Sports Science Exchange (2015) Vol. 28, No. 143, 1-6

SSE #143

GATORADE SPORTS SCIENCE INSTITUTE

AMERICAN FOOTBALL TASK FORCE

PHYSIOLOGICAL DEMANDS OF AMERICAN FOOTBALL

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KEY POINTS

- Strength, power and speed can differentiate starters from nonstarters, and between various levels of competition.
- During a football game, the rate of force development appears to be maintained, but peak force and power may decrease. With appropriate recovery and strategic substitution patterns, peak force and power may be maintained during a game.
- Some increases in muscle damage markers are seen immediately post-game, but with minimal disruption of the adrenal-testicular axis.
- Markers of muscle damage are elevated during the preseason training camp, but return to baseline concentrations by the beginning of the season and remain at baseline levels until the season's conclusion. This represents a degree of muscle desensitization to contact and has been termed "contact adaptation."
- Contact adaptation may provide a mechanism for a player to withstand the physical punishment associated with the game of football.
- The rate of performance improvements declines over the course of a college football career. Strength improvements appear more rapidly, but speed and agility improvements may take longer to be realized.

INTRODUCTION

The physical requirements for playing American football have been well documented for the past 25 years, demonstrating the importance of strength, power and speed at various levels of competition (Berg et al., 1990; Black & Roundy, 1994; Fry & Kraemer, 1991; Garstecki et al., 2004; Kraemer & Gotshalk, 2000). Investigations have shown that strength, power and speed can differentiate starters from nonstarters, and may be able to differentiate athletes between different levels of competition (Berg et al., 1990; Fry & Kraemer, 1991; Kraemer & Gotshalk, 2000). This has provided information for coaches on what type of athlete to recruit, and has provided an impetus on the part of sport scientists to examine various types of training paradigms and their potential effect on improving strength, power and speed performance in football athletes (Hoffman et al., 2004a; 2005a; 2009). Interestingly, physical performance improvements in college football players appear to occur in the early part of their playing career (Hoffman et al., 2011; Miller et al., 2002) and subsequent performance improvements appear to be more difficult to attain. This suggests the importance of appropriate selection or recruitment, as the ability of training programs to alter the physical ability of athletes may be limited.

DESCRIPTION AND PHYSIOLOGICAL DEMANDS OF AMERICAN FOOTBALL

Research on the physiology of the sport of American football is very limited compared to the work on strength, power or speed development. This is likely related to the separation between sport science and university athletic programs within the United States, and the lack of understanding of the potential contributions that sport science may have in American football. As such, there have been only limited attempts to examine the physiological stresses of a game or competitive season. Therefore, much of the understanding of the physiological requirements for the game is based upon an empirical examination of the sport.

The game of football is primarily comprised of repeated, short, maximum-intensity bouts of exercise. The game consists of four 12-15 min quarters with a 12-20 min halftime, depending on the league and level. There are 11 players per team on the field at a time. Players participate on either offense or defense, but rarely will a player perform both offense and defense, especially at the higher levels of competition (e.g., college or professional). Each playing position on the field has specific responsibilities that may alter the physical demands experienced by each player. However, the predominant energy systems during play for all football players, regardless of their position on the field, are the anaerobic energy systems (Hoffman, 2008; Kraemer & Gotshalk, 2000). Although research examining the physiological response of players during a football game is limited (e.g., no studies are known that have examined metabolic or cardiovascular changes in a game), the expectation of players to provide 100% of their effort on each play, regardless of their position and the short duration of each play, suggests that the primary energy provision during a specific play relies primarily on the phosphagen and anaerobic glycolytic energy systems. The intensity and duration needed on specific plays undoubtedly also puts demands on the aerobic system, as does repeated plays with short rest periods, but this has not been documented in American football. The physical needs though of each position may differ, as linemen may potentially have more contact than skill position players (i.e., wide receivers and running backs). During each play, linemen have a specific blocking assignment, whereas skill position players are often attempting to avoid contact. However, when the skill position player does make contact, the potential impact may be much greater than the linemen's, as impact appears to occur at a higher velocity of movement. This is supported by Funk and colleagues (2012) who reported that linemen sustained a higher overall number of head impacts, but skill position players had a greater incidence of severe head impacts as reflected by a greater acceleration upon impact.

