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A Series of Studies—The Physiological Basis for Strength Training in American Football: Fact Over Philosophy

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ABSTRACT

The purpose of this series of investigations was to gain insight on resistance training in American football and address some of the myths. Many theories about resistance training have been proposed, yet there has been little if any research on some of these training philosophies. This series of studies represents an accumulation of data that helped to formulate a training approach. Rather than having a training *philosophy*, it might be more productive to have a training *approach* based on facts and critical monitoring of test variables representative of the physical development possible through strength and conditioning programs. It was demonstrated that football players are capable of multiple maximal efforts in resistance training and that the length of the rest period was a determining factor. In general, multiple sets and various periodized training programs were superior to single-set programs in the rate and magnitude of improvements in body composition, strength, local muscular endurance, and power. Such data indicate that for building programs in previously trained football players, multiple-set programs that provide variation are more appropriate.

Key Words: periodization, single sets, high intensity training, local muscular endurance, multiple sets

Introduction

Having started my career as an undergraduate laboratory research assistant, I was always interested in the data on how to strength train for football. My interest in football arose from my participation as a player, football coach, and strength coach. The view of these data is now framed by scientific training and a longer historical perspective on the scientific study of resistance training. This series of studies represents a data base I accumulated over many years as a football coach and strength coach. The purpose of this series of studies was to go back and do a more formal analysis of the data and reexamine some of the questions that seemed important in years past. While for me the answers were initially determined through my role as a coach, I feel that even greater perspective, context, and meaning can be gained from publishing these results now in the hopes they may benefit football coaches, strength coaches, and sport scientists. These data may help provide insights and perspective for strength training in American football.

Historical Perspective

It is important to briefly discuss the evolution of strength training in American football and its impact on the context of training philosophies in the sport. Football is the least studied sport in the U.S. today. We have very little direct scientific evidence on the physical demands of the sport, the recovery process, or the effects of long-term participation. The reasons for the lack of direct research on a sport that is one of the leaders in revenue generation remain unclear. Research on the training related aspects of the sport also remains indirect and speculative, due to the fact that the subjects are typically untrained men and not football players.

In hindsight, I now understand that the difficulty of approaching football through a scientific perspective is that football coaches and strength coaches are not scientists. Yet one must certainly respect the scholarly approach taken by various strength coaches today in the attempt to give their players the best program possible. Conversely, many scientists have never been coaches or have never been involved with weight training. In addition, science rarely yields quick answers that immediately lead to wins on the field. The impatience with science is also promoted by the "just win, baby" attitude that appears to be supported by university administrators. Thus, science can be too slow to satisfy coaches who are mostly worried about the upcoming game or season.

From the perspective of resistance training, one must also remember that it is only one factor in the whole process of player development, and while it is important, other factors are also involved with the success of a team (recruiting, team tradition, skilled coaching, nutrition, academic counselors, etc.). The key to the proper use of sport science in strength training for football is related to the evaluation and development of the players' physical abilities and the prevention of injuries. It is hypothesized that the increases in critical physical abilities of the football player will result in enhanced performance as well as enhanced physiological adaptations of tissues to prevent injury (11).

American football has played a major role in providing the fertile soil that gave rise to the strength and conditioning profession in college and university athletic departments across the U.S. Most strength and conditioning coaches came from backgrounds in track and field and American football and had experience in weight training or lifting (48). It was American football that first gave the strength and conditioning profession the exposure it needed on the national level. The development of the strength coaching profession was formalized with the birth of the National Strength Coaches Association in 1978 (today, National Strength and Conditioning Association).

Football coaches had an inherent interest in weight training due to the perceived benefits of increased size, strength, and speed that a strength training program might produce in their players. However, many head football coaches had little if any real understanding about the techniques of strength training, due primarily to a lack of exposure in their playing and coaching careers from the 1940s through the '70s. Many of them were turned on to this type of training by other coaches or by former football players, track and field athletes, or "lifters" who promoted the benefits of strength training in the hope of finding a niche for involvement with the team. Today almost all head strength and conditioning coaches are men who have had experience as former football players and/or lifters; thus has the profession evolved (48).

In the 1960s and '70s, facts from scientific research to support conventional lifting protocols were hard to find as to what worked best for football strength training programs. First, only a handful of studies had been published and most of them had used untrained college-age students (5–8, 43; for extensive reviews, see Refs. 2 and 11). Second, only partial training programs were typically examined in these studies such as the bench press or squat, outside the context of a total resistance training program. Third, only short-training durations were examined (4–8 weeks), which made it difficult to determine whether there were differences among the programs. Finally, the programs examined were very conservative—a far cry from what was being used by football teams or in competitive training protocols around the world (11, 33, 38, 59). Thus strength coaches had to rely on their observations in the weight room and on personal lifting experience as to what seemed to work best. Their need for more understanding led many strength coaches to look for scientific data to support the approaches they used in training their athletes.

In the 1970s the pseudo science and marketing claims about weight training equipment and the associated philosophies to sell that equipment started to influence the decisions of strength coaches hungry for information. Often it was easier to sell a single answer to address all training needs. It became obvious to many that, while attractive, no one approach would work for everyone for all times; thus the principle of training variation as developed by various periodization models became an important concept in year-round training (10, 38, 54, 58). It also became apparent that programs would have to be individualized no matter what approach was used at the beginning.

Many times the training programs used and their factual efficacy remained relatively unknown except for the personal convictions of the coach. If a team was winning with a certain type of "strength training" program, it continued based on pure football coaching instincts: you go with what works! Yet in reality the physical development related to a strength training program may or may not be related to a team's success. Success on the football field might well have been due to a host of other factors including the genetic component of the players and the coaching staff's choice of offense or defense style.

