INVITED COMMENTARY

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The Applied Physiology of American Football

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American football is the most popular sport in the United States. Its popularity is likely related to the intense, fast-paced, physical style of play. The importance of strength and conditioning to success in football has been long understood. In fact, the strength and conditioning profession in North America can take its roots from American football. However, only recently has scientific study confirmed the positive relationships between strength, speed, and power to success in this sport. Although strength and conditioning are integral to every American football program, the collaboration with sport scientists has not been as fruitful. Only limited studies are available examining the physiological effects of actual competition and physiological adaptations or maladaptations during a season of competition. Most studies on American football have primarily focused on physical performance characteristics of these athletes and how various training paradigms can be used to improve performance.

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American football is the most popular spectator sport in America. The Super Bowl, the championship game of the National Football League (NFL), is watched by more than half of the households in the United States and in more than 150 countries. Despite this popularity, the scientific examination of this sport has not shared the same enthusiasm. This is likely more of a function of the separation between sport science and athletics in the United States versus a lack of scientific interest. As a result, our basic understanding of the physiological demands of this sport is primarily based upon empirical observation and deduction. There have been only limited attempts to examine the stresses placed upon football players during an acute competition or a competitive season. Most sport science research examining American football has been focused on player selection, and training programs used to enhance player performance. The focus of this commentary is to provide some insight on the research on American football and to share some of the College of New Jersey's research experience with American Football.

American football is a game that is primarily comprised of repeated maximum intensity bouts of exercise. The game consists of four 15-minute quarters with a 20-minute halftime. There are eleven players per team on the field at a time. Players participate on either offense or defense; rarely does a player perform both

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offense and defense, and when it does occur it is usually brief and for a specific strategic reason. Each position has specific responsibilities. Subsequently, the physical demands that are experienced by each player are quite different. It has been suggested that the anaerobic energy system is the principal energy system responsible for providing energy to the body during a game of football.[1,2] These authors have suggested that up to 90% of the energy production during a football game is provided for by the phosphagen energy system, while the remaining energy production is the result of the glycolytic energy system.

A football game can be separated into a series of plays. In an examination of a National Collegiate Athletic Association (NCAA) Division III football season there was on average 14.4 offensive series per team with an average of 4.6 plays per series.[3] This is slightly more than the average number of series reported in NFL contests.[4] However, NFL teams run approximately one more play per series than reported for the college football teams (between 5.3 to 5.6 plays per series). Each play has been reported to last for an average of 5.49 s (ranging from 1.87 to 12.88 s) in college football,[2] whereas the average NFL play is reported to be 5.0 s in duration.[4] Between each play each team has a maximum of 25 s to begin the next play. However, the play clock does not begin until the referee has set the ball. Thus, the rest interval between each play generally exceeds 25 s. In limited reports the average time between plays in a college football game is 32.7 s,[2] whereas in the NFL the average rest interval between plays has been reported to range between 26.9 to 36.4 s.[4] The average time per play and rest time between plays allows for a more precise understanding of the physiological demands of the game. It also provides important information regarding the development of the anaerobic exercise prescription.

Only one study to date has actually examined physiological, hormonal, and biochemical changes during the course of a competitive football game.[5] Significant performance decrements (peak force and peak power) were seen in football players within the first quarter of play and continued to decline until performance decrements reached a plateau at halftime. Both force and power performance returned to baseline levels by the games conclusion. This was likely related to the recovery occurring in players that were substituted for near the game's conclusion (the particular game examined turned into a rout in the second half that allowed the coaching staff to substitute freely). In a more closely battled contest these results may have been different. Hormonal analysis revealed no significant change in testosterone concentrations, but significant differences in plasma cortisol concentrations were seen between starters and "red shirt" players. Red shirt players are in uniform, participate in the pregame warm-up, but do not play in the game. Red shirt players are generally freshmen players that practice with the team, but preserve a year of college eligibility by not playing in any games. In addition, plasma myoglobin concentrations, a marker of muscle damage, were significantly elevated at the conclusion of the game and were significantly higher in starters versus the red shirt players. The results of this study suggested that if recovery is allowed to occur during the game, perhaps through appropriate substitution patterns, the football player may have a better opportunity to maintain force and power performance during competition.

Examination During a Season of Competition

Preseason training camp is generally associated with high intensity practice (generally two per day) with limited time for recovery. Players generally report in peak condition and although strength and conditioning is part of training camp, the primary focus of preseason training is to install the offensive and defensive schemes, and have players compete for a starting position. Recently the NCAA required its member institutions to limit the number of two-a-day practices due to the potential risk of heat illness during these high intensity practices that take place during the summer months. Before the change in these rules we examined performance, endocrine, and biochemical changes during preseason training camp in collegiate football players.[6] Interestingly, during the 10-day, 20-practice training camp no significant decreases in strength or power were evident. However, the high contact nature of the sport was clearly reflected by the significant elevation in creatine kinase (a marker of muscle damage) at the end of the camp. Testosterone concentrations remained at baseline levels, but cortisol concentrations were reduced and the testosterone-to-cortisol ratio became elevated. Despite significant elevations in markers of muscle damage, the endocrine profile suggested that highly conditioned athletes were able to withstand the stress and strain of preseason training camp.