Player substitutions are unlimited, so players can be interchanged between each play. Therefore, coaches can put the players on the field that provide the best opportunity to be successful for a given play. For example, an offensive coach may decide that he wants to predominantly pass the ball and thus puts in an extra receiver instead of a running back. To counter that substitution, the defensive coach may substitute another defensive back for either a defensive lineman or a linebacker. The only rule regarding players is that the offense is required to have at least five offensive linemen on the field and a total of seven players have to line up on the line of scrimmage (where the ball is placed). The other four players can line up anywhere behind the line of scrimmage, but are not permitted to be on the line of scrimmage. Offensive linemen are not eligible to catch the ball or go past the line of scrimmage until the ball itself crosses the line of scrimmage. In contrast, the defensive players are permitted to line up in any location on the field.

As mentioned, there are 11 players per team on the field at any given time. The offensive team is comprised of five linemen (two tackles, two guards and a center). These are generally the bigger players whose primary responsibility is to protect the quarterback when he passes the ball or block for the running backs as they run the ball. In addition, the offense generally consists of a quarterback whose responsibilities include calling the plays, passing the ball or running with the ball; one or two running backs whose primary responsibilities are to run the ball, catch the ball and block; and three to four receivers whose responsibility is to catch the ball when it's thrown and block during running plays. One of the receivers may be a tight end, who lines up next to one of the tackles (hence the term "tight") and is generally a bigger athlete who has greater blocking responsibility than the other receivers. The other receivers generally line up away from the linemen and are called "wide" receivers. On the defensive side of the ball, the composition of the team can vary depending upon the schemes of the coach or in response to the substitution pattern of the offense.

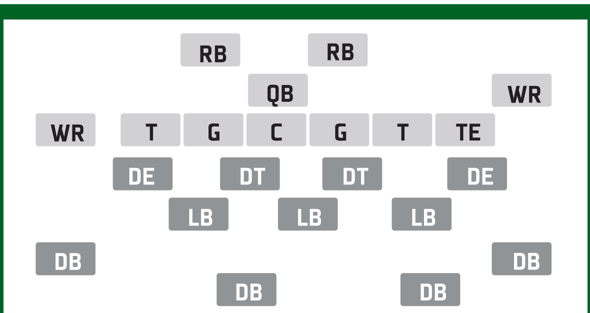

Figure 1: Basic Offensive and Defensive Player Formation
RB - Running Back; QB – Quarter Back; WR – Wide Receiver; T – Tackle; G – Guard; C – Center; TE – Tight End; DE – Defensive End; L – Linebacker; DB – Defensive Back

In general, the defense consists of a combination of three to four defensive linemen, three to four linebackers and four to five defensive backs. Figure 1 depicts the basic offensive and defensive player formation. In contrast to other sports such as basketball, hockey and soccer, the game of American football is not continuous. The game is comprised of a series of plays. If successful, defined as the ability to gain at least 10 yards in four plays, the series can continue. If not, the teams switch from offense to defense or from defense to offense. The goal of the defensive players is to prevent the offense from moving the ball 10 yards. The more successful the defense is in achieving their goals (i.e., stopping the offense), the quicker they get off the field and the greater potential there is for rest and recovery. The ultimate goal for the offense is to score a touchdown or kick a field goal. This can occur in a single play or after a long series of plays. In an examination of a National Collegiate Athletic Association (NCAA) Division III football season, an average of 14.4 offensive series per team per game was noted with an average of 4.6 plays per series (Hoffman, 2014). This appears to be slightly more than the average number of series reported in National Football League (NFL) contests (Plisk & Gambetta, 1997). However, on average, NFL teams run approximately one more play per series than seen among college football teams (between 5.3-5.6 plays per series). The duration of each play can vary from 1.9-12.9 s with the average duration of play lasting 5.5 s in college football (Kraemer & Gotshalk, 2000). The length of play in the NFL appears to be slightly lower with an average duration reported to be 5.0 s (Plisk & Gambetta, 1997). The time between plays is dependent upon when the referee sets the ball and blows the whistle for the play clock to begin. Once the whistle is blown, each team has a maximum of 25 s to begin the next play. However, the strategy of some teams may be to line up quickly and snap the ball (i.e., begin the play) with minimal rest to exhaust the opponent or prevent the opponent from substituting rested players. Thus, the rest interval between each play can vary from several seconds to a maximum of 25 s in duration. In limited reports, the average time between plays in a college football game is 32.7 s (Kraemer & Gotshalk, 2000), while the average rest interval between plays in the NFL has been reported to range between 26.9-36.4 s (Plisk & Gambetta, 1997). However, these studies are 15–17 yrs old and with changes in playing strategy, these times should be considered as an approximation. The ability to determine 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.