To date there are no scientific data on the relationship between a team's weight training program and its win–loss record. This is due to the impossibility of isolating such causal effects in an experiment. However, there are data analyzing the relationships between measures of physical development (e.g., strength, speed, power) and the level (Div. I, II, or III) a player participates in and whether or not he is a starter on the team (12). Whatever the source, then, it appears that physical size and performance play an important role in a player's success. Still, the contribution of genetics, training, psychology, or other factors remains unclear, yet very important in any discussion. Thus we are left to examine the effectiveness of training programs on measures of physical ability and to determine whether a program can improve it. It is thought that enhanced physical development will help the football player perform better and without injury.

For the strength and conditioning specialist, it is important that the strength program used be judged primarily on its effectiveness in developing the individual player for specific physical characteristics or testable goals of the program, not on wins and losses. Thus a reliable and appropriate testing profile needs to be developed and incorporated into every football program, because without such information it is impossible to evaluate the effectiveness of changes in a player's exercise prescription.

However, problems have haunted this process for years. Testing information has been misused by football coaches (e.g., making comparisons of bench press strength to what another coach says his team can do), the sports media (e.g., publication or mention of a few isolated tests for good players and assuming this is the sole reason for their success), and strength coaches (e.g., focusing on one variable rather than a host of variables which differ in their progression and goals for each player based on analysis) (32). Time, limited numbers of strength and conditioning staff, and large numbers of players to be tested have also made for less than optimal practice of exercise prescription in the weight room.

The most common question asked of a strength coach over the years has been, "What is your philosophy?" Rather than, "What is the factual basis for the training program each athlete is performing?" The most important point to understand is this: If one simple system of X sets and X repetitions worked for all players at all times throughout their careers, and it was that simple to do, the strength coaching profession would not be needed. Too often football coaches want simple answers to very complex questions, and there are none. If you do it right, training football players is an exhaustive and tedious process of continual assessment, changing of programs, motivation, and education for players and coaches alike.

Therefore, scientific study of the training programs used by football players can only comment on the "big picture" principles, and such information can be used to point the development of a program in a general direction. But the day-to-day and step-by-step changes in the exercise prescription involving choice and order of exercises, number of sets, level of intensity, and length of rest period between sets and exercises remain dynamic even in a developed program for each player. This requires the advanced education, hard work, and experience of a strength and conditioning professional.

The answers are complex, not simple. Player development is individual. That is why we need highly educated and trained strength coaches as the clinical shepherds of player development. It is then up to the strength and conditioning specialist to alter the team approach based on testing data as to what best takes a specific player to a particular training goal (11, 32).

Thus, in this series of studies I attempt to examine some of the "big picture" principles that remain in question even today, in order to point to general program choices related to "building" programs used in American football. *In no way are the exact choices made in these studies the only way to put a workout together.* Rather, they represent the larger context of a style of training used for comparison purposes. I hope that such data that was informative to me at the time and helped contribute to my understanding of general constructs of training theory in American football will be helpful to others and represent a glimpse into the evolution of the strength and conditioning field over the past 20 years.

EXPERIMENT 1: Can More Than One Set be Performed at 10-RM Load?

One philosophy that started in the 1970s was the idea that a person can only perform one set to failure or with maximum effort. If this were true, then one might question the benefit of multiple sets for strength development. Thus the purpose this experiment was to determine whether one could perform more than one set to failure with the same load, and what factors, if any, contributed to reductions in repeated performance.

Methods

To test this hypothesis, 20 Div. I football players (age 21 ± 1.3 yrs; height 185 ± 3.9 cm, body mass 115 ± 30 kg) who had been participating in regular in-season and off-season training programs involving multiple sets with heavier loads and 2–3-min rest periods for at least 2 years volunteered and gave informed consent to participate in this project. According to methods published in detail elsewhere (30), a 10-repetition maximum (RM) was determined in the bench press (free weights) and leg press (Nautilus) as "marker" exercises for upper and lower body movements. Test-retest intraclass reliabilities for the tests were $R \geq 0.96$. Bench press and leg press exercises were tested on separate days. Players were given 3 min rest between sets and were asked to lift their same 10-RM load for 3 sets with 3 min rest between sets. The same tests were repeated on separate days using only 1-min rest periods.

ANOVAs with repeated measures were used to analyze the data with Tukey post hoc tests when appropriate. Significance was set at $p \leq 0.05$.

Results

Each player was able to perform 3 sets of 10-RM with 3 min rest between sets for both the bench press (mean ± *SD*, 141 ± 55 kg) and the leg press (225 ± 90 kg). When rest was reduced to 1 min, the mean number of repetitions were: Set 1 = 10 ± 0, Set 2 = 8 ± 1.4, Set 3 = 7.1 ± 3.5. A significant reduction in number of repetitions with the same absolute 10-RM load was observed when rest was reduced to 1 min. It appears that the length of the rest period is the crucial variable in the determination of lift performance with multiple sets.

Discussion

A prior study by Kraemer et al. (35) showed that power lifters who were not accustomed to short rest protocols dramatically dropped off in the load used for their 10-RM over 3 sets whereas bodybuilders who trained with short rest periods had a much lower % dropoff, even with only 30 sec rest between sets. In the present study the load was kept constant and the repetitions were used to indicate performance. The football players had never used short rest periods in their training.

Kraemer et al. (31, 34) demonstrated that lactate concentrations were lower (under 4 mmol · L^{-1}) when 3-min rest periods were used in a total body protocol consisting of 3 sets each of 8 exercises using 10-RM loads. When 1-min rest periods were used for the same workout, the increases in blood lactate concentrations were 3- to 8-fold higher (31, 34). It appears the ability to reproduce a 10-RM set is based on several factors including the ability to buffer acid, recover energy stores (ATP), and tolerate the protocol psychologically (14, 57). Ultimately, maximal effort can be reproduced if adequate rest is allowed. Thus it might be proposed that one can be trained to handle more weight with less rest between sets (11).

