

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

CAN MONITORING TRAINING LOAD DETER PERFORMANCE DROP-OFF
DURING OFF-SEASON TRAINING IN DIVISION III AMERICAN FOOTBALL
PLAYERS?

A Manuscript Style Thesis Submitted in Partial Fulfilment of the Requirements for the
Degree of Master of Science

Ashley R. Kildow

College of Science and Health
Applied Sports Science

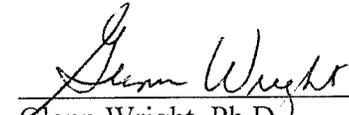
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CAN MONITORING TRAINING LOAD DETER PERFORMACE DROP-OFF
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By Ashley R. Kildow

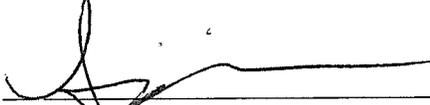
We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Human Performance (Applied Sports Science Emphasis).

The candidate has completed the oral defense of the thesis.



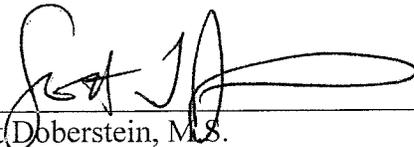
Glenn Wright, Ph.D.
Thesis Committee Chairperson

5/4/18
Date



Salvador Jaime, Ph.D.
Thesis Committee Member

5/4/18
Date



Scott Doberstein, M.S.
Thesis Committee Member

5/4/18
Date

Thesis accepted



Meredith Thomsen, Ph.D.
Graduate Studies Director

5-18-18
Date

ABSTRACT

Kildow, A.R. Can monitoring training load deter performance drop-off during off-season training in division III American football players? MS in Human Performance, May 2018, 83pp. (G. Wright)

PURPOSE: The aim of this investigation was to monitor the physical demands of Division III American football players during off-season training and to investigate differences in training responses between linemen and non-line and freshmen and upperclassmen players. **METHODS:** Twenty-three subjects (11 linemen, 12 non-line; 11 freshmen, 12 upperclassmen) from the university's football team were recruited from an Exercise Science 100 conditioning class to participate in a 15-week off-season training program. Phase I consisted of concurrent strength and speed/endurance training (3-4 days/week) for 7 weeks. Phase II consisted of strength training and spring football practice (3-4 days/week) for 4 weeks. Strength and speed training continued for 3 weeks following spring practices. Countermovement jump, estimated 1 repetition maximum (1RM) bench press and back squat, 505 change of direction (COD), repeated 30-yard sprint anaerobic test (RSAT), and body weight were all measured prior, mid-way through, and following the study. **RESULTS:** A two-way ANOVA with repeated measures revealed no significant interaction between linemen and non-line players or between freshmen and upperclassmen for all performance variables ($p > .05$). Over the course of the study, RSAT % decrement, 505 COD times, and estimated 1RM performance for bench and squat significantly improved ($p \leq .05$). No significant changes were detected in CMJ, RSAT best time, or body weight ($p > .05$). **CONCLUSION:** Results indicate that linemen and non-line players and freshmen and upperclassmen did not respond significantly different to the present training program. Change of direction skill, speed, anaerobic capacity, and muscular strength all improved throughout the study. Further, all performance changes except vertical jump were maintained through the end of the study.

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INTRODUCTION

The physical demands of a collegiate football player are highly complex, in which a player's improvement in performance is gauged by sport-specific tasks and performance variables related to strength, speed, agility, and power (Garsteckie, Latin, & Cuppett, 2004; Bishop & Girard. 2013). Different periods of the training year involve manipulation of volume, intensity, and frequency of strength training and conditioning to improve these desired performance variables. Specifically, the off-season period in American collegiate football takes place during the spring but is designed to prepare the athlete for upcoming physical demands of the fall season. It is common during this period for strength training to be concurrently stressed with conditioning loads and 4 weeks of spring practice for 3-4 days per week.

To improve performance, football players train with multiple types of training sessions including strength training, plyometrics, linear and multidirectional speed, and anaerobic endurance training. In addition, during the spring off season, collegiate football is allowed 4 weeks of practice, 3-4 days per week. As a result, multiple training sessions per day may be inevitable, leading to the high training loads (Gamble, 2006). Previous studies have detected non-functional overreaching (i.e. short-term performance decrements as a result of under recovery and high-volume training loads) (Moore & Fry, 2007) or failed to maintain training adaptations (Hoffman, 2015) during the off-season in American football. For continued progress in improvement in performance, appropriate periodization of all concurrent training and adequate assessment of training are essential.

Given that these types of training include movements that involve whole-body displacements in forward, backward, lateral, and vertical directions, triaxial accelerometer derived measures are becoming increasingly popular to monitor external training load during training, practice, and competition. Knowledge of the training loads allows the strength and conditioning staff to base volume and intensity of training decisions on actual work being performed and allows the football coaching staff to consider the accumulated physical demands being placed on their players when planning spring practices.

Within a football team, various positions and players with lesser training histories require different movement skills, intensities, and volumes of training to improve performance (Hoffman, 2015; Pincivero & Bompa, 1997). Monitoring training loads of conditioning sessions may benefit in determining whether the strength and conditioning program prescribed is appropriate for all players. It is paramount to determine the effectiveness of various off season training demands on performance during the off season for football players of different position and training history. Specifically, more research is needed to determine whether performance responses to various off-season training programs are the same between linemen (L) and non-linemen (NL) players and freshmen (F) and upperclassmen (UC) players.

Therefore, the primary aim of the present investigation is to determine whether quantifying training loads via monitoring can deter performance drop-offs during the off-season period. The secondary aim is to see if L and NL position players and F and UC respond differently to the present training program.

METHODS

Experimental Approach to the Problem

A 15-week off-season training program was implemented to investigate the effects of integrated training on performance on NCAA Division III football players. Wearable technology devices with a built-in triaxial accelerometer were used to monitor external training load during each conditioning session for the first 7 weeks and during all spring football practices. The training program was divided into two phases; the two phases were broken up with a weeklong unloading period in the form of spring break. The first 7 weeks of the training program (Phase I) consisted of strength training and conditioning designed by the team's strength and conditioning staff. Phase II consisted of 2 weeks of similar drills from Phase I including strength training and sprint mechanics training designed by the strength and conditioning staff. Training load was not monitored during these brief (10-15 minutes) sprint mechanics training sessions. The remaining 4 weeks of phase II consisted of spring football practices designed and implemented by the football coaching staff. Performance testing was performed during week 1 (Pre), week 7 (mid) and week 15 (post).

Subjects

Subjects were recruited from a spring semester sport conditioning class in the Exercise and Sport Science department at the university. The class was 7 weeks in length and designed for football conditioning. The class was open to not only the university

football players, but any other student on campus. From the total number of students, twenty-three players from the university’s football team volunteered to be monitored through class conditioning and until the end of spring football practices. Subjects included 12 (NL) position players (running back, defensive back, linebacker, wide receiver, and quarterback) and 11 (L) players. Of the subjects, 11 were (F), 12 were (UC) (sophomores, n=6, juniors n=6) preparing for the fall season. Descriptive characteristics of the subjects are presented in Table 1.

Table 1. Descriptive characteristics of the subjects (mean \pm SD).

Variable	Total (N=23)	NL (N=12)	L (N=11)	F (N=11)	UC (N=12)
Age (y)	20.0 \pm 0.99	19.7 \pm 0.91	20.3 \pm 1.10	19.0 \pm 0.87	21.0 \pm 0.67
Height (cm)	182.7 \pm 6.18	179.8 \pm 5.82	186.3 \pm 4.99	181.7 \pm 7.14	184.5 \pm 4.72
Weight (kg)	103.1 \pm 17.84	89.0 \pm 6.85	120.1 \pm 11.30	96.5 \pm 14.21	109.73 \pm 17.96

The research protocol was approved by the University Institutional Review Board. All details of the study were explained to the subjects prior to obtaining the informed consent and subsequent signing to confirm participation in the study. All conditioning, strength training, spring football practices, and testing were completed on campus facilities.

Strength Training Program

The strength and conditioning staff monitored all strength training sessions and provided the strength periodization and programming summary information. Subjects completed four strength training sessions per week for weeks 1-4, strength training sessions were reduced to three sessions per week during weeks 5 through 15. All strength training sessions were scheduled in the afternoon hours and lasted approximately 55-65

minutes. Intensity (Table 2) and repetition-volume (Figure 1) were prescribed for each y exercises were considered bilateral, multijoint movements that were able to be loaded to meet the strength theme of the block. Examples include front and back squat, Romanian deadlift, bench press, shoulder press, pulldowns, pull ups, and rows. Secondary exercises were unilateral and consisted of multiple variations of the primary exercises. Circuit exercises were bilateral, unilateral, or assistance exercises that support the increase in total volume of the exercise prescription of the day. Volume and intensity assignments were implemented based on the primary focus of the strength-training mesocycle modified from Stone, et al. (1982). Prior to the start of the study, subjects were asked to perform a 3 week long, 3 days per week, high volume-low intensity workout on their own during winter break, prior to the start of this study. There were four mesocycles throughout the duration of the study, these cycles included basic strength (weeks 1-4), hypertrophy (weeks 5-7), no weight training was assigned during spring break (week 8) , max strength phase (weeks 9-11), and explosive strength phase (weeks 12-14). Week 15 was a moderate unload week to prepare for final performance testing.

Table 2. Mean intensity for Phases I and II (sets x reps per week)

Week	Focus	Total Body	Primary	Secondary	Circuit
1	Test Week	2 x 8	3-4 x 4-6	3 x 8-10	2 x 8-12
2-4	Basic Strength	3 x 6	4-5 x 6	4-5 x 6	2 x 8-10
5-7	Hypertrophy	3 x 6	3-4 x 10	3-4 x 10	3 x 8-20
8	Spring Break	----	----	----	----
9-11	Max Strength	4 x 3-5	4 x 3-5	4 x 5-8	2 x 8-10
12-14	Explosive Strength	4 x 2-4	4 x 3-5	4 x 3-5	2 x 6-10
15	Test Week	3 x 5	3-4 x 4-6	3 x 6-8	2 x 8-12

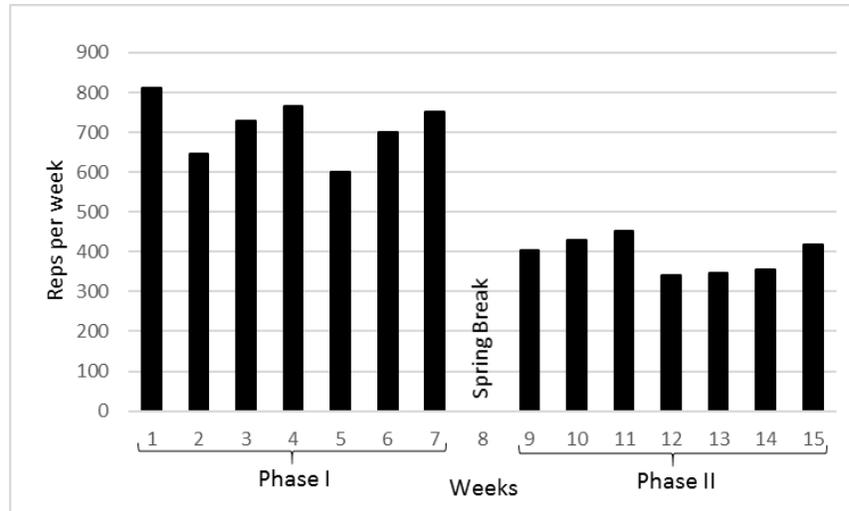


Figure 1. Repetition-volume of strength training workouts for phases I and II (total number of repetitions per week).

Conditioning Class

Conditioning classes (Phase I) were held twice per week (Tuesday/Thursday) at 6:00 am during Phase I (Weeks 1-7). Subjects agreed to wear a technology device (Bioharness 3™; Zephyr™, Annapolis, MD) that included an accelerometer on the left side of the chest by an elastic strap during all conditioning classes. Software of the technology device (Omnisense Analysis, version 4.1, Zephyr™, Annapolis, MD) quantified external load for each session. Mechanical load is the specific terminology used by the software of the technology device to describe external training load. To avoid confusion, mechanical load will be used to describe external training load for the remainder of this manuscript.

Mechanical load was determined by summing the systems mechanical intensity values which was determined by the highest peak acceleration in the vertical, lateral, or sagittal axis of an internal triaxial accelerometer during each second epoch sampled at 100 Hz. The mechanical intensity is determined by the acceleration (g) forces on a 0-10 linear

scale, in which 0.5g equals 0 and > 6g equals 10. The device was turned on just prior to the beginning of the warm up and turned off within 2 minutes after the last drill. Total mechanical load per week for conditioning classes (Phase I) may be found in Figure 2. All conditioning classes were 60-72 minutes (mean \pm SD; 65 ± 4.3 min) in duration and consisted of the following components:

Warm-up

The dynamic warm-up for each workout and each practice was 10-12 minutes in length and included various movement patterns and dynamic stretching exercises to increase mobility and stability of the shoulders, hips, and core while at the same time increasing tissue temperature. Movement patterns included jumping jacks, skipping, running, back pedaling, carioca, and various types of lunges.

