UTILIZING FORCE-VELOCITY PROFILES TO IMPROVE ATHLETIC PERFORMANCE IN AMERICAN FOOTBALL PLAYERS

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LIST OF ABBREVIATIONS

1-RM	One repetition maximum
%FV imbalance	Percent force-velocity imbalance
ASIS	Anterior superior iliac spine
CMJ	Countermovement jumps
CSCS	Certified Strength and Conditioning Specialist
d	Cohen's d
DRF	Decrease of ratio in force
ES	Effect size
F0	Theoretical maximal force
FD	Force-deficient
FV	Force-velocity
FVP	Force-velocity profile
kg	kilograms
m	meters
NCAA	National Collegiate Athletics Association
P_{max}	Theoretical maximal power
V0	Theoretical maximal velocity
VD	Velocity-deficient
WB	Well-balanced

ABSTRACT

Introduction: American football requires strength, power, and speed. Force-velocity (FV) profiling describes the relationship between muscular force production and contraction velocity, and when multiplied together, the resulting product is power. FV profiling uses loaded jumps in the vertical plane and running speed in the horizontal direction to predict the imbalance between velocity and force development. **Purpose:** The first purpose of this study was to determine if FV profiling and optimized training improves performance metrics in American collegiate football players (i.e., countermovement vertical jump (CMJ), flying 10's sprinting speed, 1-repetition maximum (1-RM) barbell back squat, 1-RM power clean). The second purpose was to determine if a 6-week optimized training regimen would correct FV imbalances. **Methods:** Eighty-two male, division-I collegiate American football athletes (20.7 ± 1.5 years old) provided written informed consent to participate in this study. Subjects were grouped by their position (i.e., offense or defense). Each subject participated in unloaded and loaded squat jumps (for vertical FV profiling) and unloaded sprints (for horizontal FV profiling). The following day, sprinting speed during a flying 10 and a full clean 1-repetition maximum (1-RM) were measured. Either 24 or 48 hours later, 2 additional performance metrics were measured: CMJ and a 1-RM back squat. **Results:** Of the 82 football players enrolled in the study, 50 subjects completed the protocol. The vertical FV profiling revealed that 9 athletes were velocity-deficient, 16 athletes were well-balanced, and 25 athletes were force-deficient. Descriptive statistics showed that the %FV imbalance of the velocity- and force-deficient groups decreased or increased, respectively, and each group's imbalance moved toward the well-balanced category (90-110%). Results indicate that %FV imbalances improved as a result of the training in the velocity- and force-deficient groups, and the well-balanced group retained its well-balanced standing. **Conclusion:** Six weeks of individualized training was sufficient to improve performance metrics in collegiate American football players and notably, correct FV imbalances. Utilization of FV profiling catered to the individual needs of athletes as opposed to a one-size-fits-all approach, where all athletes utilize the same training program.

INTRODUCTION

American football requires strength, power, and speed to overcome the competition. Training interventions in the off-season and preseason workouts are implemented in order to improve athletic performance for the subsequent season of play. There are many assessment protocols used to enhance athletic performance. For instance, force-velocity profiling (FV) has been used in sports such as rugby,[18] soccer,[12] ice hockey,[25] netball,[7] and ballet.[6] FV profiling describes the relationship between muscular force production and contraction velocity, and when multiplied together, their resulting product is power. Mechanical power output is the foundation of explosive sport movements.[18] Studies have shown that there is an optimal FV profile for every athlete, and this is achieved by optimizing both contraction velocity and force production.[15, 21] Maximum force production of a concentric contraction occurs at a submaximal velocity as time is needed to maximally recruit motor units.[2] Maximum contraction velocity is dependent on the load and slows at the end of the movement due to deceleration.[8] Thus, peak power is attained when force and velocity are optimized and occurs at different timepoints among individuals.