Practical Applications

From this study it was determined that even when performing sets to failure, multiple sets are possible if enough rest is allowed. With shorter rest periods, some time (e.g., 6 to 8 wks) is needed in progressively reducing the duration of rest intervals to allow for the necessary changes in acid-base buffer mechanisms, energy recovery, and psychological toleration. Being able to produce more force with less rest between efforts may be a training goal if no-huddle offenses are used or if better recovery between plays run in a series are strategically important.

EXPERIMENT 2: One Set Circuit vs. Multiple Set Circuit

In the 1970s circuit training was very popular, even for football teams, since large numbers of players could be trained by one coach (13). The concept of using one circuit with each set performed to failure also started becoming popular in the mid-1970s. The so-called Nautilus Express Circuit approach was thought to be a way to save time while making dramatic gains. With NCAA training-time constraints in the 1990s, some coaches still see single-set protocols as a way to save time and get the same results as multiple-set programs. The purpose of this study at the time was to compare a multiple-set circuit to a single-set circuit for changes in strength and local muscular endurance over a 10-week spring training program.

Methods

Forty Div. I football players (20 ± 2.3 yrs, 187 ± 5.9 cm, 125 ± 30 kg) were matched for position, starting strength, training background, age, and body size. They were randomly placed into one of two training groups, 20 per group. Players were tested as part of their athletic training program and gave informed consent. They were tested prior to an off-season training program and again after a 10-week training program.

Exercise and Testing Protocols

All players had participated in an in-season weight training program 2 days a week up through November; their off-season program ran from mid-January to the start of spring football. Training took place 3 times a week. Players in the single-circuit group (SSC) performed 8- to 12-RM to failure (with forced reps at the end) on each Nautilus machine in circuit fashion with 1-min rest between exercises. Exercises in the circuit consisted of the leg press, bench press, chest flys, lateral raises, military press, knee extensions, leg curls, biceps curls, calf raises, and lat pullovers. Resistance for an exercise was increased when a player could do more than 12 reps.

The multiple-set circuit group (MSC) performed 3 circuits using the same protocol as the SSC group: 8- to 12-RM loads (no forced reps) with 1-min rest between sets and exercises. None of the subjects suffered any injuries that would make them stop participating in the training program. Compliance was 100% for both groups.

Maximal 1-RM strength tests for the bench press and leg press were used as markers for upper and lower body strength according to previously reported methods and weight determinations for Nautilus machines (31, 35). Relative strength tests at 80% of 1-RM for the bench press and 85% of 1-RM for the leg press were also determined (30). Test-retest intraclass reliabilities were $R \geq 0.96$ for all tests performed.

A MANOVA was used to analyze the data with Tukey post hoc tests when appropriate. Significance was set at $p \leq 0.05$.

Results

The results of the relative tests and the1-RM strength tests are shown in Table 1. For the relative strength tests, the MSC group demonstrated significant increases from pretraining values which were significantly greater than those of the SSC group. For both 1-RM strength markers, the MSC demonstrated significant increases in 1-RM strength pre- to posttraining, and the magnitude of increase was greater than for the SSC. The SSC demonstrated an increase in bench press and leg press strength.

Discussion

The primary findings of this experiment were that after an in-season program, football players who performed a multiple-set circuit training protocol increased in both 1-RM strength and local muscular endurance at a greater magnitude than the SSC group. The SSC demonstrated increases that for the previously trained football players acted like a maintenance program for local muscular endurance. The larger increases in strength and local muscular endurance for the MSC could well be related to the adaptation of acid base mechanisms that allow for greater toleration of heavier RM loads over the training period (35). Their greater adaptational response may also have been related to a greater anabolic hormone response.

Table 1
Results of Relative and 1-RM Strength Tests

Group	Pretraining *M*	Pretraining *±SD*	Posttraining *M*	Posttraining *±SD*
No. of reps @ 80% 1-RM in bench press				
SSC	11.1	2.2	12.2	3.2
MSC	11.5	2.6	15.2	2.8*†
No. of reps @ 85% 1-RM in leg press				
SSC	12.1	2.3	13.6	3.6
MSC	12.6	3.6	17.1	2.2*†
1-RM strength test for bench press (kg)				
SSC	145	87	151	78*
MSC	143	95	161	96*†
1-RM strength test for leg press (kg)				
SSC	176	39	181	35*
MSC	175	43	208	44*†

*$p < 0.05$ from pretraining value or corresponding pretest;
†$p < 0.05$ from SSC group.

Gotshalk et al. (15) observed higher levels of testosterone and growth hormone for 1 hour into recovery when a 3-set vs. a 1-set protocol was used with 1-min rest periods.

These data contradict the findings of Ostrowski et al. (44) but agree with those of J.B. Kramer et al. (37) on the magnitude of strength gain with multiple-set or multiple periodized set resistance training. One can speculate that differences may be due to a wide array of experimental controls and design factors, for example, the athlete's training level, number of times a week each exercise was addressed in the training protocol (3 in the present study, once in the Ostrowski et al. study, 2–3 periodized in the Kramer et al. study), number of weeks training, or design factors of the protocol used (circuit, short rest, load variation, etc.).

It could be that in the Ostrowski et al. (44) study the limited training exposure of the tested exercise movement (once a week) may have contributed to the finding of no differences over a short-term 10-wk training program between low and high volume resistance exercise workouts in moderately trained individuals. For all the dramatic claims of superiority of single-set systems published in the lay press, the best that can be supported by fact is no difference over short training periods under one set of experimental comparative conditions (44, 45, 51, 56), whereas distinct superiority has been demonstrated repeatedly for multiple-set systems (37, 53, 55, 59).

The use of 1-min rest periods with the MSC also may have enhanced acid-base buffer mechanisms which allowed for greater loads to be lifted in training and led to greater local muscular endurance (14, 35). It may be that single-set systems can demonstrate strength increases but are less able to get at other adaptational characteristics of muscle in football players who have already achieved a basic strength fitness (about 2 yrs training). SSC demonstrated an increase in 1-RM strength but not in local muscular endurance.