ACUTE PHYSIOLOGICAL RESPONSE DURING A FOOTBALL GAME

Due to obvious logistical issues, studies examining physiological changes during actual football games are very limited. Hoffman and colleagues (2002) examined the physiological, hormonal and biochemical changes during a competitive NCAA Division III football game. Comparisons were made between starters (n=11) and "red-shirt" freshmen (n=10; players that were preserving a year of eligibility and were not playing in the game). Measures of peak power and peak force were calculated from a vertical jump performed on a force plate, which was set up on the team's sideline. Assessments were performed 10 min prior to the kickoff and at the end of the first, second, third and fourth quarters. In addition, blood samples were obtained 24 h- and 2.5-h prior to the game and within 15 min following the contest. Results revealed no significant change in the maximum rate of force development during the game. However, significant decreases were observed in both peak force and peak power at the end of the first quarter of play. These performance variables continued to decline throughout the second quarter. However, both force and power performance returned to baseline levels by the game's conclusion. This was likely related to the recovery in players that were substituted for near the game's conclusion (the particular game examined turned into a rout in the second half that permitted 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 from pre-game concentrations, and no differences were observed between starters and red-shirt players. However, significant elevations in plasma cortisol concentrations were observed in starters and this elevation was significantly greater than the red-shirt players. 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 than the red-shirt players. No changes were noted though in creatine kinase concentrations, another marker of muscle damage. Differences in myoglobin and creatine kinase responses are likely related to the timing of the blood draw. Myoglobin is a smaller molecule than creatine kinase and leaks out of damaged tissue more quickly than creatine kinase. Myoglobin concentrations will generally peak shortly after exercise, where elevations in creatine kinase generally peak 24–48 h following intense exercise. Thus, a post-game blood draw may not provide sufficient time to capture elevations in creatine kinase. The results of this study suggested that the rate of force development is maintained during the course of a game; however, with strategically managed substitution patterns, force and power performance may be maintained. In addition, hormonal and biochemical responses to the game did indicate some elevation in markers of muscle damage and stress.

Kraemer and colleagues (2009) examined the acute biochemical and endocrine response in NCAA Division I football players the day before a game, 18–20 h following the game (e.g., day after game) and 42–44 h after the game (e.g., 2 days after game). Sixteen starters that played the entire game were compared to 12 players that did not play. Blood samples were analyzed for creatine kinase, lactate dehydrogenase, myoglobin, testosterone and cortisol. Those players that participated in the game demonstrated a significant increase in all markers of muscle damage (creatine kinase, myoglobin and lactate dehydrogenase). However, no changes were noted in testosterone and cortisol concentrations, and no differences were noted between players that participated in the game and those that did not. These results support the earlier work of Hoffman et al. (2002), which indicates that a game of football may result in an elevation in markers of muscle damage; however, this occurs with minimal disruption to the adrenal-testicular axis.

PHYSIOLOGICAL DEMANDS OF COMPETITIVE FOOTBALL SEASON

Prior to the onset of the competitive season, players report to preseason training camp that may last, depending upon the level of competition, between 3–6 wk. Preseason training is generally associated with high-intensity practice (sometimes two per day) with limited time for recovery. Players generally report in peak condition, and although strength and conditioning are 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. Recent rule changes by 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. The rule changes required a gradual increase in equipment used (from helmets only to full practice gear) and reduced the number of practices per day. This appears to have provided players with a sufficient time frame to acclimatize to the heat of summer training camp and enhance their exercise-heat tolerance (Yeargin et al., 2006).