FV profiling uses force production in loaded jumps in the vertical plane and running velocity in the horizontal direction to predict the imbalance between velocity and force development.[15] Jimenez-Reyes previously demonstrated that athletes with the smallest FV imbalances (FV_{imb}) had the greatest maximal power (P_{max}) measurements.[14] The concerns are not knowing the cause of their imbalance, which way the imbalance is shifted towards, and the magnitude of the imbalance. This could potentially lead to suboptimal training programming, as baseline performance should dictate the training focus. Research has shown that by first quantifying the FV imbalances of an athlete, adapting the training prescription to the individual's

needs is a more effective approach to optimizing their athletic profile.[14] Vertical jumps and unloaded sprints are used for FV profiling and can be used to determine if the athlete is force-deficient, velocity-deficient, or is well-balanced between force and velocity.

An athlete who is able to generate large forces at slower contraction velocities are characterized as velocity-deficient. Athletes who are capable of faster contraction velocities, but are unable to generate large force productions, are characterized as being force-deficient. By evaluating an athlete's FV profile for deficiencies (force or velocity), athletes and performance professionals will know which performance variable to target. Individual imbalances between force and velocity development can guide training regimens. For example, an athlete with a force deficit would benefit from strength training of high load and low repetitions, whereas a velocity-deficient athlete would benefit from speed training, reduced load and increased tempo. Theoretically, by improving the deficient area, maximal power output should increase, thus enhancing sport performance.

Utilizing FV profiles to group athletes into designated training programs has shown to decrease the within-group response variation of one overarching program for everyone to follow.[15] This process is known as “optimized training” as published by Jimenez-Reyes et al.[15] Defining FV imbalances and employing optimized training to correct imbalances have shown to boost performance measurements in other sports such as rugby,[18] soccer,[12] ice hockey,[25] netball,[7] and ballet.[6] One study which used FV profiling and optimized training in semi-professional soccer and rugby players showed that a 9-week group intervention was more effective than traditional resistance training in improving vertical jump performance.[15] Another study that tested the effects of an individualized, 9-week training regimen based on FV profiling for jump

performance in professional female classic ballet dancers and found significant improvements in their countermovement jumps.[7]

To our knowledge, use of FV profiling in collegiate, American football athletes has not been employed for the purpose of optimizing training and performance. Therefore, the first purpose of this study was to determine if FV profiling and optimized training improves performance metrics in American Football players (i.e., countermovement vertical jump, flying 10's sprinting speed, 1-repetition maximum (1-RM) barbell back squat, 1-RM power clean). The second purpose was to determine if a 6-week optimized training regimen would correct FV imbalances.

METHODS

Subjects

Eighty-two male, collegiate American football athletes (20.7 ± 1.5 years old) provided written informed consent to participate in this study. This was approved by the University of Hawaii Institutional Review Board (IRB #2022-00845). All subjects were NCAA approved and eligible athletes. The subjects had a training age ranging from 0 to 5 years, indicating the number of years an athlete has been properly trained in resistance training. Prior to testing, all participants were familiarized with the testing and training procedures and training program. All testing took place between 6 and 10 AM. All performance measures, with the exception of the timed sprints, took place in an air conditioned weight room. The sprints took place on an outdoor, artificial turf field. In the case that athletes were unable to attend training sessions due to sickness, they were allowed to make it up before the start of the next training week. Athletes

who suffered injuries within the time of study were excluded if the athletic training staff did not allow for continued participation.

Procedures

This study occurred over a 9-week span. During week 1, FV profiling and performance metrics were measured, which was followed by 6 weeks of optimized training for the three groups as determined by FV profiling (force-deficit, velocity-deficit, well-balanced). Week 8 featured a tapering period, where athletes were not permitted to participate in any of their group-prescribed training sessions, but were allowed to do all daily post-training activities. This included active recovery modalities such as activation and stretching, foam rolling, cupping, and massage. The taper period is a usual part of collegiate football pre-season training in preparation for fall camp and for this particular study, provided rest from the demanding training prior to post-testing. Following the taper period during week 9, athletes were re-tested using the same assessments performed during week 1.