SSC or one-set systems may not be very prolific in increasing the local muscular endurance component of the muscle, due to less total work for a given muscle over a training cycle (2). Anderson and Kearney (1) demonstrated that endurance capability is related to the RM load used in training, and indirectly to the number of repetitions performed in a set. The same training repetition range was used in the present study, but the number of circuits was three times greater with the MSC group. These data indicate that the volume of exercise plays an important role in the magnitude of 1-RM strength gain and local muscular endurance even with short-term training periods.

Practical Applications

If a circuit style program is used, multiple circuits elicit greater strength gains and local muscular endurance. The added value of local muscular endurance as a significant training effect may be important for enhancing a player's ability to recover between plays and produce more force. Volume of total work appears to be important for eliciting further gains in previously trained football players.

EXPERIMENT 3: One-Set Circuit vs. Periodized Multi-Set Power Training

In 1994 Newton and Kraemer (41) gave an overview of the different parts of the power equation and discussed how different factors must contribute to its development. It was called a "mixed model" theory in which strength, rate of force development, hypertrophy, skill, and coordination contributed in different amounts to the development of power. Opponents of such ideas have expressed the notion that one need only develop the force variable in the power equation "force × distance over time" and then the skills practiced in the sport will enhance the power. However, it is typically impractical to load the muscles in sport movements. Furthermore, the idea advanced by some individuals was that this could be done with the use of non-explosive isolated-joint machine exercises.

Studies had shown that with heavy weight training, the rate of force development would not change in the very rapid portion of the force time curve of 200 msec or less (17, 18, 20). The concept that explosive exercises were dangerous was developed in the early 1970s and for the most part was based on marketing approaches for machines, but no such data existed. When resistance training has been properly performed, injury to football players has in fact been shown to be very low (61).

In a recent study, Newton et al. (42) showed that exploding with an exercise movement using light loads (45% of 1-RM) that required one to hold on to the accelerating mass would be detrimental to power generation. Therefore it is prudent not to perform such "speed movements" with certain exercises in which the joint would suffer if the weight were not decelerated over the range of motion. Performing speed reps with such isolated joint exercises (e.g., bench press, knee extension, or shoulder press) may well reduce power development, as the body would attempt to slow the mass down prior to the end of the range of motion.

With certain exercises, then, the use of controlled repetitions in these cases made sense and thus as a tool were limited to contributing to the power equation except from just one variable, force. Conversely, movements such as power cleans or many other Olympic lifting exercises gained acceptance as being "power" exercises, as they did not have the problem with protecting the joints since the mass could be accelerated naturally up the linear line of the body (28, 33, 60). Medicine ball exercises also proved useful as the mass could be released, especially in upper body lifts (11). The purpose of this experiment was to compare a single-set machine exercise training protocol to a predominately free-weight periodized resistance training protocol on strength and power development in previously trained college football players.

Methods

Thirty-four Div. III football players (20 ± 4.3 yrs, 184 ± 9.9 cm, 105 ± 26 kg) were matched for position, starting strength, training background, age, and body size; they were then randomly placed into one of two training groups, 17 in each group. All were familiar with all testing protocols and lifts from prior training. Each group averaged 3 ± 1.2 and 3 ± 1.4 yrs of resistance training experience, respectively. Players were tested as part of their athletic training program and gave informed consent. They were tested prior to an off-season training program and again after 7 and 14 weeks of the program.

Exercise Protocol

Training took place 3 times a week. Players in the single-set group (SS) performed 8- to 10-RM to failure (with forced reps) on each exercise, consisting of knee extensions, leg curls, bench press, military press, arm curls, sit-ups, calf raises, leg press, and lat pulldowns. The rest period between exercises was 2 min. Exercises were performed on Universal and Marcy weight machines. Resistance for an exercise was increased when a player could perform more than 10 reps.

On Monday and Friday the multiple-set strength/power training group (MS) performed structural exercises consisting of free weight squats, push press, hang cleans or power cleans, bench press (Universal machine on this one lift for test specificity comparisons), and small-muscle-group assistance exercises (arm curls, hamstring curls via machine, rotator cuff exercises, triceps pushdowns, sit-ups). On Wednesday they performed pulls from midthigh, lunges with dumbbells, and the same small-muscle-group assistance exercises. All assistance exercises involved 2 to 3 sets of 8- to 10-RM.

A classical periodized training protocol of two 7-week cycles was used for strength and power over the 14 weeks. Weeks 1, 2, and 3: 8–10 reps for 2 to 3 sets at loads of 50–70% 1-RM; Weeks 4 and 5: 3 to 4 sets of 6 reps at loads of 70–85% 1-RM; Weeks 6 and 7: 3 to 5 sets of 1–4 reps at 85–95% 1-RM. Length of rest periods depended on the loads lifted with 1–2 min between sets and exercises for assistance exercises, and 2–4 min between sets and exercises greater than 70% 1–RM.

Testing Protocols

Maximal 1-RM strength tests were performed for related training lifts during the training protocol each week or when needed. Due to prior experience, all players were familiar with testing protocols and proficient in all lifting techniques and were allowed to practice prior to testing. The 1-RM was determined for hang cleans from the knees and machine bench press (30). Changes in vertical jump (countermovement and one step) measures were determined using a previously described technique (22). A Wingate test for the legs was also performed using a standard protocol previously described but with only digital counts of each pedal cycle movement (sensitivity of ±0.5 pedal revolutions) (36). Body composition was determined via standard 7-site skinfold technique and % fat was determined via the Siri equation (24, 50). Test-retest intraclass reliabilities were $R \geq 0.96$ for all tests. None of the subjects suffered any serious injuries that would make them stop participating in the training program. Compliance to the training programs was 100% for both groups.