Conditioning Stations

Plyometrics (10-15 minutes)

Plyometrics included 4-5 exercises per session with 2-3 sets of 2-5 repetitions. Various exercises containing non-countermovement and countermovement linear and lateral jumps, hops, and bounds were performed to increase the stabilization of landing and increase stretch shortening cycle ability of the lower body. The exercises were progressed from double leg to single leg.

Medicine Ball (10-15 minutes)

The medicine ball station included 3-4 exercises per session with 2-3 sets of 4-10 repetitions. Exercises containing chest and overhead throws, rotational throws and slams, squat to press throw, and granny toss vertical throw were performed. Exercises progressed from kneeling to standing positions.

Linear and Multidirectional Sprint Mechanics (10-15 minutes)

Various acceleration drills working on linear speed including front side and back side mechanics using wall drills, marches, skips, sprint starts and deceleration were programmed over the 7 weeks. Multidirectional running mechanics included lateral marches, skips, shuffles and change of direction cuts and crossover drills. Every session consisted of 3-5 exercises, 2-8 reps of each exercise. During most weeks there was one workout focused on linear mechanics and one workout focused on multidirectional mechanics.

Energy System Development (10-15 min)

Energy system development (ESD) training consisted of short repeated runs at the end of the training session. ESD workouts consisted of 55 – 65-yard tempo runs, 40-yard build-ups, or 60-yard shuttle runs. In addition to the short ESD training at the end of the conditioning sessions, athletes were encouraged to complete two high intensity interval training workouts on their own time each week. Each of these workouts consisted of 18-24 minutes that included 10-15 minutes of repeated, brief, high intensity intervals (10-30 sec each) followed by low intensity recovery intervals of 30-120 secs on low impact exercise equipment (cycle ergometer, elliptical, inclined treadmill walking).

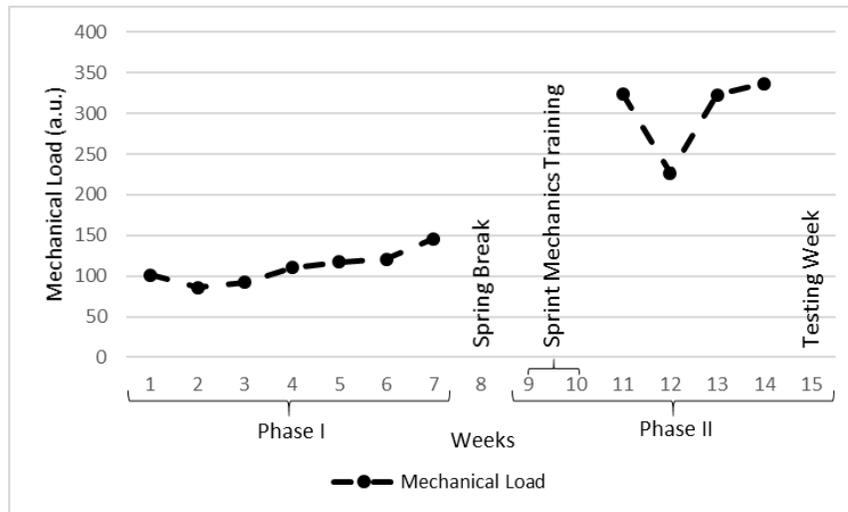


Figure 2. Total mechanical load of non-strength related training per week.

Football Practice

Spring football (Phase II) consisted of 15 practice sessions during the 30-day period as allowed by the NCAA Division III rules. Practice durations ranged from 87 minutes to 120 minutes (mean \pm SD; 102.7 ± 9.9 min). All football practices were designed and carried out by the football training staff. With NCAA Division III spring practice being non-padded and limited on equipment, the focus was on the basic installment of offensive and defensive schemes and general skills associated with each position group. Practices are typically shorter in duration due to the limitations on contact that a fall practice would include. As with the conditioning sessions, to quantify mechanical training load, subjects wore the technology devices during all spring football practices. Devices were turned on as they set foot on the field for each practice and turned off within 2 minutes of the completion of the last drill. Total mechanical load per week for spring practices (Phase II) may be found in Figure 2.

Performance Testing

The performance tests utilized in the current study were chosen to assess changes in performance in common physical requirements for a collegiate American football player resulting from the current training program. Performance testing was performed during week 1 (Pre), week 7 (mid) and week 15 (post) of the training program. The following tests were performed in the order listed following a self-selected 5-10 minute dynamic warm-up:

Physical Measures: Body weight was measured to the nearest 0.1 kg on a calibrated scale (Healthometer Professionals, McCook, IL), at pre, mid, and post testing days. Height (cm) was recorded only at the beginning of the study.

Countermovement Jump: Subjects performed three single, maximal effort countermovement jumps (CMJ) with a self-selected counter movement depth. Hands were placed on hips during the jump to remove any additional benefit gained by upper body motion. Approximately 30 seconds of passive recovery was allowed between jumps. Jump height was determined using flight time measured by a contact mat (Probotics Inc., Huntsville, AL). Jump height was determined by using the best of the three completed jumps.

Change of direction ability: The 505 change of direction (COD) test was performed using an electronic timing system (Brower Timing Systems, Draper, Utah). The test began with the subject standing on a marked baseline. On an auditory signal, the athlete sprinted to a line 15 yards (13.7 meters) away, planted a foot, turned 180°, and sprinted 5 yards (4.6 meters) back toward the baseline (Figure 3). The adapted 505 change of direction test was designed to be more football specific by changing the

distance from meters to yards. Lockie, Farzad, Orjalo, Giuliano, Moreno, & Wright (2017) found that this modification for American football testing using yards as the unit length vs. the original 505 COD test using meters was able to detect moderate changes in change of direction performance, has construct validity, and can discriminate between different positional groups in football that should have different COD abilities. Four total trials were completed with approximately 90-120 sec between attempts, alternating right and left sides each trial (2 trials each side). The best trial from the right and left sides were recorded and used for data analysis.

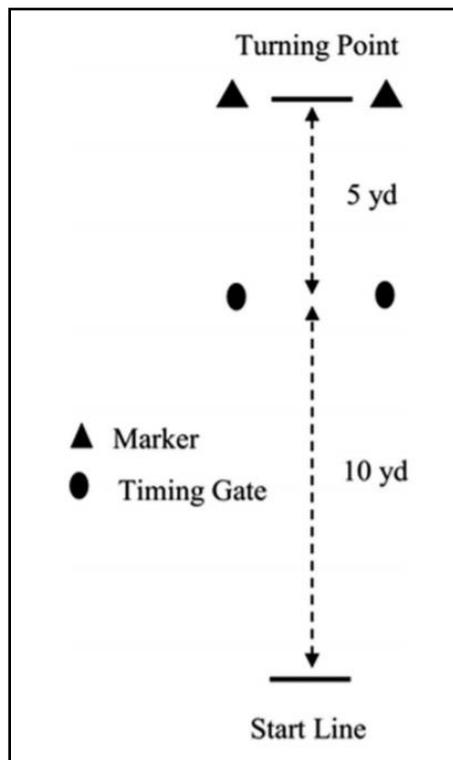


Figure 3. Structure and dimensions of the adapted 505 Change-of-Direction speed test.

Sprinting speed/anaerobic capacity: A modified repeated anaerobic sprint test (RAST) was performed on an indoor running track to measure anaerobic capacity. Six sprints repeated every 20 seconds were timed with an electronic timing system (Brower Timing Systems, Draper, Utah) with the infrared photocell gates spaced 30-yards (27.4 meters) apart. Each sprint was started from a staggered two-point stance 0.5 meters behind the timing system gates to avoid falsely triggering the timer before starting the sprint. After the first sprint, successive sprints were started from the finish line of the previous sprint. Performance was determined by calculating the sprint decrement, $[S_{dec} (\%) = (\text{sum of all sprint times}) / (\text{best time} * \text{number of sprints}) - 1 * 100]$ (Spencer, Bishop, Dawson, & Goodman, 2005) which indicated the ability to maintain acceleration ability. The best time of the six 30-yard (27.4 m) sprints was also used to determine acceleration ability.

Muscular Strength: Five repetition max (5RM) was determined for the bench press and back squat exercises at the beginning of a strength training session on separate days during weeks 1, 7, and 15. Subjects completed 3 submaximal warm-up sets prior to attempting a 5RM. Warm-up sets consisted of 5 repetitions with a load at ~10RM, 4 repetitions with a load at ~8RM, and 3 repetitions with a load at ~6RM. Following the submaximal warm-up sets, subjects rested for three minutes and then were instructed to add enough weight to reach failure between 4-6 reps. One rep max (1RM) was then estimated using the Epley equation, $1RM = [0.033 (\text{reps to failure})](\text{rep weight}) + \text{rep weight}$ (Epley, 1985).

Statistical Analysis

Separate two-way ANOVAs with repeated measures (2 groups x 3 collection times) were used to determine significant interaction between independent variables. Independent variables were defined in terms of the different groups (L vs. NL) and (F vs. UC) and the 3 collection times (pre training program, mid training program, and post training program). The dependent variables were body weight, estimated 1RM strength for bench and squat exercises, RSAT performance (best time and sprint decrement) CMJ height, and 505 COD performance times turning off both right and left legs. If significance was observed, a Fisher's post hoc test was used to identify where differences existed. An alpha level of $p \leq 0.05$ was set as the measure for significance.

RESULTS

As mentioned previously, total repetition-volume during strength training sessions may be found in Figure 1. Total weekly mechanical load for phases I (conditioning class) and II (spring ball practices) may be found in Figure 2.

Vertical Jump

Linemen Vs. Non-linemen. There was no significant interaction between L and NL groups ($p=0.103$). In addition, there was no significant change in vertical jump between pre, mid and post testing ($p=0.294$) (Figure 4a).

Freshmen Vs. Upperclassmen. There was no significant interaction between F and UC groups ($p=0.454$). In addition, there was no significant differences in vertical jump between pre, mid, and post testing ($p=0.402$) (Figure 4b).

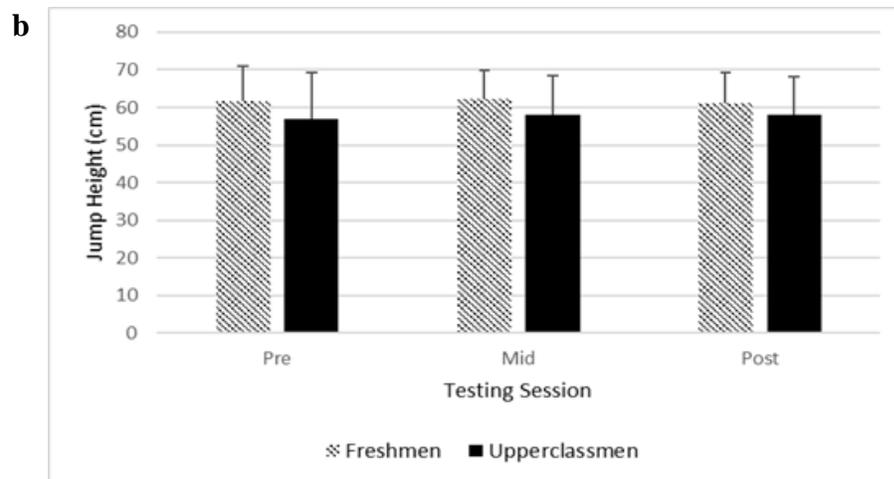
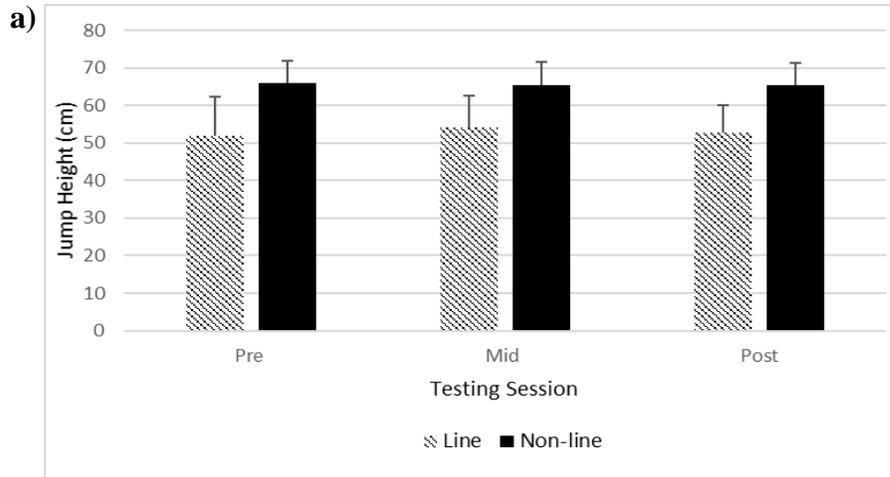


Figure 4. Vertical Jump (cm; mean \pm SD) for a) linemen vs. non-linemen, b) freshmen vs. upperclassmen. Pre = Week 1, Mid = Week 7, Post = Week 15.