The physiological stresses associated with preseason training have been examined in only a limited number of studies. One study was published prior to the change in the preseason summer practice schedule and examined performance, endocrine and biochemical changes during a 10-day, 20-practice training camp in NCAA Division III football players (Hoffman et al., 2004b). The study revealed no significant decrements in strength or power. However, the physical nature of the sport of football was clearly apparent as evidenced by a significant elevation in creatine kinase at the end of the 10-day training camp. Hormonal analysis revealed no changes in testosterone concentrations during the training camp, but cortisol concentrations were elevated initially, increasing the testosterone to cortisol ratio, but cortisol levels subsequently returned to normal. The initial elevation in cortisol that was measured likely reflected the initial anxiety associated with the onset of training camp. Despite elevations in markers of muscle damage, the lack of change in both testosterone and cortisol suggests that highly conditioned athletes were able to withstand the stress of 10 days of two-a-day practice sessions.

A recent study examined the physical demands of NCAA Division I college football players during summer training camp (DeMartini et al., 2011). The average daily practice time was 144 ± 13 min per session. The total distance covered during each practice was significantly higher among non-linemen (running backs, defensive backs, linebackers, tight ends and receivers) than linemen (tackles, guards, centers, defensive tackles and defensive ends) (3.5 ± 0.9 km vs. 2.6 ± 0.5 km, respectively). In addition, non-linemen spent a significantly greater amount of time jogging (6.1–12.0 km/h), running (12.1–16.0 km/h) and sprinting (>16 km/h) than linemen (5.1 ± 1.8% vs. 4.1 ± 1.0%, 0.9 ± 0.0% vs. 0.4 ± 0.5%, and 0.8 ± 0.4% vs. 0.1 ± 0.3%, respectively). No differences were noted between the positions in time spent standing or walking (~92-94% of the time). When starting players were compared to non-starting players, the only significant difference observed was in the time spent standing. Nonstarters spent significantly more time standing (78.1 ± 5.6%) compared to starters (74.6 ± 5.1%). No significant differences were noted between non-linemen and linemen in average heart rate attained during practice (135 ± 11 vs. 136 ± 7 b/min, respectively), but non-linemen did reach a significantly greater maximum heart rate (203 ± 8 b/min) than linemen (197 ± 9 b/min).

Other studies have focused on the physiological changes in football players during an entire season of competition. Hoffman and colleagues (2005b) compared the biochemical and hormonal responses in starters and non-starters during a NCAA Division III football season. They reported minimal disruption to the adrenal-testicular axis (e.g., 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 levels by the first month of the season and remained at these levels throughout the remainder of the season in both starters and non-starters. This response pattern suggested a degree of skeletal muscle sensitization to the repeated traumas occurring during the season and has been termed “contact adaptation.” This has been supported by others (Kraemer et al., 2013) that showed similar response patterns in NCAA Division I football players. The contact adaptation occurring in football players is theorized to be part of the physiological adaptation to a season of competition, which provides a mechanism for the player to withstand the physical punishment associated with the game of football (Hoffman, 2008).

Physiological adaptations resulting from football practices and games also appear to enhance muscle oxygen kinetics and recovery (Hoffman et al., 2004c). In a study of NCAA Division III football players, 30-second Wingate anaerobic power tests were assessed throughout the season. In addition, muscle oxygenation post-exercise was measured with near infrared spectroscopy. Testing was initiated at the onset of training camp and then every 4 weeks until the end of the regular season. Results showed a significant reduction in the extent of muscle deoxygenation and a significantly faster time for reoxygenation. This adaptation appeared to occur without any significant changes noted in peak power, mean power, rate of fatigue and total work performed during the monthly assessments.