A MANOVA with repeated measures was used to analyze the data with Tukey post hoc tests when appropriate. Significance was set at $p \leq 0.05$.

Results

The results of body composition, vertical jump, 1-RM for bench press, 1-RM for hang clean, and Wingate cycle power output are shown in Table 2.

Discussion

The primary finding from this study was that a periodized MS program focusing on strength and power development is superior to a machine-emphasized SS program in all variables measured. At best the SS acted as a type of maintenance program. The rate of increase was also dramatically greater in the MS program over the first 7 weeks. In the test protocols, every attempt was made to eliminate learning effects that can inflate early phase-training adaptations and add variance to the measures (9). It is quite possible that protocols that find no differences may have problems with error variances, making the sensitivity of the measures between groups difficult at best.

Willoughby (59) had demonstrated in football players that a periodized training program was superior to other constant set/rep multiple-set programs. In addition, other studies using periodized training methods had also demonstrated superior results when compared to lower volume protocols (53–55). Conversely, when

Table 2
Results of Training on Various Parameters

Groups		Pretraining *M*	Pretraining *±SD*	7 Weeks *M*	7 Weeks *±SD*	14 Weeks *M*	14 Weeks *±SD*
Changes in % fat and body mass (kg)							
SS	%fat	17.6	7.9	16.8	6.2	16.1	5.9*
	BM	104.2	24.1	105.2	22.9	105.6	22.2
MS	%fat	18.1	6.2	16.0	5.2*	13.8	4.3*†
	BM	105.3	23.6	107.1	23.4*	109.6	23.2*†
% Changes in vertical jump							
SS		58.42	19.2cm	0.9%	1.2%	3.4%	2.3%
MS		57.92	18.7cm	8.7%	3.4%*†	16.8%	5.3%*†
Changes in machine bench press 1-RM strength (kg)							
SS		117	59	119	29	121	32*
MS		116	54	123	32*†	129	25*†
Changes in hang clean from knees 1-RM strength (kg)							
SS		95.5	62.1	96.8	54.5	98.8	43.1
MS		96.1	54.2	102.2	43.2*†	114.9	34.9*†
Changes in leg Wingate power output (W)							
SS		894	250	901	256	902	256
MS		893	256	960	188*†	1022	166*†

*$p < 0.05$ from pretraining value; †$p < 0.05$ from SS group.

making comparisons using partial programs (1 or 2 exercises) or less frequent exercise exposure (only once a week), generally no differences were seen when comparing 1 vs. 3 sets (44, 51, 56).

This study strongly demonstrated that SS protocols that focus on isolated joint exercises and do not contain the additional elements of the mixed-model theory are not effective in power development, especially in subjects who already have an established strength/power training base. Our program comparison was intentionally striking, and differences in total work and motor recruitment pattern are obvious reasons for the differences observed (16, 25–28). Too often the program comparisons made (e.g., 1 vs. 3 sets of 1 or 2 exercises) are never really used in the field.

It is interesting to note that the superiority of MS training was even observed in the one common upper body test exercise, the machine bench press, and with a nonspecific Wingate power test for the lower body. This supports previous findings for changes in Wingate power measures with a similar type of program (36). Thus such data strongly point to the importance of higher absolute total work volume requirements, velocity of movement, and loading variation in any "building program" directed to power/strength and body composition development, especially when dealing with American football players who have prior training experience (9, 25, 38, 47, 53, 58, 59).

These data indicate that an SS program focused on isolated joint and machine multijoint exercises performed in a controlled manner (2 sec up, 4 sec down) with forced reps does not enhance power development in trained football players. This finding is supported in general by Ostrowski et al. (44). The obvious lack of explosive power exercises in Ostrowski et al.'s program may account for the lack of impact on power development, as the authors themselves stated about their training protocol. In addition, several studies have shown that when power protocols are used, they are superior to conventional heavy resistance exercise using just heavy loads (18, 20, 21, 60). In this study, specific power exercises were included in distinct contrast to the SS protocol to determine whether such an SS program was capable of the claims being made in the late 1970s regarding high intensity training. The obvious answer was no, and this shaped my approach to training for power development in football.

Body composition changes in American football are important because body mass affects success (12). Hoffman et al. (23) showed that aggressive protocols with a high enough frequency of training could alter body composition, but that took 4- and 5-day-a-week programs. J.B. Kramer et al. (37) observed no changes over a 14-week program, indicating that either local muscle changes that did not contribute to whole body changes were made or that neural mechanisms dominated the neuromuscular development over the training period (39, 40, 49).

Our study paid attention to a significant body-building type of protocol, the assistance exercise protocol. While speculative, the weight gain observed may have been due to more total work and greater emphasis on muscle hypertrophy, with the addition of assistance exercises using a body-building protocol throughout the training program. Hoffman et al. (23) had demonstrated the importance of assistance exercises in football training programs in that they appear to improve body composition. This again could be due to a greater hormonal response in the recovery period due to the higher total work (15).

Ostrowski et al. (44) observed increased site-specific muscle size with all 3 training volumes used (low, moderate, high), but smaller increases in total body mass than in our study. In American football, while a power component is important, a body-building component may also be important due to the need for higher body mass and specific site hypertrophy (e.g., shoulders) in certain positions. This represents an integration of training styles to achieve different developmental profiles for football.

The concept remains that the adaptations are highly related to the specific exercise protocol's acute program variable in these comparisons: choice of exercise, loading scheme, and rest periods. Coaches must use test data to see whether adequate progress is being made if the goal is to improve the test variable as fast as possible and to gain the most function.

Practical Applications

At the time, we found that the claims of superiority for SS did not meet expectations for player development of strength and power variables if dramatic program comparisons were made. More important, these data now indicate that additional total work derived from assistance exercise programs may be important in improving body composition in short-term programs. Special attention to the acute program variables in the design of a training protocol is vital for observing desired training effects (11, 32).