505 Change of Direction

Linemen Vs. Non-linemen. There was no significant interaction between L and NL groups for both right ($p=0.169$) and left ($p=0.180$) 505 change of direction times. Significant decreases in time were detected between pre and post ($p=0.001$) for the right side (Figure 5a) and between pre and post ($p=0.001$) and mid and post ($p=0.029$) for the left side (Figure 5b).

Freshmen Vs. Upperclassmen. There was no significant interaction between F and UC groups for both right ($p=0.477$) and left ($p=0.836$) 505 change of direction times. Significant decreases in time were detected between pre and post ($p=0.004$) for the right side (Figure 6a) and between pre and post ($p=0.005$) and mid and post ($p=0.046$) for the left side (Figure 6b).

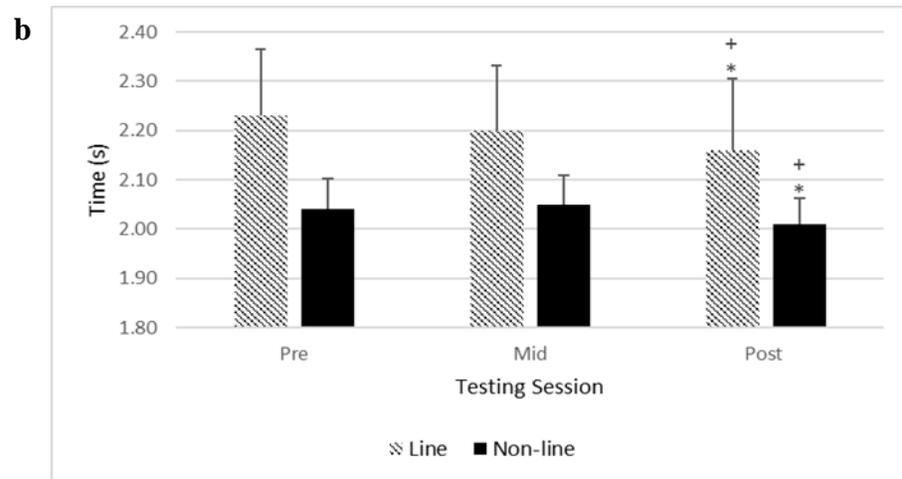
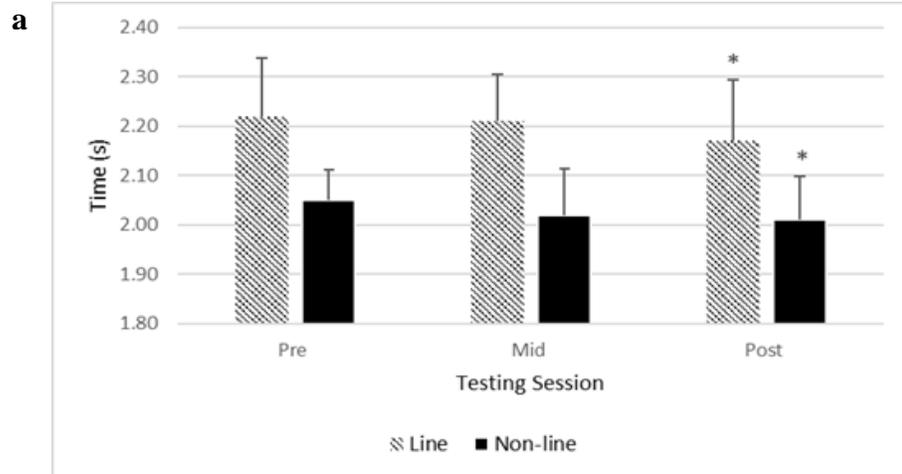


Figure 5. 505 Change of Direction test (seconds; mean \pm SD) for linemen vs. non-linemen players, a) right side, b) left side. *Significantly less than Pre, + Significantly less than Mid. Pre = Week 1, Mid = Week 7, Post = Week 15. $p < 0.05$

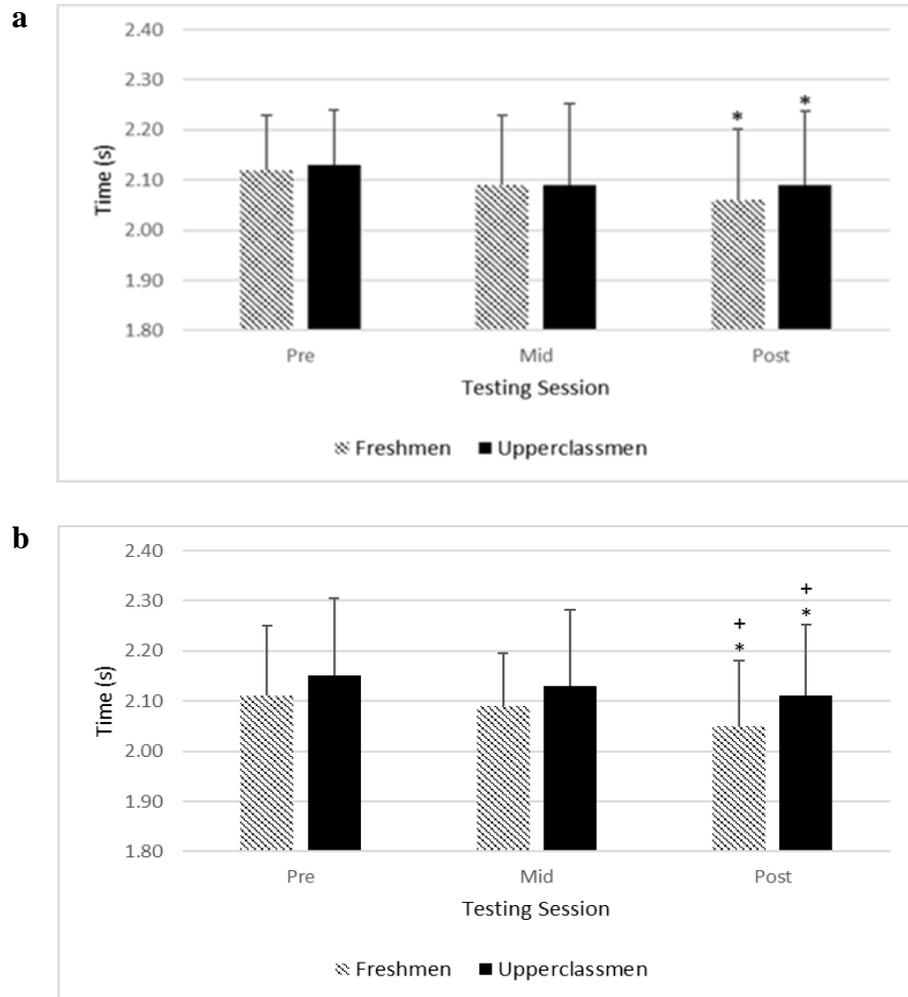


Figure 6. 505 Change of Direction test (seconds; mean \pm SD) for freshmen vs. upperclassmen players, a) right side, b) left side. *Significantly less than Pre, + Significantly less than Mid. Pre = Week 1, Mid = Week 7, Post = Week 15. $p < 0.05$

Repeat Anaerobic Sprint Test

Linemen Vs. Non-Linemen. There was no significant interaction between L and NL groups for percent decrement ($p=0.728$) and 30-yard best time ($p=0.169$). Significant decreases in percent decrement were detected between pre and mid ($p=0.003$) and between pre and post ($p<0.001$) (Figure 7a). However, no significant changes were detected in 30-yard best time between pre, mid, and post ($p=0.059$) (Figure 8a).

Freshmen Vs. Upperclassmen. A significant interaction between F and UC was detected for percent decrement ($p=0.010$). However, no interaction was found for 30-yard best time ($p=0.325$). Significant decreases in percent decrement were found between pre and mid ($p=0.001$) and pre and post ($p<0.001$) (Figure 7b). No significant differences were detected in 30-yard best time between pre, mid, and post ($p=0.053$) (Figure 8b).

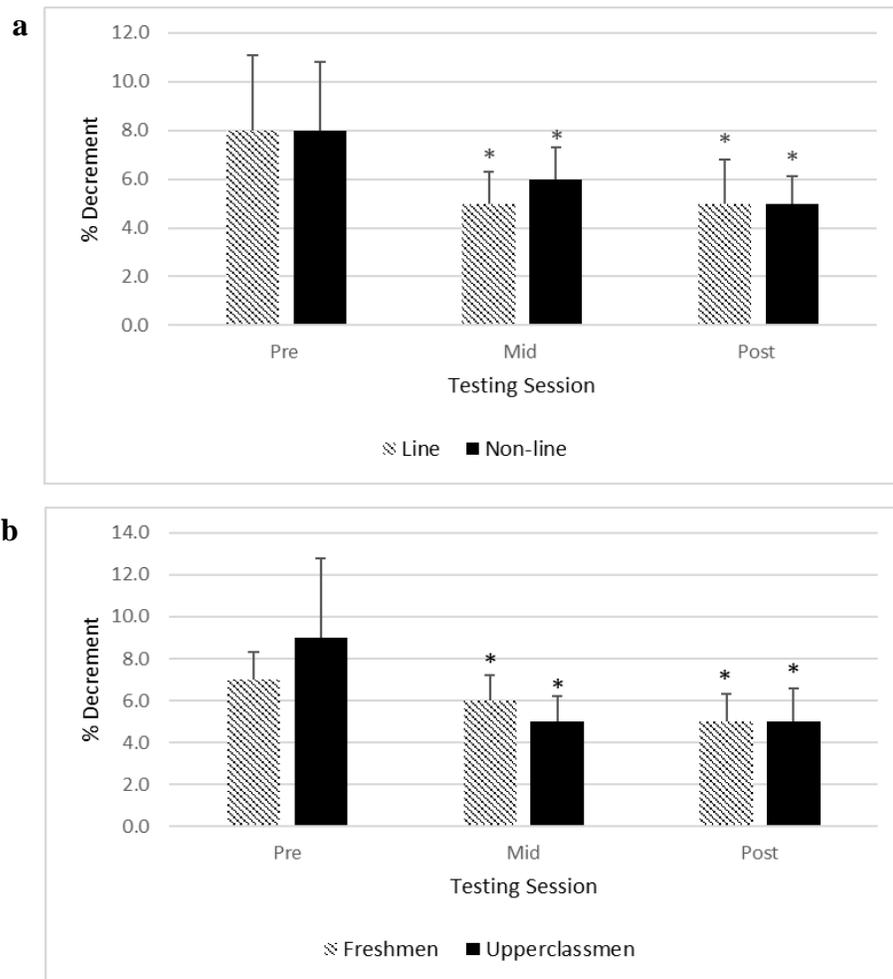


Figure 7. Repeat anaerobic sprint test on percent decrement (percent; mean \pm SD) for a) linemen vs. non-linemen, b) freshmen vs. upperclassmen. * Significantly less than Pre. Pre = Week 1, Mid = Week 7, Post = Week 15. $p < 0.05$

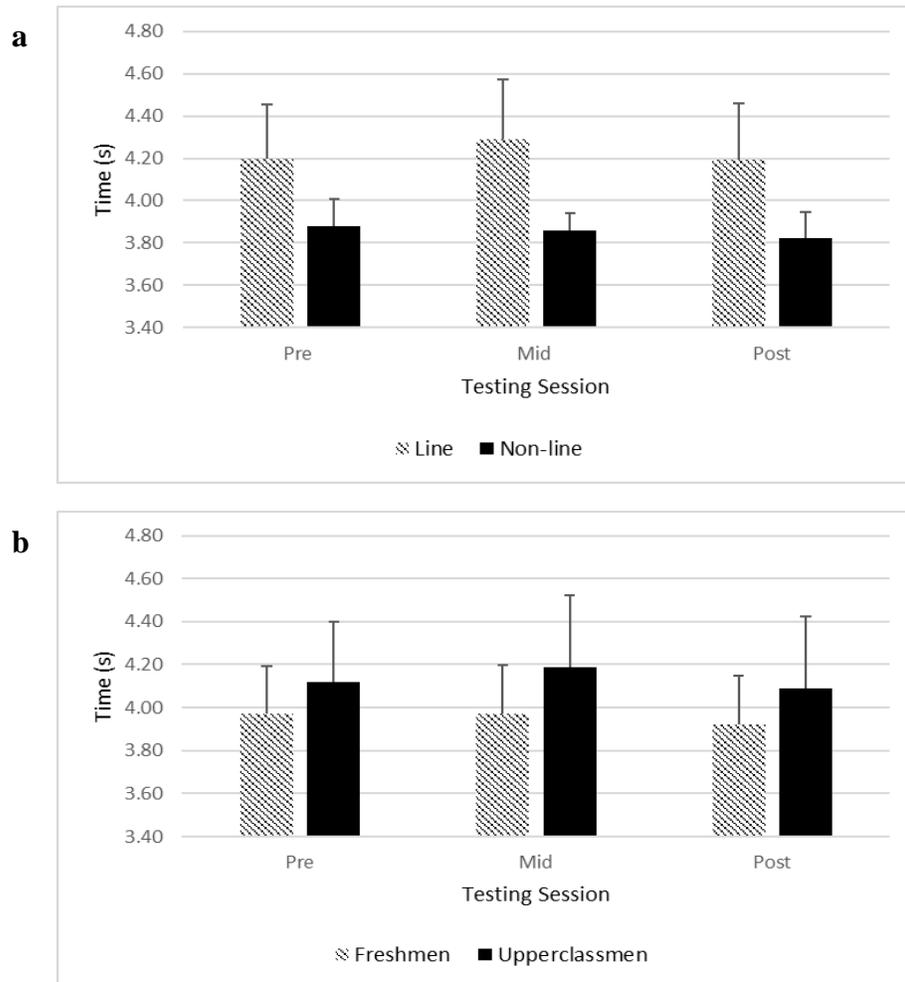


Figure 8. Repeat anaerobic sprint test 30-yard best time (seconds; mean \pm SD) for a) linemen vs. non-linemen, b) freshmen vs. upperclassmen. Pre = Week 1, Mid = Week 7, Post = Week 15.