Football players also appear to maintain both their upper and lower body strength during the competitive season (Hoffman & Kang, 2003). Maintenance of strength appears to be accomplished in college football players while using a 2 d/wk maintenance program with loads equating to 80% of the athlete’s maximal strength (1-RM) in each core exercise. Interestingly, when training intensity exceeds 80% of the player’s 1-RM, the ability to stimulate strength improvements is significantly greater than when training intensity is below 80%, especially in first-year players (Hoffman & Kang, 2003). It is possible that the accumulated fatigue occurring in players that have greater playing time limits the extent of muscle adaptation during the season.

PHYSICAL PERFORMANCE CHANGES IN THE FOOTBALL PLAYER’S CAREER

The importance of strength, power and speed for success in playing the game of football has been well-established (Berg et al., 1990; Black & Roundy, 1994; Fry & Kraemer, 1991; Kraemer & Gotshalk, 2000). This understanding has led to the growth of the strength coaching profession and a greater emphasis placed on strength and conditioning programs at all levels of football (Hoffman, 2008). An examination of the physical changes in football players from 1987–2000 reported a significant increase in the strength, power and speed of players during that time span (Secora et al., 2004). The increase in awareness of the importance of strength and conditioning programs and the hiring of dedicated coaches to focus program development at the scholastic level appears to have raised the level of physical ability at this level, which translates to a more prepared player at the next level of competition.

There are only a limited number of studies that have examined physical and performance changes in scholastic football players. A recent study indicated that a maturation process is seen in high school football players with the largest changes in performance occurring between the 10th and 11th grades (Dupler et al., 2010). This was consistent across offensive and defensive players. Consideration for adjusting rosters (e.g., varsity vs. junior varsity teams) to account for athlete maturation may provide a method of not pushing or rushing athletes before they are physically ready for the next level of competition.

Studies examining performance changes in the college careers of football players are also limited. A recent study in NCAA Division III football players indicated that strength and power gains are achieved throughout their playing career (Hoffman et al., 2011). Strength gains were consistent between non-linemen and linemen. Improvements in 1-RM bench press (31%) and squat (36%) strength seen during the course of the athletes’ collegiate career were similar to those reported for NCAA Division I football players (Miller et al., 2002). However, the greatest gains in strength occurred between the first and second (7.9% and 9.1% strength increase in the bench press and squat exercises, respectively) and the second and third (6.7% and 8.8% strength increase in the bench press and squat exercises, respectively) years of competition. The rate of strength increases was reduced between the third and fourth years (3.1% in the 1-RM bench press and 3.2% in the 1-RM squat). The response pattern was similar to other studies that reported that the majority of the strength gains in Division I football players occurred during the first 2 years of competition (Miller et al., 2002).

Improvements in speed, agility and vertical jump height appear to be more limited, and if improved, generally occur during the latter stages of the athlete's playing career (Hoffman et al., 2011). In a study of 289 NCAA Division III college football players that played over an 8-yr period, investigators examining players' performance assessments (e.g., agility, body composition, power, speed and strength) reported that vertical jump power was significantly greater at year 2 compared to the athlete's initial year of competition, and significantly greater at year 4 vs. all previous seasons. This appeared to be related to increases in both body mass and vertical jump height. Only during the fourth year of competition did vertical jump height increase significantly compared to the athlete's first year. These results were consistent with other longitudinal studies examining collegiate football (Miller et al., 2002). It is likely that these performance variables are a function of the genetic factors that impact the athletic potential of all athletes.

PRACTICAL APPLICATIONS

- Physical performance measures may help coaches differentiate starters from nonstarters.
- Development of an appropriate substitution pattern may enhance the ability of football players to maintain their force and power performance during a game.
- Preseason contact appears to provide a degree of muscle desensitization and may enable a player to withstand the physical punishment associated with football.
- Strength and power can be developed during an athlete's career, but speed and agility improvements may be harder to realize.

CONCLUSIONS

Although tremendous growth and understanding have been seen in strength and conditioning programs for football in the past 25 years, our understanding of the physiological responses to the game and our understanding of the physiological effect of a prolonged playing career are very limited. Evidence does suggest that players become desensitized to the constant contact, and that the anabolic and catabolic hormonal responses do appear to remain consistent during a competitive season.

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