EXPERIMENT 4: Nonlinear Periodization vs. High Intensity Single-Set Program

The concept of periodized training has been developed over the last 30 years and applied to sport training programs to reduce the potential for overtraining, especially with long-term protocols, and to allow for scheduled periods of rest (32, 54, 58). Changes in the intensity and volume of exercise can be manipulated to provide for variation in the training protocol. A host of training periodization models exist and it is incumbent upon the strength and conditioning specialist to determine what factors are being promoted for development (3, 47, 54).

The periodized training program used in this study would now be classified as an undulating or nonlinear program; it featured strength/power days and body-building hypertrophy days. The goal of such a program was to develop strength and power as well as tissue hypertrophy (36). Thus, program design was developed to optimize strength, power, local muscular endurance, and body composition. Speed and agility were addressed in sprint conditioning programs with each unit on the football team. At the time, the thought was that a high-intensity single-set training program could achieve the same goals. Yet it was not clear whether this was true or not, as few data existed as to its efficacy (45). Thus the primary purpose of the study was to compare two distinctly different training programs over a long-term training period to determine the pattern of changes in various strength, power, and body composition variables.

Methods

Forty-four Div. III football players (19.9 ± 4.3 yrs, 185 ± 9.9 cm, 102 ± 36 kg) were matched for position, starting strength, training background, age, and body size; they were randomly placed into one of two training groups, 22 in each group. All were familiar with all testing protocols and lifts. The groups averaged 2.7 ± 1.5 and 2.9 ± 1.3 yrs, respectively, of resistance training experience.

Players were tested as part of their athletic training program and gave informed consent. They had taken part in the in-season program which lasted until December and then lifted on their own until the start of the study about 4 weeks later. Thus they had a similar fitness and training base prior to the start of the study. Subjects were tested prior to an off-season training program and again after 7, 14, and 24 weeks of the training programs. To provide for recovery in both training programs, a 1-week active rest period (no weight training) was used after 14 weeks; training then resumed with Weeks 15, 16, etc.

Exercise Protocols

Training took place 3 times a week for the SS protocol, and exercises were varied to reduce boredom and reflect the changes in exercise angles proposed to be effective in single-set high intensity training programs. Thus it was called Circuit A and Circuit B; exercises were used and interchanged with 2 "A" workouts or 2 "B" workouts performed alternately each week. A combination of variable-resistance machine and some free-weight exercises (arm curls, chest flys, rotator cuff exercises) were used. Rest periods between exercises were 1 to 2 min. Loading was 8- to 12-RM performed to failure, with forced reps at the end of each set.

Circuit A	*Circuit B*
Leg press	Knee extension
Bench press	Chest fly
Leg curl	Leg curl
Seated row	Lateral raise
Calf raise	Calf raise (seated)
Arm curl	Triceps pushdown
Sit-up	Back hyperextension
Pullover	Upright row
Military press	Rotator cuff exercises
AB/AD exercises	Lat pulldown

The nonlinear periodization MS strength/power training program was performed 4 days a week.

Workout S/P (Mon & Th)	*Hyper. (Tue & Fri)*
Hang clean/Power clean	| Leg press
Squat	| Upright row
Split squat	| DB Military press
Bench press	| Arm curl
Push press	| Triceps pushdown
Rotator cuff exercises	| Lat pulldown (front)
Leg curl	| Seated row
Sit-up	| Sit-up
	| Side bend
note: | = superset	| Obliques
	| Leg curl
	| Calf raise
	| Lunge

Loading for the S/P workout was varied between heavy, moderate, and light loads (3–5, 8–10, and 12–15 RM, respectively). Hang cleans and power cleans used sets of 5 at heavy (85–90% of 1-RM), moderate (65–70% of 1-RM), and light (40–60% of 1-RM). Each exercise involved 2 to 4 sets that were varied within a workout (i.e., different set combinations were used) to provide for changes in volume and recovery within a week. Rest periods were 1–2 min for light and moderate intensities and 3–4 min for heavy intensities. Loading for the H workout used 8–10 RM with 1-2 min rest between super sets. Individual responses in progression were monitored for the progression of all acute program variables (resistance used, rest periods, etc.) (11). Thus the program represented a comprehensive interaction with the players.

Run workouts and agility unit drills were performed 2 to 3 days a week but no exercise was scheduled on weekends. Both groups did the same conditioning program outside the weight room. The leg press was used as a common marker exercise as well as to stimulate an overall metabolic response (greater anabolic hormone increase early in the hypertrophy workout) prior to exercising smaller muscle groups in a super-set fashion (19, 31, 36).

Testing Protocols

Due to prior experience, all players were familiar with testing protocols and proficient in all lifting techniques and were allowed to practice prior to testing. Maximal 1-RM strength tests for the bench press and leg press (training-specific modes) were used as markers for upper and lower body strength according to methods previously reported (30, 31). Relative strength tests at 80% of 1-RM for the bench press and 85% of 1-RM for the leg press were also determined (30). The 1-RM was determined for hang cleans from the knees as a loaded power marker. Changes in vertical jump (countermovement and one step) were also determined (22). A Wingate test for the legs was performed using a standard protocol but with only digital counts of each pedal cycle movement (sensitivity of ± 0.5 pedal rev.) (36).

Body composition was determined via standard 7-site skinfold technique and % fat was determined via the Siri equation (24, 50). Test-retest reliabilities were determined to have an intraclass of $R \geq 0.95$ for all tests. None of the subjects suffered any injuries that would make them stop participating in the study. Compliance to the training programs was 100% for all groups.

A MANOVA with repeated measures was used to analyze the data with Tukey post hoc tests when appropriate. Significance was set at $p \leq 0.05$.

Results

The relative strength for the bench press and leg press are shown in Table 3. The MS group demonstrated a significantly greater difference over the training time points and between groups starting at 7 weeks for both exercise movements. Consecutive increases in the number of repetitions were observed for the MS group with 24-wk values higher than 7- and 14-wk values for both exercises.