Muscular Strength (One rep max)

Linemen Vs. Non-linemen. There was no significant interaction between L and NL groups for back squat ($p=0.335$) and bench press ($p=0.163$). Significant increases in back squat were detected between pre and mid ($p<0.001$), mid and post ($p<0.001$), and pre and post ($p<0.001$) (Figure 9a). Bench press performance significantly improved between pre and mid ($p<0.001$) and pre and post ($p<0.001$) (Figure 10a).

Freshmen Vs. Upperclassmen. There was no significant interaction between F and UC groups for back squat ($p=0.452$) and bench press ($p=0.838$). Significant increases in back squat were detected between pre and mid ($p<0.001$), mid and post ($p=0.001$), and pre and post ($p<0.001$) (Figure 9b). Bench press performance significantly improved between pre and mid ($p<0.001$) and pre and post ($p<0.001$) (Figure 10b).

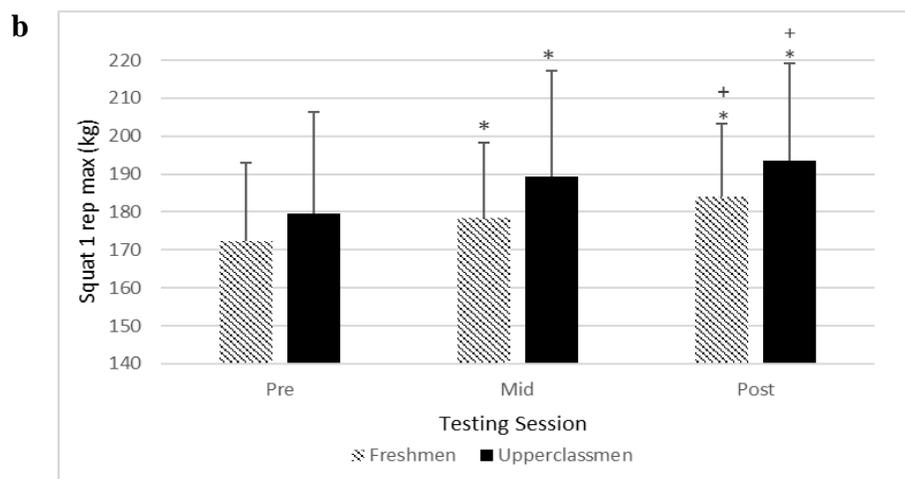
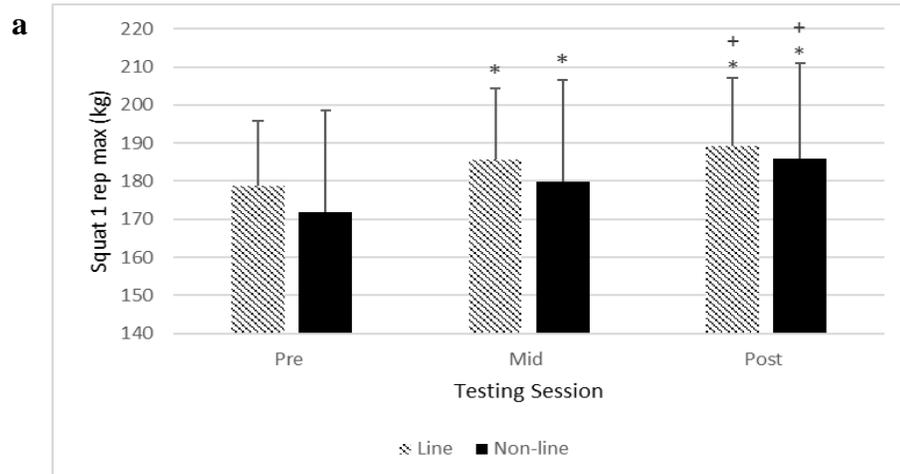


Figure 9. One rep max strength for back squat (kg; mean + SD) a) linemen vs. non-linemen, b) freshmen vs. upperclassmen. * Significantly greater than Pre, + Significantly greater than Mid. Pre = Week 1, Mid = Week 7, Post = Week 15. $p < 0.05$

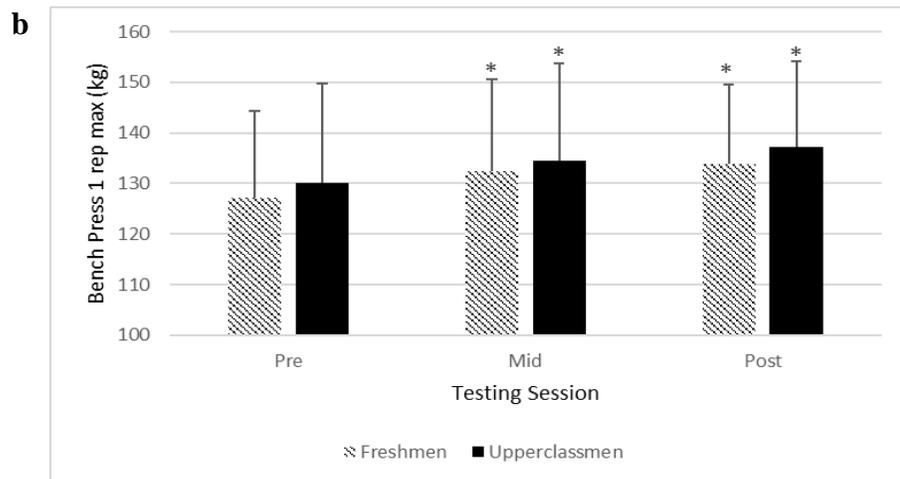
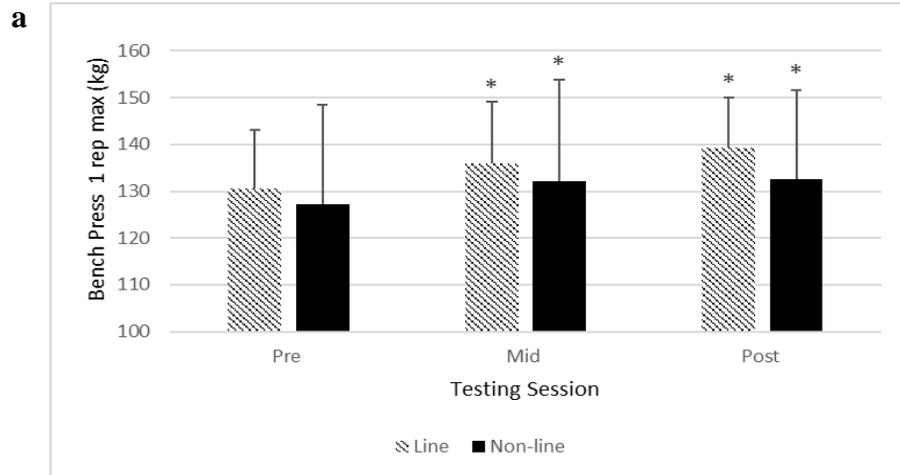


Figure 10. One rep max strength for bench press (kg; mean + SD) . a) linemen vs. non-linemen, b) freshmen vs. upperclassmen. * Significantly greater than Pre. Pre = Week 1, Mid = Week 7, Post = Week 15. $p < 0.05$

DISCUSSION

The primary purpose of the current investigation was to determine whether monitoring and manipulating the training loads of football players using integrated types of training during the off-season can deter performance drop-off following the allowed spring practice in Division III football players. The secondary aim was to compare the responses to the current off-season training program between positions (i.e. L vs. NL) and between year of eligibility (i.e. F vs. UC). Taken collectively, it was apparent from the present study that performance drop-off may be prevented with the ability to manipulate training loads of Division III American football players based on knowledge of their training loads in real-time.

The main findings from the present training study include significant improvements in, and maintenance of, muscular strength, COD ability, and anaerobic capacity indicated by percent decrement on the RAST. Additionally, while vertical jump and linear sprint speed performance did not improve, these physical qualities did not decrease, but were rather maintained throughout the spring practices. In regard to difference in responses to the training program, L and NL players showed no significant interactions in any of the performance variables measured over the course of the study. Thus, the two positional groups responded similarly to the current program. Additionally, F and UC responded similarly to all training variables except for percent decrement during the RAST, where F showed greater improvements over the course of the study

compared to UC.

Due to the difference in mechanical demands between L and NL positions Moore and Fry (2007) noted that the two groups may respond differently to various programs in their 15- week study using Division I football players during spring training and practice. However, our results using Division III football players are in contrast to Moore and Fry as both groups responded similarly to the current off-season program. A few speculations can be noted to why L and NL groups responded similarly in our study. Firstly, both groups participated in the same conditioning class and strength program during Phase I. Thus, there was little difference in strength training volume and mechanical load between the two positions. Average volume during conditioning classes in Phase I were 58 and 51 arbitrary units (a.u.) for L and NL, respectively (data not shown in Results). The second speculation relates to the demands during sport-specific spring practice between the two positions. Typically, NL players cover more distance in practices compared to L, due to the demands of their position, where running 30+ yards to catch a pass and jogging back to the line of scrimmage between plays is common. Linemen are required to block and tackle, which typically only occurs within a few yards of the line of scrimmage. Further, NL players are exposed to greater running volumes, faster running velocities, and a higher number of acceleration and deceleration efforts compared to L players, which could accumulate to higher mechanical loads (DeMartini et al., 2011; Pincivero & Bompa, 1997; Wellman, Coad, Goulet, & McLellan, 2016). We observed that the average mechanical loads during spring practices were slightly lower for L players compared to NL demonstrating that the L produced 85% (L= 74 a.u.; NL= 87 a.u.) of the mechanical loads as the NL during practices. Interestingly, in a study observing Division

I football players for positional differences in training load during preseason training camp, Wellmen et al. (PAP) observed Player Load (accelerometer data similar to Mechanical Load) of the L to be ~84% of the NL during practices as well. DeMartini et al. (2011) compared total distance covered between L and NL using GPS technology and observed that L covered only 72% of the total distances covered by NL, indicating using accelerometer data may be a better indicator of comparing movement demands between the position groups to acknowledge the volume of physical demands for all positions may not be represented best by total distance traveled.

A consideration when comparing the studies done with these studies using Division 1 football players during preseason that must be acknowledged is that, due to NCAA regulations (National Collegiate Athletic Association, 2016), the spring practices of Division III football only allow teams to emphasize learning the installment of offensive and defensive schemes and general skills within the different position groups. Further, DIII spring practice is non-padded and may not involve contact. These limitations resulted in the average practice time to be shorter in duration when compared to in-season practice. As a result, the demands during the present off-season spring practice would not mimic the demands that L or NL position players would experience at a DI level preseason practice schedule; however, the comparison of studies using percentage of L to NL accelerometer and GPS data is meant to overcome this limitation of comparing positional differences during practice.