Subjects were grouped by their position (i.e., offense or defense). Offensive athletes were tested as a group and rotated through a series of tests that were administered by trained personnel to determine horizontal FV and vertical FV profiling. Defensive athletes were tested after the offensive athletes, and this protocol enabled all FV profiling to be completed on day 1. Specifically, each subject participated in unloaded and loaded squat jumps (for vertical FV profiling) and unloaded sprints (for horizontal FV profiling). The following day, sprinting speed during a flying 10 and a full clean 1-repetition maximum (1-RM) were measured. Either 24 or 48 hours later, 2 additional performance metrics were measured: a countermovement jump (vertical jump height) and a 1-RM back squat. Table 1 outlines the testing schedule.

Prior to all testing and training sessions, athletes were led through an 8-minute standardized dynamic warm-up that focused on increasing blood circulation, tissue temperatures, rhythmic movements, and stretch-shortening cycle priming (seen in Appendixes A through D). All athletes were instructed with the same verbal script prior to each testing session by the same administrator. All individual performance and testing measures completed pre- and post-training intervention and were cued and performed the same way. Also, verbal encouragement was provided by test administrators and coaches during training and testing sessions.

Table 1A. PRE-TESTING SCHEDULE BY POSITION

	Monday	Tuesday	Wednesday	Thursday
Time 1	ALL OFFENSE	OL	RB	ALL OFFENSE
		QB	WR	
		TE	SPEC	
Time 2	ALL DEFENSE	DL	$AF	ALL DEFENSE
		LB	CB	

Note. OL (Offensive Line), QB (Quarterback), TE (Tight End), RB (Running Back), WR (Wide Receiver), SPEC (Special Teams), DL (Defensive Line), LB (Linebacker), $AF (Safety), CB (Cornerback).

Table 1B. PRE-TESTING SCHEDULE BY TEST

	Monday	Tuesday	Wednesday	Thursday
Time 1	Bodyweight HOR+ VERT FVP	Flying 10s Cleans	Flying 10s Cleans	CMJ Back Squat
Time 2	Bodyweight HOR+ VERT FVP	Flying 10s Cleans	Flying 10s Cleans	CMJ Back Squat

Note. Bodyweight. HOR + VERT FVP (Horizontal and Vertical Force-Velocity Profiling), Flying 10s, Cleans (Full Cleans), CMJ (Counter-movement Jump), Back Squat.

Vertical Force-Velocity Testing

The subjects' height, lower limb length, body weight and initial jump height were required for FV profiling computing, so these anthropometrics were measured first. Body weight was measured with an analog scale (Toledo Scale Company, OH), and lower limb length (distance from anterior superior iliac spine [ASIS] to toes with ankle plantarflexion with shoes), and initial hip height (distance from ASIS to the floor with knees flexed 90° while seated on a plyometric box) were measured with a tape measure. For the initial jump height of each subject, knee flexion at 90° was determined by aligning a square on the lateral side of the right knee joint, so that the arms of the square aligned with the midline of the thigh and midline of the shin. Using their initial jump height and assigned plyometric box, athletes were asked to stand on the Just Jump! mat, lower down to the box while bending their knees, and jump as high as possible.