The biochemical and hormonal responses during an entire season of competition was also examined by our laboratory.[7] We compared starters to nonstarters and showed that a season of intercollegiate football caused minimal disruption to the adrenal-testicular axis in these athletes (eg, no significant changes in resting testosterone or cortisol concentrations outside of that seen during training camp). Furthermore, the significant elevations seen in creatine kinase concentrations at the end of training camp returned to baseline concentrations by the first month of the season and remained at these levels throughout the remainder of the season in both starters and nonstarters. This response pattern suggested a degree of skeletal muscle sensitization to the repeated traumas occurring during the season. This was thought to represent a "contact adaptation" that occurs in football players as part of the physiological adaptation to a season of competition, and specifically provide a mechanism for the player to withstand the physical punishment associated with the game of football.

Physiological adaptations resulting from football practices and game also appear to enhance muscle oxygen kinetics and recovery.[8] Using near-infrared spectroscopy (NIRS) we demonstrated that during the course of the competitive season football players significantly reduce the magnitude of muscle deoxygenation and significantly improve their time for reoxygenation. It appears that part of the physiological adaptation associated with football practices and games involve enhancing muscle oxygen kinetics and recovery.

In regard to changes in physical performance, our experience at the College of New Jersey is that power performance (assessed by a Wingate anaerobic power test) can be maintained during a season of competition in both starters and nonstarters.[8] No significant changes were noted in peak power, mean power, rate of fatigue, and total work performed. In addition, upper and lower body strength

(one repetition maximum [1RM] bench press and squat, respectively) does not only appear to be maintained during the competitive football season, but strength improvements in the 1RM squat have also been reported in Division III college football players.[9] Improvements in strength during the season appear to be related to the intensity of training used during the in-season resistance training program. When training intensity exceeds 80% of the players' 1RM the ability to stimulate strength improvements is significantly greater than when training intensity is below 80%. This appears to be more prevalent in first-year players than in the upper classmen. It is likely the accumulated fatigue occurring in players that have greater playing time limit the extent of muscle adaptation during the season. In addition, the increase in lower body strength compared with upper body strength is thought to be related to the player's resistance training experience. Most college football players have been resistance training for at least 2 years before entering college. However, we have found that many of these athletes had limited experience in the squat exercise. It is probable that the greatest window of adaptation in the younger (freshmen) players is in lower body strength attainment.

Physical Performance Characteristics of Football Players

Scientific examination of American football has primarily focused in two areas: player performance characteristics and how to improve these performance characteristics during off-season conditioning. Several studies have demonstrated that differences in power, size, strength, and speed can differentiate between playing divisions in college football.[10–12] Strength, speed, and power performance has also been reported to differentiate between starters and nonstarters.[11,12] However, the only performance variable to differentiate between teams within a division regarding performance (related to final NCAA ranking) has been power.[13] Regarding professional football players, power, speed, and agility have been shown to be valid predictors of draft status[14] and have been found to differentiate between college players that are drafted by the NFL and players that do not get drafted.[15] An interesting study recently showed that football players have become stronger, faster, and more powerful over the past 20 years.[16] This coincides with the growth of the strength coaching profession and the greater emphasis placed on strength and conditioning at all levels of football.

Off-Season Conditioning Programs for Football

One of the more fruitful areas of research is in the examination of various training paradigms for preparing football players for competition. The most difficult part of doing these studies is getting good collaboration between exercise scientists and strength coaches in university settings. We have been quite fortunate to have established good relationship with the football. As a result, our laboratory has made a concerted effort to better understand differences between various training programs and which programs may significantly enhance athletic performance in these athletes. We have found that a traditional power lifting program may not

provide the optimal training stimulus in football players. We have demonstrated that by including Olympic lifting exercises in the training program of these athletes we can enhance leg strength and running speed to a greater extent.[17] Furthermore, when coaching experienced resistance trained football players the addition of ballistic exercises (ie, jump squats and bench press throws) may further augment the training response in these players.[18] There are a host of training paradigms that a coach can opt to use for training football players. Interestingly, a recent study from our laboratory was unable to provide clear evidence to support either periodized linear, planned nonlinear, or nonperiodized training programs in a 15-week off-season resistance training program in experienced resistance trained football players.[19] It appears that a longer period of training may be needed to explore what the optimal training program may be for experienced resistance trained football players. In addition, when examining college football players there are several potential confounding variables that need to be accounted for during the interpretation of the effectiveness of training programs. These include, but are not limited to the effect of spring practice and academic requirements.

Conclusions

Although tremendous growth has been seen in strength and conditioning programs in American football for the past 25 years, the utilization of sport science to maximize the performance ability of American football players is still lacking. Considering the great popularity of this sport and its revenue-generating ability, the development of a dedicated sport science program could potentially provide a significant stimulus in achieving each player's potential and assist in understanding the specific needs and demands of this sport.

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