The second analysis was done comparing the responses of F vs. UC to the present training program. Previous research has indicated that strength and power development in collegiate American football players has the greatest rate of increase during the first few

years of training (Miller, White, Kinley, Congleton, & Clark, 2002; Hoffman, 2015; Jacobson, Conchola, Glass, & Thompson, 2013; Stodden & Galitski, 2010; Smith et al., 2013). Our data indicate that, while freshmen showed significant improvement in most of the strength and power related variables, they did not present a significantly greater improvement compared to upperclassmen. The lack of difference could be due to the particular players assigned to each group. Hoffman, Ratamess, & Kang (2011), Smith et al. (2013), and Miller et al. (2002). However, the freshmen in these studies were either tested prior to starting any formal training in their first year (Hoffman et al., 2011), were in their first year of a structured strength program (Smith et al., 2013), or were tested within the 1st and 2nd semesters during their first year (Miller et al., 2002). The freshmen's training history in the aforementioned studies differs from that in the present study, whereas the freshmen in this study participated in the in-season training the previous competitive season. These factors may have potentially put them at a level of training experience where substantial neural adaptations already occurred and may not represent a novice training age seen in many true freshmen Division III football players. Neural factors such as an increase in motor unit recruitment, antagonist co-activation, inter-muscle coordination, and altered reflex inputs to motoneurons are seen to account for increases in strength during the early stages of training (i.e. < 8 weeks) (MacDougall & Sale, 2014; Zatsiorsky & Kraemer, 2006). Compared to an athlete with a longer training history, a novice athlete who has little training experience is more susceptible to rapidly increase strength via the previously mentioned neural factors.

With respect to the similar responses to the present training program between positional groups (i.e. L and NL) and between F and UC, the following interpretations

regarding performance variables are explained by the group as a whole, regardless of their role or eligibility year on the team.

Muscular strength improved significantly over Phase I and Phase II. Specifically, lower body strength (Figure 9) improved over the duration of the study despite the reduction in repetition-volume in Phase II, while upper-body strength (Figure 10) only improved during Phase I, and continued to be maintained during Phase II. Lack of improvements in upper body strength during Phase II may have been due to the reduction in strength training volume. Previously Miller et al. (2002) speculated that upper-body strength may be more compromised compared to lower-body strength when sport-specific practice volume is high (i.e., spring practices) and strength training volume is low. Therefore, it is possible that lower-body strength during Phase II was less influenced by the reduction in strength training volume and that the amount of lower-body anaerobic work performed during spring practice may have influenced the improvements seen in back squat 1RM. It is evident that the repetition-volume and the training emphasis (i.e. basic strength and hypertrophy phases) implemented during Phase I was sufficient enough to produce strength adaptations in both upper and lower body, while maintaining or improving these adaptations during spring practices (Phase II).

Improvements in strength may have been augmented by the variation in strength training volume. Allowing for periods of variation in intensity and overall training loads was recommended by Moore and Fry (2007) to increase the effectiveness of stimulation and maintaining adaptations with further training and to deter monotony. Additionally, periods of unloading allow for fatigue to be reduced and for adaptations to take place (Gamble, 2006; Turner, 2011). Thus, in the present strength training program there was a

significant reduction in volume load at the beginning of each mesocycle (i.e. week 5 of phase I, week 8 (spring break), and week 12 of Phase II) (Figure 1). In regards to improvements in performance and the ability to maintain adaptations throughout spring practices (Phase II) indicates that with the use of monitoring mechanical training loads during Phases I and II, the strength and conditioning staff was able to manage fatigue and appropriately manipulate the volume of strength training to prevent performance decrements during the off-season. Due to the cumulative stresses of strength and conditioning (i.e., plyometric, speed, agility, and anaerobic training) activities being stressed concurrently, high training loads are inevitable during this time. Figures 1 and 2 show that when strength training volume is high, mechanical loads for conditioning are low (Phase I) and vice versa for Phase II. Lack of monitoring during the off-season in American football players has led to decrements in performance in previous studies (Moore & Fry, 2007; Hoffman et al., 2008). Therefore, repetition-volume in strength training and mechanical loads during conditioning classes and spring practices can be carefully implemented to ensure that when mechanical loads are high, strength training repetition-volume is modified to prevent performance drop-off as a result of accumulating fatigue.

Further, it should be noted that in addition to the variation in the strength training program, the strength gains may have been subjected to neurological adaptations, not muscular changes. This is evident by the lack in body weight changes over the course of the study. This result also supports previous research, which has indicated that it is difficult to increase body weight over a short training period (i.e. 10 weeks) and many strength improvements are related to neural factors (Smith et al., 2013).

Change of direction time significantly decreased over the course of the study (Figure 5). Further, even though there were no significant differences in performance over time between freshmen and upperclassmen, COD times improved better between pre, mid, and post for the freshmen group compared to the upperclassmen. These data are supported by previous research where the greatest improvements in COD agility, indicated by 18.3-meter shuttle sprint, were noted to occur in the first year of training across all positional groups (Stodden & Galitski, 2010). Previous research has indicated that increases in concentric, eccentric, and isometric strength are all strong factors in improving COD ability (Lockie, Dawes, & Jones, 2018; Hammami et al., 2018; Suchomel, Nimphius, & Stone, 2017; Spiteri et al., 2013; Spiteri et al., 2014). A greater eccentric strength capacity improves the breaking force (Spiteri et al., 2014), thus the ability to accept and apply force during this phase is enhanced. Isometric strength allows the athlete to maintain lower-body position during the breaking and propulsive phases, which will augment triple extension of the hip, knee, and ankle during the turn. A greater concentric force increases the ability to apply greater force during the propulsive phase. Thus, in the present training program, improvement in muscular strength likely had the greatest impact on COD ability.

Percent decrement during the RAST decreased significantly during Phase I and was maintained throughout spring practices (Phase II). An improvement in percent decrement may be attributed to the stations incorporated in conditioning class designed to improve running mechanics, stretch-shortening cycle ability and anaerobic capacity. Brocherie, Millet, and Girard (2015) mentioned that the ability to maintain constant performance (i.e. running velocity across repetitions) may be influenced by running

mechanics, whereas an inefficient stride as a result of fatigue may lead to slower sprint times. However, other research indicates a greater VO_2 max may improve the ability to restore energy stores during recovery between sprints and may be a better indicator of fatigue resistance during repeated sprints (Bogdanis, Nevill, Boobis, & Lakomy, 1996; Gharbi et al., 2015). In addition to the conditioning class stations, separate energy system development (ESD) workouts were recommended twice per week for the players in our study to complete on their own. These workouts were designed to improve aerobic and anaerobic capacity and may have ameliorated their RAST performance.

A few studies have also examined the role of the stretch-shortening cycle (SSC) in repeat sprint performance, whereas a greater contribution from elastic energy by the use of the SSC during locomotion could possibly enhance the repeat sprint ability in athletes (Gamble, 2013; Dalleau, Belli, Bourdin, & Lacour, 1998; Voigt, Bojsen-Moller, Simonsen, & Dyhre-Poulsen, 1995). Previous research has indicated that elastic energy does not play a significant role in enhancing force production, but more so on its ability to reduce metabolic cost of movement, whereas an athlete who optimally uses SSC mechanics would incur less metabolic work in tasks such as RAST (Bobbert, Gerritsen, Litjens, & Van Soest, 1996). The lack of impact elastic energy has on force production could explain why a possible improvement in SSC ability did not affect vertical jump or sprint speed in the present study, given these are high force producing movements. In the conditioning class, linear running mechanics, plyometric training and energy system development stations were addressed to improve all the aforementioned factors that may affect performance during the RAST. These stations, in addition to voluntary ESD workouts, were successful at enhancing the athlete's ability to maintain maximal effort

and efficiently recover, as indicated by an improvement in percent decrement (Figure 7). Further, the fast pace tempo during spring practices (Phase II) may have augmented the ability to maintain this adaptation throughout the spring season.

Over the course of the study, players showed no significant improvements in vertical jump (Figure 4). The lack of change in vertical jump performance from the present study is in concert with previous research indicating the vertical jump performance is one of the more challenging factors to improve throughout an athlete's collegiate career (Hoffman, Ratamess, & Kang, 2011; Miller, et al., 2002). Therefore, improvement in vertical jump performance is unlikely to be observed during a single 15-week off-season training program (Hoffman et al., 2011).

There were no changes in linear speed indicated by the best 30-yard time during the repeat anaerobic sprint test (Figure 8). In agreement with previous studies (Jacobson et al., 2013; Noyes, Barber-Westin, Smith, Campbell, & Garrison, 2012; Jovanovic, Sporis, Omrcen, & Fioretini, 2011) and in line with vertical jump performance mentioned previously, sprint speed is another performance factor that is difficult to improve with training. Jacobson and colleagues (2013) found speed to improve by only 2.7% in linemen and 1.7% in skill positions (i.e. wide receivers and defensive backs) over a 4-year collegiate career. Further, Hoffman, Ratamess, & Kang (2011) mentioned that speed, agility, and power measures are difficult to significantly change within a year, even more so within a 10-week training program where previous adaptations already exist. Our data coincides with Jacobson et al. (2013) & Hoffman et al. (2011), where over the 15-week training program, our L and NL players only improved speed by 2.3 & 1.5%, respectively.

In addition to the benefits of monitoring training loads for the strength and conditioning staff, providing feedback of training loads has shown to be beneficial for the sport coaches as well (Halson, 2014; Bourdon et al., 2017; Vanrenterghem, Nedergaard, Robinson, & Drust, 2017). In the present study, mechanical load data with feedback from the researchers were available to the football coaching staff to interpret within a few hours following each spring practice. The ability to see and understand the training load during practices allowed the coaching staff to better determine the demands during practices and assist in the decision making process for the design of future practice sessions. Duration is seen to impact overall training load during practices. Ritchie, Hopkins, Buchheit, Cordy, & Barlett (2016) demonstrated that total player load during practice is a response of practice duration. Specifically, a 30% reduction in duration resulted in a ~30% reduction in player load (i.e. training load). It can be noted that manipulating practice duration in a periodized fashion may be an effective strategy to reduce training load and facilitate recovery between practices. In the present study, practice sessions throughout the week varied in duration during the spring ball season, which had an effect on the variation in total mechanical load. Thus, this variation during spring practices may have resulted in the ability to keep the players healthy and ready to train to improve performance during the off-season.

Practical Applications

The ability to manipulate training variables to allow for sufficient fitness adaptations while avoiding accumulation of fatigue is challenging during the off-season. Due to the cumulative stresses of resistance, plyometric, speed, agility, and anaerobic training being stressed concurrently, high training loads are inevitable during this time. It

is crucial to know how much stress is being placed on the athlete by monitoring them during conditioning and spring ball practices. Furthermore, in addition to the benefits of monitoring training load for the strength and conditioning staff, the training load information may have assisted the coaching staff in planning their spring ball practices. Thus, the coaching staff can manipulate practice duration and intensity to ensure their players were able to recover properly.

Overall, the communication between the strength and conditioning staff, coaching staff, and researchers regarding mechanical training loads may have resulted in the ability to keep the players healthy and ready to train to improve performance during the off-season. Future training programs during spring off season training that includes spring practice should utilize some method to quantify training loads as it is shown to be effective at managing athlete fatigue and optimize performance year round.

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APPENDIX A
INFORMED CONSENT FORM

Informed Consent

Protocol Title: Can Monitoring Training Load Deter Performance Drop-off During Off-season Training in Division III American Football Players?

Principal Investigator: Ashley Kildow
222 Mitchell Hall
La Crosse, WI 54601
(402) 320-0533
Kildow.ashley@uwlax.edu

Emergency Contact: Ashley Kildow
(402) 320-0533
Kildow.ashley@uwlax.edu

Purpose and Procedure

- The purpose of the present study was to investigate whether or not performance drop-offs could be prevented by quantifying external training load via an accelerometer device during all practices and conditioning classes.
- The secondary purpose of this study is to compare the different responses of linemen and non-line players and freshmen and upperclassmen to the present training program.
- Participants will wear a chest strap housing an accelerometer around the torso during all practices throughout the whole season. Accelerometers will measure mechanical load (i.e. external training load).

Potential Risks

- There is a small chance injury will occur as a result of this study. The Bioharness straps that house the accelerometers are padded to decrease discomfort. If an injury does occur, a certified athletic trainer will be present during all practices when the accelerometers will be worn.

Rights & Confidentiality

- Information from this study may be published or presented at professional meetings or conferences.
- No identifying information will be used during the publication process or presentations.
- Your participation in the study will remain confidential, all information gathered during this study will be kept on a password-secured computer.

Possible Benefits

- There will be no direct benefits to the participants of this study. However, data collected from this study may lead to a better understanding of training loads to enhance physical performance and recovery during the competitive season.

Questions regarding study procedures may be directed to Ashley Kildow (402-320-0533), the principal investigator, or the study advisor Dr. Glenn Wright, Department of Exercise and Sport Science, UW-L (608-785-8689). Questions regarding the protection of human subjects may be addressed to the UW-La-Crosse Institutional Review Board for the Protection of Human Subjects, (608-785-8124 or irb@uwlax.edu).

I HAVE READ ALL THE ABOVE, ASKED QUESTIONS, RECEIVED ANSWERS CONCERNING MY QUESTIONS, AND I WILLINGLY GIVE MY CONSENT TO PARTICIPATE IN THIS STUDY. UPON SIGNING THIS FORM, I WILL RECEIVE A COPY.