Power development measures are shown in Table 3 and Figure 1. The pattern of change in all 3 measurements demonstrated a superior increase in power measurements using different tasks and loadings (i.e., unloaded VJ vs. loaded hang cleans). Consecutive increases in the pattern of response were observed in the MS group, with players improving at each test period.

Table 3
Relative Strength and Power Development Measures

	Pretraining		7 Weeks		14 Weeks		24 Weeks	
Groups	*M*	±*SD*	*M*	±*SD*	*M*	±*SD*	*M*	±*SD*
No. of reps @ 80% 1-RM in bench press								
SS	10.1	4.2	12.2	2.2	13.2	3.4*	13.9*	2.7*
MS	10.5	4.6	14.2	2.2*†	15.3	3.2*†	16.4*†	3.1*†
No. of reps @ 85% 1-RM in leg press								
SS	11.1	4.3	12.6	2.6	13.2	3.2*	13.6	2.3*
MS	12.1	4.6	15.1	3.5*†	16.9	3.4*†	17.1	3.9*†
Leg Wingate power (W)								
SS	898	250	905	234	940	265	942	220*
MS	902	250	975	190*	1156.3	133*†	1396	230*†
% Changes in vertical jump								
SS	51.22	15.2cm	0.6%	2.2%	5.4%	4.3%	6.9%	3.5%*
MS	50.82	12.5cm	8.7%	3.4%*†	17.8%	6.3%*†	23.1%	3.9%*†
Changes in % fat and body mass (kg)								
SS %fat	17.1	9.9	16.9	7.2	16.1	5.9	15.9	6.6*
BM	103.2	34.1	104.2	26.9	105.6	24.3	105.2	23.1*
MS%fat	17.9	7.2	16.0	5.2*	13.8	4.3*†	12.0	3.9*†
BM	104.3	33.6	107.1	23.4*	109.8	33.2*†	110.9	4.9*†
Changes in 1-RM leg press (kg)								
SS	173.1	44.3	176.6	52.6	179.2	33.2*	183.6	43.3*
MS	172.1	54.6	185.1	43.5*†	196.9	53.4*†	207.1	63.9*†
% Changes in bench press in training-specific modality								
SS	n/a		7.2%	3.5%	8.4%	5.3%*	12.9%	3.5%*
MS	n/a		8.7%	3.4%*	17.8%	5.3%*†	29.1%	5.9%*†

*$p < 0.05$ from pretraining value; †$p < 0.05$ from SS group.

Discussion

This represents the first long-term study comparing such resistance training protocols. The primary findings of this long-term study support the same pattern of changes as were observed in the shorter study (Experiment 3), despite the comparison with an SS program that had more variation. Interestingly, the longer period of time did not allow for any further gains in the SS program while the MS program saw consecutive stepwise increases in almost all training variables. The theory of "banked or accumulated training effects" that facilitate continued adaptations when using the MS program remains attractive and may now have some support, especially concerning previously trained men (11).

These data show that while training differences may be small in the early stages of a program, the style of training might set the stage for future gains. Part of the problem with many Div. I programs is a constant interruption in off-season training, primarily due to spring football that requires a maintenance program to be undertaken; this may not promote optimal player development. In addition, many players are just back from an injury rehabilitation program. These data show that when training can be undertaken for an extended period of time, dramatic gains in physical development appear possible. Nevertheless, the program comparisons made in this study reveal differences even at 7 weeks of training in previously trained football players; the differences are most likely due to the dramatic contrast in the programs employed.

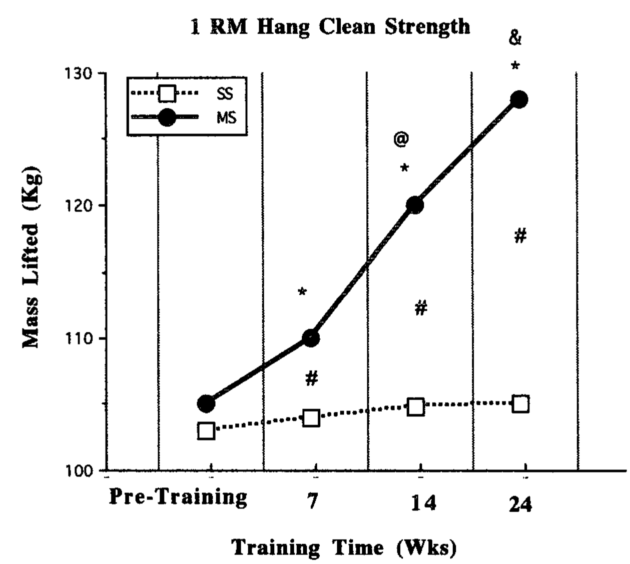

Figure 1. Change in 1-RM hang clean strength from the knees. *$p \leq 0.05$ from corresponding pretraining value; @$p \leq 0.05$ from corresponding 7-wk training value; &$p \leq 0.05$ from corresponding 14-wk training value; #$p \leq 0.05$ from corresponding SS group value.

The use of total program comparisons is also important for generalizing the results to real-life training situations. This is exemplified by the recent study of Starkey et al. (51), in which, in untrained subjects, only dynamic knee extensions and leg curls were used. Starkey et al. found no differences in nontraining-specific isometric strength between two groups of subjects who trained twice a week for 14 weeks and performed 1 or 3 sets of each exercise. The use of static isometric tests to examine dynamic strength training effects appears to be inappropriate for determining functional capacity for real-life force production (30).

It might be theorized that program differences or separations between training styles depend on the population studied, the protocol used, training status of the subjects, length of training time, and amount of variation to provide for recovery from training. Also, the finding of no differences in a study may reflect the amount of variance in a testing procedure (9) or the lack of dramatic program differences in design (11).

