:

Relationship (only if not participant):_______________________________

- I agree that my blood sample may be used for gene testing in this study:
  Initials of participant: _____ YES or _____ NO

- I agree that my blood sample and gene data may be used for unspecified future studies:
  Initials of participant: _____ YES or _____ NO

____________________	____________________	__________
Signature of Person Obtaining Consent	Print Name:	Date:

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