Participant: _____ Date: _____

Researcher: _____ Date: _____

APPENDIX B
REVIEW OF LITERATURE

**Can Monitoring Training Load Deter Performance Drop-off During the Off-season
Training in Division III American Football Players? – A Review of Related
Research Literature**

Introduction

Fatigue is a complex phenomenon that occurs within all team sports. During an athlete's training year, variations in intensity and volume are utilized by coaches, athletic trainers, and sports scientists in attempt to manage fatigue in their athletes. The goal of a proper periodized program for team sports is to allow for the athletes to adapt to increasing training loads while achieving optimal performance. For this goal to be accomplished, a training schedule with a physical demand that is high enough to stress the biological systems is essential to initiate training adaptations. Thus, the ability for team sport athletes to continuously improve performance, the overload principle must be applied to the yearly training program, which can be achieved by increasing the overall training volume, resistance, and/or alternating rest periods (Lorenz, Reiman, & Walker, 2010). Additionally, to continually increase performance in an exercise program, stress to the muscle must be progressively increased as it becomes capable of producing greater force, power, or endurance. If the athlete does not continue to adapt, he or she will eventually plateau and potentially regress (Kraemer & Newton, 2000). Hypertrophy, maximum strength, explosive power, and metabolic conditioning are all desirable factors as a result

from a properly designed training regimen (Gamble, 2006). For team sport athletes, these factors are enhanced when the overload principle is appropriately applied to the training program. Overload principle can be determined as functional overreaching, where supercompensation occurs following a period of recovery to allow for fatigue to subside. However, accumulation of intense training loads in the attempt of overloading without sufficient recovery will lead the athlete to feel stale and fatigued and may result in nonfunctional overreaching or overtraining. (Halson, 2014; Vanrenterghem, Nedergaard, Robinson, & Drust, 2017). Therefore, feedback provided to the coaching staff regarding their athlete's responses to training load has become very popular in the athletics (Halson, 2014; Bourdon, et al., 2017) and can be achieved via monitoring the training load for individual athletes during practice or competition. The capability to plan and monitor training load allows the coaching staff to manipulate training stressors to better manage fatigue while optimizing performance (Haff, 2010). Furthermore, monitoring team sports can aid in determining whether an individual is adapting properly to the training stimulus (Halson, 2014). Hence, the phenomenon of monitoring team sports has been broadly accepted and heavily studied within the sports community in recent years (Foster, Rodriguez-Marroyo, & de Koning, 2017; Alexiou & Coutts, 2008; Halson, 2014; Vanrenterghem, Nedergaard, Robinson, & Drust, 2017)

The use of monitoring for team sports is advisable, especially when training for multiple biomotor abilities during the same time frame. For example, a football athlete needs to train for various physical abilities to optimize performance. These abilities include but are not limited to power, strength, linear and multidirectional speed, and

endurance. Additionally, these abilities may vary for different positional requirements (Pincivero & Bompa, 1997). Depending on the mesocycle of training, variables such as strength training may concurrently be stressed with practice loads and conditioning loads. An accumulation of training load from each of these different areas of training can lead to high total training loads, which makes recovery between training sessions challenging (Turner, 2011). If rapid overloading of these training variables occurs without proper recovery or adaptation the result can lead to unwanted outcomes such as nonfunctional overreaching or even more problematic, overtraining (Chiu & Barnes, 2003; Borresen & Lambert, 2009; Halson, 2014; Gamble, 2006). Therefore, for the purpose of this review, is to provide information regarding analysis of the current research related to the models behind training responses in individuals, the theories leading to proper implementation of overload on team sport athletes, external vs. internal training loads and their significance, and a brief review of various performance tests for assessments of individual responses to training programs for team sport athletes.

General Adaptation Syndrome and Fitness-Fatigue Model

Within the literature, there are two major models that express an individual's responses to a stressor or stimulus: the general adaptation syndrome (GAS) (Seyle, 1956) and the fitness-fatigue model (MacDougall, Wenger, & Green, 1991). The GAS is described as an organism's response to certain stressors. It was proposed there were three different stages in response to a stressor. Beginning with the alarm stage, this occurs upon the stressor where the physiological state of the organism is suppressed, that is, the organism experiences shock (Gamble, 2006). Following the alarm stage is the resistance stage. This stage brings about positive adaptations, where supercompensation occurs and

the body adapts to increase the specific capabilities affected by the particular stressor (Brown & Greenwood, 2005; Wathen, Baechle, & Earle, 2000). If the stimulus continues the organism may reach a terminal state, also characterized as the exhaustion stage. This stage is defined when imposed stress is greater than the physiological system can recover from (Chiu & Barnes, 2003). Researchers have concluded that varying training in a periodized fashion was developed to concentrate on manipulating volume and intensity of training while avoiding maladaptation, which may lead to the individual reaching an exhaustion stage (Brown & Greenwood, 2005; Wathen et al., 2000; Stone, O'Bryant, & Garhammer, 1981).

Considering a stimulus, one unified physiological response as described by the GAS model has received criticism and lacks evidence in the literature (Chiu & Barnes, 2003). The GAS model is thought to be too simplistic in terms of describing physiological responses to stimuli (Chiu & Barnes, 2003), it is speculated that there are multiple responses following training that the GAS model poorly illustrates. Therefore, the fitness-fatigue model may be a more appropriate way to determine the physiological responses to various training stresses (Chiu & Barnes, 2003; Borresen & Lambert, 2009, Turner, 2011).

Similar to the GAS model, the fitness-fatigue model argues that the actions of a given stressor relate to the individual's neuromuscular and metabolic responses (Chiu & Barnes, 2003). The baseline of the organism is considering the individual's general fitness without any training stimulus. Upon the general fitness state, the individual can respond to the training stimulus through either fitness adaption, which is thought to positively influence performance, or by fatigue, which negatively influences performance

(Chiu & Barnes, 2003). The two responses, fitness and fatigue, work in relation to each other in both magnitude and duration of a stressor. It is thought that the net effect of fitness and fatigue aftereffects determines the neuromuscular and metabolic states the individual may be in (Chiu & Barnes, 2003). Various neuromuscular and metabolic fitness adaptations occur when a systematic paradigm is implemented to decrease training monotony and optimize performance (MacDougall & Sale, 2014). However, though the fitness and fatigue responses are independent, they have a cumulative effect resulting in the performance outcome of the individual (Bourdon et al., 2017; Chiu & Barnes, 2003). Additionally, there may be multiple fitness and fatigue after-effects, which are highly dependent on the specific training stimulus induced.

The numerous accumulated fitness and fatigue after-effects differ between specific biomotor abilities (i.e. power, strength, speed, endurance). Thus, an athlete's response to training stimuli will change according to which biomotor ability is being stressed. For example, team sport athletes are unable to improve maximum strength, anaerobic endurance, and aerobic endurance concurrently. The greatest improvements in one of the aforementioned motor abilities can be achieved only if the athlete concentrates on the particular type of training for a reasonable duration (i.e. 1-2 mesocycles) (Zatsiorsky & Kraemer, 2006). Due to various responses to different training stimuli, it is essential for team sport athletes to acquire a training program that emphasizes improving these individual biomotor abilities by altering high-volume with high-intensity training loads. (Zatsiorsky & Kraemer, 2006; Haff & Triplett, 2016).

The result of some biomotor abilities declining while the others are improving relate to the concept of residual training effects which refer to the longevity of

adaptations following an acute withdrawal of training load or absolute cessation of training (Issurin & Lustig, 2004). For example, Issurin (2016) explains when a strength/power mesocycle is followed by a mesocycle of aerobic endurance training, the ability to maintain strength firmly depends on the duration of their residual training effect, which for strength is roughly 30 days. If the second block duration is substantially longer than 30 days, a noticeable decrease in strength gains will take place (Issurin, 2016). The duration in which residual training effects occur differ among the various biomotor abilities. With respect to the maintenance of maximal strength and aerobic endurance, adaptations will decrease following training cessation of 30 ± 5 days. Other biomotor abilities such as anaerobic glycolytic endurance, strength endurance, and speed/power will see decrements in adaptations following a cessation of 18 ± 4 days, 15 ± 5 days, and 5 ± 3 days, respectively (Issurin & Lustig, 2004). Therefore, depending on the duration of training cessation with respect to the residual effects of biomotor abilities, adaptations will eventually decrease over time.

Considering residual training effects, the adaptations attained from training may diminish in a mirrored fashion during complete cessation of training. For example, the rate at which of muscular (structural) adaptations and neural adaptations are gained may be lost in a reversed pattern following detraining (Bogdanis, 2012; Izquierdo et al., 2007; Staron et al., 1991; García-Pallarés, Sánchez-Medina, Esteban-Pérez, Izquierdo-Gabarren, & Izquierdo, 2010). To further support this reversal effect, it is crucial to be aware of the time course of the neural and muscular adaptations that resistance training induces. For example, Seyennes, Boer, & Narici (2007) noted a 38% increase in maximal muscle strength following a 35-day high-intensity resistance training protocol. After ten

days of training, the authors observed a significant gain in maximal voluntary contraction (MVC) during the knee extension exercise. This was five times greater than the increase in muscular cross-sectional area (CSA) of the quadriceps at that time, which indicated that the initial increase in muscular strength represented by MVC was due to neural related factors, including increases neural drive and the ability to recruit larger motor units. The results from Seynnes, Boer, & Narici (2007) study agree with other literature supporting the notion that neural factors have been typically found to account for the early strength gains occurring within the first 4-5 weeks of training, whereas the muscular factors (i.e. hypertrophy) have been seen to occur at a later onset (Haff & Triplett, 2016; Sale, 1988; Moritani & deVries, 1979; Zatsiorsky & Kraemer, 2006).

Considering team sport athletes rarely discontinue training completely, a more practical approach would be to implement a period when volume of training decreases while intensity remains high. This practical approach will allow for a maintenance in the fitness after-effects and reduce any fatigue aftereffects (Chiu & Barnes, 2003). Further, performance at its highest level occurs when the fitness aftereffects are greater than the fatigue aftereffects, that is, fitness aftereffects are maximal while the fatigue aftereffects are minimal (Chiu & Barnes, 2003). Also, it is essential to note that the favorable fitness aftereffects do not occur immediately after a training phase (Pritchard et al. 2017). This is evident in a study conducted by Pritchard et al., (2017) measuring the effects on strength performance following two different cessation durations (3.5 vs. 5.5 days) after a 4-week training program. Results indicated that peak force of the bench press and mid-thigh pull in addition to countermovement jump height all increased after 3.5 and 5.5 days of training termination, with no significant differences between the two cessation durations.

Authors concluded the increase in performance may be attributed to a decrease in neuromuscular fatigue. A period of reduced volume following heavy training is needed to suppress fatigue and allow the fitness effects of training to occur. The period of reduced volume to promote a delayed training effect is known as a taper (Purvis, Gonsalves, & Deuster, 2010; Chiu & Barnes, 2003; Aubry, Hausswirth, Louis, Coutts, & Meur, 2014; MacDougall & Sale, 2014). The taper phase has been referred to as a progressive, nonlinear reduction of training load in the period before important competitions or where optimal performance is needed (Aubry et al., 2014). The best competition performances are often achieved following a taper phase. Moreover, in the absence of a taper period, it is difficult to acknowledge the true influence of the training program on team sport athletes (Chiu & Barnes, 2003).

The length of the recovery period necessary following a training load depends on the type of training implemented or the overall nature of the training stimulus (Schlumberger & Schmidtbleicher, 1998; Zatsiorsky & Kraemer, 2006). Further, reduced volume with maintained or slightly increased intensity appears to be the key element for tapering in team sport athletes (Murach & Bagley, 2015). Professional rugby players showed a positive change in power output and performance variables when strength training sessions were reduced from 3-4 sessions per week to 1 session per week (~80% reduction in total weekly repetitions) during a 21-day taper (Lacey et al., 2014). Authors of the aforementioned study attributed the increase in performance to a reduction in fatigue following a taper period. Similarly, Coutts et al. (2006) noted improvements in endurance, strength, and power measures in rugby players following a 7-day taper. The taper consisted of a 55% reduction in training volume and 17.4% reduction in training

intensity. Coutts et al. (2006) attributed the performance enhancements following the taper period to an increase in muscle anabolism and a decrease in muscle damage. Evidence indicates that the reduction in volume and maintenance of intensity during the taper period for strength and power athletes to be effective for up to four weeks following heavy training (Murach & Bagley, 2015). However, the duration of a taper is positively correlated with training load increments prior to the taper. Thus, a greater increase in the training load will result in the need for a longer taper period (Zatsiorsky & Kraemer, 2006).