For 1-RM strength development in both the leg press and bench press, the MS group demonstrated superior changes in both rate and magnitude of change. While intensity plays a major role, the dramatic volume differences between the two protocols in this study may also have interacted to produce these findings. In addition, a more dramatic muscle-building program integrated into the weekly program addresses the need for a hypertrophy component in any periodization model (36, 38, 53, 54, 58). While attempting to equalize various factors to partial out their individual effects is important for a scientific understanding of the component parts, it becomes difficult to make adequate judgments regarding the very different types of programs and philosophies being promoted in football coaching circles.

These data are both dramatic and appropriately comparative as to the general nature of overall training concepts, and the findings can be generalized to larger program implications as they relate to volume and variation of training, velocity of movement, and intensity for football. While individual needs and goals of positions and players will vary within a program, concepts of how to achieve these goals efficiently are up to the strength and conditioning specialist. Such data can help in the choice of general direction for a resistance training program.

The development of muscle size and body mass has long been thought critical to success on the football field despite concerns about the player's health after his football days are over (11, 12). The data from this study indicate that when a program focuses on developing lean muscle mass and emphasizes proper nutrition, body fat can be reduced. This former trend in player development differs from today's. Players today, especially linemen, attempt to gain bulk (e.g., 320–340 lbs) by adding large amounts of fat to levels well over what might be possible with drug-free resistance-trained increases in muscle mass alone. The impact of this trend on the health and longevity of football players remains a topic of concern.

Prior short-term studies using single sets have shown that site-specific increases in muscle mass or circumference can be achieved if adequately stimulated, but changes in body mass may be less obvious (37, 51, 55). Any continued improvements in a "building" program for body composition changes are most likely dependent on genetics and the specific training program being used. The large changes in muscle mass development postured by single-set high intensity training protocols over short and even longer duration training programs is not supported from our data on football players.

The so-called benefits of body-building appeared to augment local muscular endurance and may have set the stage for adequate development of tissue support for strength and power parameters—due to changes in muscle protein and the associated increases in anabolic hormones with this training component (15, 33, 52). This acute recovery anabolic hormonal contribution to skeletal muscle remodeling may have been diminished in the SS program due to a lower amount of total work and less impact on the natural anabolic hormonal changes (15). In addition, better toleration of acid-base changes in the local muscular endurance tasks examined in this study could have contributed to the changes in both groups, but more prominently in the MS group due to a higher number of repetitions performed over a week, and to distinct super setting orders (1, 11).

The results of this investigation examining the power development set of measures showed that a specific MS program focusing on power development exercises can result in dramatic changes in this characteristic of muscle. The inclusion of power exercises (e.g., hang pulls) along with strength is required for optimal gains in loaded and unloaded power production (4, 8, 25, 41, 42, 60).

In this experiment we used hypertrophy and strength and power components on different days of the weekly training cycle. This is common in periodization models (10, 38, 54). Since the players were previously trained (i.e., not just starting a weight training program), they would require a different magnitude of progression in intensity and volume. However, exercise selection, variation, and volume of training would still be important factors in developing a base for advanced training over a football career but was beyond the scope of this study (11).

Based on training specificity alone, the MS group had the type of exercise stimulus to increase unloaded to loaded power measurements. The concept that you just need to get stronger and practice the sport to develop power is not supported by these data. It is interesting to note that such drills and sprint activities did not augment the SS groups' vertical or leg power component; this may be due to an already advanced level of sprint abilities in college football players, as previously shown (23). However, in the mixed-model theory (41), multiple components need to be developed; skill and force are only two factors. Needed is an integrated program for multiple performance characteristics of muscle in American football players, and such requirements are not completely met by low volume, high intensity, single-set training protocols.

Practical Applications

While SS are at times touted as superior in the football player's physical development, data from this investigation and others demonstrate that short-term and long-term adaptations in strength, power, local muscular endurance, and body composition are greater with a periodized multiple-set training program. The choice of exercises, variations in intensity and volume, recovery days, and training cycle time are all important considerations for a "building" training program in American football. There are many approaches to program design. Thus it is vital that the coach determine the goals of the program so that a model can be developed that focuses on those goals and the best program for achieving them.

Apart from scientific study, individualized programs using training concepts and principles will be required to address needs as well as individual and position goal differences. Limiting a program to low volume, high intensity, single-set protocols may not be appropriate as the way to train American football players and optimize player development.

EXPERIMENT 5: A Research Note—Adherence to Single-Set Programs

Different from experimental settings, many times claims are made in the "real world" as to the gains made with SS programs, despite the lack of measured variables. Often the claims are based on the look of the players, the team's record, or other subjective information. Having had the opportunity as a football coach and strength coach to take over programs that had used SS as the primary training method, I was able to at least ask the players about their adherence solely to such a program. A total of 115 players were given a survey questionnaire; anonymity was assured. In all, 89% of the players reported using other MS programs at home, during breaks, over the summer, or during off hours at health clubs to supplement the SS program prescribed by the strength coach.

The players who did only the SS program stated that they felt this was enough weight training and that they were more interested in other conditioning activities and sport practice. In addition, it was determined that many who supplemented their program with their own personal protocols did so because they wanted to perform free weight exercises such as power cleans and squats—often prohibited in many SS systems based on the unfounded fear of injury—in order to be competitive with athletes from other schools who did such exercises.

While this is only a small glimpse into the important issue of how we evaluate a training program, it suggests that what is being promoted as the final product of SS high-intensity training may not be the sole source of the athlete's development. Anecdotally, this has been documented by coaches around the country over the last 20 years. Resistance training and the needs of individual players are too dynamic and broad in scope to think a low volume, somewhat simple SS system with its limited ability to address certain fitness components (power, local muscular endurance, body mass gains, etc.) could achieve all of the goals in player development. If that were true, there would be little need to hire a highly educated, experienced, and expensive strength and conditioning specialist to work with a football team.

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