The fitness-fatigue theory and delayed training effect are essential to understand when planning a program for various levels of athletes (i.e. novices vs. elites). Every athlete requires greater training stresses to stimulate optimal outcomes (Turner, 2011). For this to occur, short-term overreaching training methods may be considered to impose desirable adaptations. However, whether the athlete is able to tolerate the greater volume and intensity from short-term overreaching is based upon the athletes needs and capabilities, regardless if they are elite or novice. Short-term overreaching must be prescribed with caution with every athlete to prevent fatigue that may be difficult to overcome. Being aware of the athlete's capabilities and needs will decrease the risk of producing unwanted maladaptation that may result from short-term overreaching. Not every athlete may be able to tolerate this training tactic (Moore & Fry, 2007).

Overreaching and Overtraining

Underperformance caused by fatigue may result following the initial stages of intense training. However, with periods of adequate recovery that allows fatigue to dissipate, supercompensation and performance improvements are likely to occur. During

the high-intensity training or overload period, transient symptoms and signs of overreaching may arise (Budgett, 1998; Chiu & Barnes, 2003; Purvis, Gonsalves, & Deuster, 2010). Short-term overreaching, also known as functional overreaching, is caused by the imposition of high training overload intermixed with periods of recovery (Chiu & Barnes, 2003) which leads to positive outcomes, thus, supercompensation (Aubry et al., 2014). The high stress periods induce large fitness aftereffects while the periods of recovery allow for fatigue related factors to diminish (Purvis et al., 2010). Hence, when training volume is appropriately reduced, recovery and supercompensation from the training stresses induced occur (Weiss, Kreider, & Fry, 2004). With functional overreaching, the symptoms are mild with little to no long lasting negative consequences. Recovery from functional overreaching may be anywhere between a couple of days to weeks depending on the intensity and duration of the training period (Purvis et al., 2010; Fry & Kraemer, 1997).

In contrast to functional overreaching, some team sport athletes may experience prolonged periods of intense exercise, competition, or outside stresses without sufficient recovery. Under recovery leads to nonfunctional overreaching. Side effects of nonfunctional overreaching include progressive fatigue, mood changes, irritability, and losses of motivation (Purvis et al., 2010; Budgett, 1998). Purvis et al. (2010) described nonfunctional overreaching as having moderate symptoms where performance typically does not improve, and fatigue does not lessen. Recovery may take weeks to months to fully adapt or return to baseline performance following nonfunctional overreaching.

Functional and nonfunctional overreaching are closely linked and merely represent the balance/imbalance between overload and recovery (Purvis et al., 2010).

Furthermore, an athlete experiencing nonfunctional overreaching may only need two weeks to restore performance, while others may need longer recovery. In cases where advanced athletes who have longer training histories and higher demanding training loads, training may extend further beyond nonfunctional overreaching by developing long-term symptoms of the overtraining syndrome. Essentially, when fatigue aftereffects greatly exceed fitness, overtraining occurs (Chiu & Barnes, 2003). The difference between nonfunctional overreaching and overtraining regards the amount of time needed for performance restoration, and not the type or duration of training stresses or degree of impairment (Meeusen, Watson, Hasegawa, Roelands, & Piacentini, 2007). While it takes weeks to months in recovery for nonfunctional overreaching, overtraining results in severe symptoms that may take months to years from which to rebound (Budgett, 1998; Purvis et al. 2010; Haff & Triplett, 2016). Lehmann et al. (1991) found endurance athletes who were in an overtrained state still had performance decrements up to a year following a reduction in training load.

While there is evidence supporting the reversal effect of adaptations following detraining, there is lack of evidence regarding the rate of neural and muscular decrements in states of nonfunctional overreaching and overtraining. Research clearly indicates that performance suffers when athletes are entering a state of nonfunctional overreaching or overtraining (Purvis et al., 2010; Budgett, 1998). However, the rate at which certain performance variables such as speed and strength start to decrease with overtraining remains unknown. Moore and Fry (2007) noted that for team sport athletes, performance decrements may be evident first in speed related variables, followed by strength deficits, as strength relates to force production. This would support the notion that the quicker the

onset of neural adaptations, the quicker they will diminish following excessive training loads or cessation of stimulus (Zatsiorsky & Kraemer, 2006). Hence, speed may be the first performance factor to decrease. Likewise, muscular adaptations (i.e. hypertrophy) that relate to force production take longer to acquire, which in return may take longer to diminish (MacDougall & Sale, 2014; McMaster, Gill, Cronin, McGuigan, 2013). It has been speculated that speed and power related variables such as 40-yard sprint, agility, power clean, and vertical jump may be more sensitive to training stresses compared to strength variables (Fry, Schilling, Weiss, Chiu, 2006). This speculation is evident in a study by Fry et al. (2006) where weight-trained men showed a 36% decrease in peak power and a 5% decrease in 1-RM following two weeks of high-intensity resistance training, in which the training protocol was designed to induce overtraining syndrome. The authors noted that muscular power may be more sensitive than 1-RM strength to high-intensity strength-training, given the decrease in power was much greater than the decrease in 1-RM strength.

Athletes who engage in multiple forms of training concurrently (i.e. metabolic/skill conditioning with weight training) are at risk to reach some state of nonfunctional overreaching or overtraining. Assessing the effectiveness of a training program cannot be solely determined by 1RM performances, given that 1 RM strength may not decrease initially. Therefore, other performance variables, such as speed, may be adversely affected during the initial stages of increased training stress. As speed variables may be more sensitive to training stimulus, observation of initial performance decrements relating to speed could be a sign of maladaptation (Fry, Webber, Weiss, Fry, & Li, 2000).

However, more research is needed to elucidate the effects of training stimulus on the rate of neural and muscular performance decrements.

When training multiple biomotor abilities is evident, the overall goal of the training year is to optimize performance via supercompensation while avoiding a state of nonfunctional overreaching or overtraining. Thus, a constructive training plan should account for fitness and fatigue effects (Moore & Fry, 2007; Chiu & Barnes, 2003).

Team Sport Training – Multifactorial Approaches that Lead to High Training Loads

Athletes that engage in team sports are required to repeatedly produce skillful actions at maximal or near-maximal effort. Additionally, depending on the sport, athletes may need to execute skillful actions while in a severe state of fatigue. Examples of movements and skills executed in team sports include multiple accelerations, changes in direction and pace, sprints, jumps, and kicks (Bishop & Girard, 2013). The physical skills required during competition are enhanced with a highly-developed, specific program that stress different biomotor abilities, which may include but not limited to: strength, power, linear and multidirectional speed, endurance, and agility. Furthermore, team sport athletes tend to train these multiple biomotor abilities concurrently, which results in the volume of training loads to approach a high level (Gamble, 2006).

Between the off-season, pre-season, and in-season, volume and intensities are manipulated to address different emphases of performance and to limit the side effects of fatigue and monotony. Off-season training, specifically to higher level athletes, the volume tends to be higher and high training loads are inevitable when training for multiple biomotor abilities at the same time (Chiu & Barnes, 2003). These high training

loads could potentially increase the risk of nonfunctional overreaching. Therefore, the coach must be aware that overreaching without sufficient recovery could be problematic, leading to prolonged performance decrements and fatigue (Chiu & Barnes, 2003; Budgett, 1998; Purvis, Gonsalves, & Deuster, 2010). Thus, it is ideal for the coach to have a systemic plan; not only throughout the week or training block, but also the subsequent bouts of exercise throughout a single training day.

Regarding designing an optimal training stimulus for athletes, it is crucial to note that throughout a week of training where multiple biomotor abilities are being stressed, it is important to prioritize the higher-intensity days at the beginning of the week (Chiu & Barnes, 2003). Not only do high-intensity bouts of training have a possibility to enhance subsequent practices in a training day, but more importantly, the fatigue aftereffects of high-intensity training are shortest and much lower compared to high-volume training (Chiu & Barnes, 2003). Following high-intensity training days, high-volume, submaximal intensity training is suggested to occur at the end of the week, closer to the days of recovery. The purpose of this arrangement is a result of the high-volume training producing a longer fatigue effect which may impair higher intensity sessions that follow if done at the beginning of the week. This arrangement of training has the smallest negative effect on subsequent training days of the week (Chiu & Barnes, 2003).

When planning training sessions for athletes, coaches need to consider that the fitness and fatigue responses to stress may be individualistic, which makes the detection of overreaching or overtraining difficult with some athletes. For higher level team sport athletes, such as collegiate athletes or elites, a concern from the training staff may be how high can training load increase for the athlete to reach functional overreaching while

additionally avoiding the risk of injury. Some studies have monitored the effects of different load manipulations with team sport athletes to assess an appropriate threshold of training (Halson, 2014). Furthermore, Taylor et al. (2010) surveyed 100 participants involved in coaching or sport science roles on the current trends in monitoring high performance athletes. From the respondents, the intentions for monitoring their athletes stemmed from preventing overtraining (22%), injury prevention (29%), evaluating the effectiveness of training programs (27%), and to monitor the maintenance of performance during competitive periods (22%). Monitoring training load is recommended as it is beneficial for the training staff to receive feedback quantifying the training demands placed on athletes and the effectiveness of the current program. Specifically, sports that may require high loads of concurrent training to induce adaptations for different biomotor abilities.

Increased Training Load and its Effects on American Football Players.

Few studies have researched training load in off-season training periods for collegiate American football players. Moore and Fry (2007) observed the effects of a typical 15-week off-season training program for Division I-A college football players on performance and hormonal responses. The goal of the study was to determine the effectiveness of a planned overreaching training phase on skill position football players with a relatively short training history (< 3 years). Due to the short training history of these players, the researchers of this study speculated that the attempt of planned overreaching through overloading the training phases of the current program may be ineffective in improving performance.

The 15-week training program was split up into three phases. Phase I included 4 weeks of weight training only. Phase II include weight training concurrent with conditioning drills which included hoop drills, bag jumps, point wave drill, shuttle run, 5-point drill, lateral bag drill, and 2-point wave drill. Following the first two phases of training, weight training and conditioning was terminated for one week in the form of spring break. The week following spring break was used for only light calisthenics. Following this 2-week unload period, phase III started, which included 15 football practice sessions over a 30-day period. Performance testing included markers of performance such as muscular strength, sprint speed, vertical jump height, and 20-yard pro-agility test. Body weight and body composition were also measured. Testing was completed prior to phase I, and following the completion of phases I, II, and III.

Results from this study indicate that muscular strength was enhanced in phase I, but either decreased or began to decrease in phase II. Consequently, strength levels continued to decrease, returning to baseline measures by the end of phase III. The effects on speed related variables (sprint speed, vertical jump, agility) seemed to be related to the training stress of overreaching. Sprint speed decreased during phase I and no improvements were observed in phase II and returned to baseline measures in phase III. Vertical jump height improved during phase I; however, jump height did not improve during the remainder of the study. Agility testing improved during phase I, returned to baseline levels during phase II and remained at baseline through phase III. Additionally, no significant changes were observed during phase I in testosterone concentration. However, testosterone significantly decreased ($p < .05$) in phase II but returned to baseline

measures following phase III. Cortisol levels did not change throughout the course of the study.

The authors concluded that although the training program presented in their study is relatively common in American football off-season training, modifications needed to be made in order to allow for sufficient recovery and to ensure increased performance was obtainable during spring ball (phase III). It is likely that the 2-week unloading period of spring break and the week that followed the overreaching period may have avoided any true overtraining symptoms by allowing sufficient recovery from the overreaching period (Phase II). Suggestions given by the authors included to decrease overall training load and increase variability in training intensity. This could be accomplished through periodic unloading periods or reduced volume or intensities. Furthermore, the benefit of these changes is to allow for greater variation of training load and in return reduce the risk of decrements or stagnation in performance, which was observed in phase II of the present training plan. It was clear from this study, that not all situations where high training loads are present are productive or result in desired outcomes as is supported by the occurrence of nonfunctional overreaching observed during this study (Moore & Fry 2007). It was also pointed out that the results of the study are relevant to skill position players and future studies should include linemen, which may have different responses due to differences in body size and training capacity.

Defining Training Loads: Internal vs. External

Measures of training load are determined by the intensity and volume of training and can be categorized as either external or internal (Halson, 2014; Bourdon et al., 2017).

External training load refers to the work completed by the athlete, which is measured independently of his or her internal responses (Wallace, Slattery, & Coutts, 2009).

Measures of monitoring external loads include power output, speed, and acceleration calculated via global positioning system (GPS) and accelerometer-derived parameters (Bourdon et al., 2017). Internal training load is defined as the relative physiological and psychological stressors imposed on the athlete during training which commonly include measures of heart rate, blood lactate concentration, oxygen consumption, and ratings of perceived exertion (Bourdon et al., 2017). Coaches and training staff should select both internal and external monitoring tools that suit their specific situation, considering the combination of work performed (external load) and impact of work performed on the player (internal load) provides an assessment of the athlete's capacity to handle the training stressors (Bourdon et al., 2017). Monitoring both external and internal training load is important since the stimulus for training induced adaptations is the physiological stress (i.e. internal load) imposed by the external load of training (Impellizzeri et al., 2005)

The focus of external and internal measures for monitoring will be on accelerometer tracking and heart rate response, respectively. Specifically, wearable technology device systems allow for measurement of mechanical loads to assess external loads. Briefly, mechanical load may be considered the musculoskeletal stress placed on the body during practice or competition (Vanrenterghem J., Nedergaard, N.J., Robinson,

M.A., & Drust, B., 2017). Mechanical load is defined as a cumulative index of effort based on accelerometer data over a period of time (Zephyr™, Annapolis, MD, 2003). Zephyr™ system determines mechanical load by the sum of all obtained mechanical intensity values from the training session. The mechanical intensity is determined by the highest peak acceleration (g force) in the vertical, lateral, or sagittal axis of an internal accelerometer during each second epoch sampled at 100 Hz. The mechanical intensity was reported on a 0-10 linear scale, in which .5g equals 0 and > 6g equals 10.

The measure of internal load is valuable to evaluate whether an athlete is responding to the training demands adequately. Heart rate is a popular method for measuring exercise intensity and monitoring internal load (Borresen & Lambert, 2009). Moreover, wearable technology devices assess the measure of physiological load in response to heart rate values. Physiological load is defined as the cumulative index of effort based on heart rate over a period of time (Zephyr™, Annapolis, MD, 2003). Zephyr™ system determines physiological load by the sum of all obtained physiological intensity values from the training session in addition to the total time spent at a given intensity zone. The physiological intensity is determined during each second epoch and is based on the subject's max heart rate (% of heart rate max). Physiological intensity level is reported on a 0-10 linear scale, where 50% heart rate max equals 0 and $\geq 100\%$ heart rate max equals 10.

With respect to monitoring internal training load, physiological and environmental implications should be considered when using heart rate response to determine exercise intensity. Specifically, hydration status of the athlete is an important physiological component to influence cardiovascular response (internal training load)

(Achten & Jeukendrup, 2003). For example, a 100-minute ride at 35 degrees Celsius resulted in a 7% decrease in stroke volume and concurrent 5% increase in heart rate in trained cyclists (González-Alonso et al., 1997). A reduction in stroke volume results in a compensatory increase in heart rate to maintain cardiac output (González-Alonso et al., 1997). Further, when exercising in a dehydrated state, independent of core temperature heart rate can increase, on average, up to 7.5% and has been shown to be positively correlated with the level of dehydration (loss in plasma volume) due to increased sweat response in an effort to dissipate heat accumulation (Achten & Jeukendrup, 2003). Thus, the more dehydrated the athlete is, heart rate to determine internal training load will become less reliable (Achten & Jeukendrup, 2003).

Training in hot or cool environments also influences heart rate response to exercise (Achten & Jeukendrup, 2003). For example, González-Alonso, Mora-Rodriguez, & Coyle (2000) investigated the effects of cycling for 30 minutes at 72% VO_2 max in either a hot environment (35°C) or cool environment (8°C). When percentage of dehydration was accounted for, heart rate response was significantly different in the hot condition compared to the cool condition. Specifically, average heart rate response increased by 10 beats/min in the hot environment compared to the cool environment. In hotter conditions, the heat loss mechanisms are seen to be less efficient. Thus, at the same exercise intensity when hydration is normalized, heart rate is higher in hot conditions compared to cool conditions. This is likely attributed to a rise in core temperature and redistribution of blood flow to the skin, reducing central blood volume and cardiac filling (Sawka et al. 1993).

Given the information above, heart rate may not be the most accurate indicator of exercise intensity when training in hot environments (Achten & Jeukendrup, 2003). Contrary to exercising in the heat, cold exposure initiates a greater efficiency of heat dissipation, which allows blood flow to be mainly distributed to the active tissues rather than the skin. This may affect heart rate response to not be as elevated in cool environments compared to hot environments.

The main purpose of monitoring internal and external training loads should be to assist and inform the coaches/training staff in the decision making of program designs and the athlete availability for training. Additionally, the feedback to coaches should be simplified and easy to interpret, this may help by limiting the monitoring to key metrics such as mechanical and physiological load (Bourdon et al., 2017; Foster, Rodriguez-Marroyo, & Koning, 2017). However, measures of internal load should be analyzed with caution in extreme environments.

External Performance Tests for Team Sport Athletes

Testing performance measures for team sport athletes offers information regarding the individual athlete's strengths and weaknesses. Further, performance testing supplies feedback on adaptive responses of particular athletes to a training program (MacDougall & Sale, 2014). Performance tests are more valuable when the specificity principle is applied, thus, the tests being performed should simulate as closely as possible the movement pattern, contraction type, and velocity of sport action (Luthi et al., 1986).

Within team sports, specifically American football, valuable performance measures would include 1-repetition max (1RM) estimates for squat and bench press, countermovement jump, 505 change of direction test to assess change in direction ability

and any right vs. left deficits, and repeated sprint anaerobic tests. These performance tests should be considered within a specific training plan to monitor athletes physical state. In the following paragraphs a detailed description of each performance test will be discussed.

Estimated One-rep Max for Squat and Bench

The 1-repetition max (1RM) is commonly used by coaches and training staff to determine maximum strength for athletes. The 1RM can be defined as the force a muscle or muscle group can exert in one maximal effort while maintaining proper form; it can be quantified by the maximum weight that can be lifted once (Haff & Triplett, 2016). Specifically, squat and bench press 1RM are commonly used tests to evaluate upper and lower body strength. The 1RM test is shown to be a reliable test for athletes. However, testing a true 1RM of an exercise carries a risk of injury, takes a lot of time, and places a large amount of stress on the athlete.

Submaximal testing can be utilized with valid prediction equations. By testing submaximal loads and applying a prediction equation, an accurate 1RM can be estimated (DiStasio, 2010). Specifically, the Epley equation is widely used for the strength and conditioning field and is easy to assess for predicting 1RM. The Epley equation is as follows:

$$1RM = [0.033 (\text{reps to failure})](\text{rep weight}) + \text{rep weight} \text{ (Epley, 1985)}$$

The Epley formula uses a multiple factor of 0.033 for each completed repetition in the submaximal set to estimate the lifter's 1RM (DiStasio, 2010).

Countermovement Vertical Jump

Power is a critical component in many sports (Pincivero & Bompa, 1997; Docherty, Robbins, & Hodgson, 2004). The countermovement jump is a simple, practical and reliable measure of power and the stretch shortening cycle in the lower-limbs. There are two ways in which the countermovement jump can be executed: 1) with hands on the hips and 2) with an arm swing. Numerous studies have shown that countermovement vertical jump with an arm swing results in greater jump height and greater velocity upon takeoff compared to hands on the hips approach. (Shetty & Etnyre, 1989; Luthanen & Komi, 1979; Harmen, Rosenstein, Frykman, & Rosenstein, 1990). Considering the arm swing clearly augments jump performance, it may be more appropriate to measure countermovement jump performance with hands on the hips (arms akimbo). By limiting the use of the arms during the jump, the results may be a more accurate representation of lower body power.

In addition, countermovement jump has been shown to have a relationship with sprint performance, 1RM squat strength, and explosive strength tests (Markstrom, & Olsson, 2013; Nuzzo, Anning, & Scharfenberg, 2011). Countermovement jump is typically expressed as jump height achieved. There are various ways to measure the result of jump height through a countermovement jump, certain apparatuses to use include contact mats, force plates, and high-speed cameras. Contact mats are of interest considering they are easily accessible and quick to collect data with large team sports. Contact mats measure vertical jump height through flight time. Flight time is defined as the recorded duration the athlete is in the air with no contact on the mat (Nuzzo, Anning,

& Scharfenberg, 2011). Thus, by knowing the flight time, vertical jump height can be determined by the following equation:

$$\text{Jump height} = (g * \text{flight time} * \text{flight time})/8 \text{ (Carlock et al., 2004)}$$

For reliability purposes, it has been suggested that vertical jump height is best scored by using the average of the completed jumps, rather than the best jump (Taylor et al. 2010). Taylor et al. (2010) found that, when assessing small changes in performance frequently for the duration of a training intervention, it was more reliable to use the average of 3-6 trials rather than a single “best” trial to reduce variation from week-to-week and reduce the total error associated with testing.

505 Change of Direction Test

The 505 change of direction (COD) test may be a useful tool to measure the change of direction of athletes who participate in a sport where similar movement patterns occur. Furthermore, this test is typically believed to distinguish the change of direction ability between dominant and non-dominant legs or in other words, be able to assess any right and left asymmetries (Sheppard & Young, 2006).

The standard 505 COD test procedures include setting up two cones at baseline, two cones at the 10-meter mark, and the last set of cones 15 meters from the baseline start. The test begins with the individual standing on the baseline, on an auditory signal, the athlete sprints forward past to the first set of cones (10m from starting line) and continues sprinting until he/she approaches the second set of cones (15 meters from starting line), at the second set of cones the athlete is required to decelerate, change directions 180° and accelerate back through the first set of cones. The athlete typically completes two trials turning off each leg (Haff & Triplett, 2016). Recently, the 505 COD

test using 10-yard run-up and 5-yard COD sprint has been validated for use testing specific to American football (Lockie et al., 2017). The adapted 505 COD test detects moderate performance changes, and can discriminate between football position groups while showing similar qualities to the original 505 COD test (Lockie et al., 2017).

Repeat Sprint Anaerobic Test

Team sport athletes are required to produce repeated short bouts of maximal effort. Thus, repeat sprint ability has been considered a strong component in team sports. Repeat sprint ability describes how efficiently an athlete can recover and maintain maximal effort during subsequent sprints. (Turner & Stewart, 2013). The repeat sprint anaerobic test (RAST) measures an athlete's anaerobic power, capacity, and therefore, the ability to maintain effort bouts. Due to its accuracy and simplicity, the RAST is commonly used by exercise professionals to monitor performance. The traditional RAST consists of six sprints over a 35-meter distance, with a 10-second recovery between each sprint (Zagatto, Beck, & Gobatto, 2009). However, certain sports may benefit from a modified version of the RAST. Further, strength and conditioning coaches agree that for specificity and validity, the repeat sprint ability testing protocol should resemble the work to rest ratio and movement mechanics of the sport that is being assessed (Turner & Stewart, 2013). For example, during a football game, the average play is roughly 5-6 seconds long with a 30-40 second rest (Rhea et al., 2006). Therefore, the work to rest ratios for the repeat sprint anaerobic test can be manipulated to 30-yard sprint repeated every 20 seconds. Considering one 30-yard sprint would equate to 4-5 seconds of work, which is similar to an average duration of a football play (Rhea, 2006), and the 20 second between the start of each sprint mimics the short recovery time between plays, this

modified version may be more appropriate for assessing the energy demands of American football. Performance of the RSAT can be analyzed through decrements during the test (i.e fatigue index) and/or anaerobic capacity by summing the total time of the six sprints. A decrease in performance during the test may be reported by using either the sprint decrement percentage (S_{dec}) or the fatigue index formula. Sprint decrement percentage is calculated by the following formula:

$$S_{dec} (\%) = (\text{sum of all sprint times}) / (\text{best sprint time} * \text{number of sprints}) - 1 * 100$$

Fatigue index is calculated as follows:

$$\text{Fatigue index } (\%) = ([\text{slowest sprint} - \text{fastest sprint}] / \text{fastest sprint}) * 100 \text{ (Spencer et al., 2005)}$$

Although both methods are considered good for measuring fatigue rate, sprint decrement (S_{dec}) accounts for all the sprints completed, therefore limiting the impact of a good or bad start or finish (Spencer et al., 2005).

The performance tests are crucial to evaluate the effectiveness of a training program. Additionally, these tests determine any negative adaptations that could occur throughout cycles of high training demands. Coaches and training staff should incorporate testing days periodically throughout the year to monitor athletes effectively. Additionally, it is important that these performance tests be given only after a day of complete recovery, when possible (MacDougall & Sale, 2014).

Conclusion

One primary goal in training team sport athletes is to implement a safe and effective progressive overload interspersed with periods of recovery to allow for fitness adaptations; while concurrently reducing the risk of nonfunctional overreaching or

overtraining. Given the aspects of high training demands, one would speculate the responses of fatigue and fitness aftereffects to determine the performance outcome in athletes. Specifically, in sports like football, periods of training that stress multiple biomotor abilities occur, thus creating accumulative high external and internal training loads. To ensure the training demand or program is effective, monitoring the athletes in addition to testing performance measures periodically throughout the training year can distinguish the effectiveness of the training program. Furthermore, if a new program is being introduced to a team, it would be helpful to receive feedback on whether the athletes are adapting correctly, not only to enhance performance but to also prepare the individual to upcoming physical demands. More research is needed to supply information to coaches and training staff of the effectiveness of certain training programs prescribed to team sport athletes. Specifically, a need to expand the aforementioned study by Moore and Fry (2007) is warranted. Considering the Moore & Fry (2007) study related mostly to the performance responses of skill position players, the impact of such off-season training programs on defensive or offensive lineman needs further investigation.

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