For the squat jump, individuals performed vertical, maximal effort squat jumps without load and against four external loads ranging from 20 to 60 kg. Loads were imposed through the back rack position using an Olympic barbell that weighed 20 kg. The protocol used in this study

is the same method used in previous FV profiling studies.[7, 14, 15] The unloaded jump consisted of using a dowel that weighed 0.4 kg, which ensured the posture of the jumps were equalized across weighted conditions. For the squat jumps, the athlete lowered into their individual starting position with knees flexed to a 90º angle, and held this position for two seconds before exploding into a maximal jump and landing on a JustJump! mat (PerformBetter, West Warwick, RI). Countermovements were not allowed. The protocol was repeated if subjects did not adhere to the instructions. Subjects performed two trials at each load, and the highest jump was recorded. For each attempt, athletes were given two minutes of recovery between trials, and 4 minutes between each load condition. Vertical force-velocity profiles were computed using the individual's limb length measurements, initial jump height measurement, jump height results, and a publically available spreadsheet that automates FV profiling calculations.[21] The spreadsheet determines the graphical slope of the subject's actual vertical FV relationship and the subjects' theoretical optimal FV profile.[21] The spreadsheet can be accessed from this website: https://jbmorin.net/2017/10/01/a-spreadsheet-for-jump-force-velocity-power-profiling/.

The graphical slope represents the individual's ratio between the external force that they develop and their maximal velocity capabilities.[20] Considering that each individual's theoretical optimal FV profile is relative to himself, their current balance between force and velocity dictates the quality of their performance and the profile is specific to each athlete.[20] FV imbalances of ≤ 90, 90-110, or ≥ 110 corresponded to the force-deficient, well-balanced, or velocity-deficient group, respectively. Results of the FV profiles determined which training regimen the athlete participated in, i.e., force-deficient group focused on high load, velocity deficient group focused on low load, well-balanced group engaged in a blend of higher load with lower velocities and less sets of repetitions in order to serve both qualities. In addition, vertical

maximal force (F0), vertical maximum velocity (V0), and maximal power output (P_{max}) were calculated using the validated MySprint app.[14] F0 and P_{max} were normalized to body weight in kilograms.

Horizontal Force-Velocity Testing

An unloaded 30 meter sprint was used for horizontal FV testing. Testing was completed on artificial turf and athletes wore football cleats. Prior to testing, subjects performed a standardized dynamic warm up. The dynamic warm-up included a progressive order of speed improvement drills, intended to prime the athletes for a maximum velocity workout. Speed sticks were set up at 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m intervals and were used as markers to measure the time it took for each athlete to cover each 5 m distance. Subjects started from a two point, staggered stance with a self-selected front foot and ran as fast as they could for the entire duration of the 30 m sprint. For the set-up of their start, all subjects were required to hold their stance for two seconds to best designate when they took off and started the run. Each subject was required to start their run from a complete stop. They were instructed that any type of movement would classify as their start and start their time for the run. Verbal encouragement was given to all participants. Each sprint was filmed using the camera of an 6th generation iPad (Apple Inc., Cupertino, CA) and a dedicated iOS app called My Sprint.[13] One valid trial was required for each subject. Subjects were required to repeat the 30 m sprint if they did not satisfy the starting position requirements. They were also required to repeat the 30 m sprint if they did not run all the way and finish through the end point of the last speed stick placed at the 30 m point.

After the pre-testing, video analysis was used to determine the split times for each 5 m distance as marked by the speed sticks. Each individual's sprint time was calculated from the

subject's first propulsive movement and using the timer on the video, each 5 m split was determined and entered into the My Sprint app containing previously validated prediction equations as reported by Samozino et al.[16] From these predictive equations, horizontal F0, horizontal V0, P_{max}, and horizontal rate of decrease in ratio of force (DRF) was calculated by the MySprint app.

Performance Metrics

The four performance variables that were measured from pre- to post-intervention were: flying 10s, countermovement vertical jump, a full clean 1-RM, and a 1-RM back squat. These variables were selected as they are the same metrics used in previous training seasons for the collegiate football team. All participants were familiar with the testing procedures as they performed them in their previous collegiate strength and conditioning program. The flying 10 is a timed sprint that measures the average peak velocity over a 10-yard distance. Two timing gates placed 10 yards apart were used to determine sprinting speed. All participants were given a specific lead-in distance before approaching the first laser gate. All linemen, offensive and defensive, had a 10 yard lead-in (10 yards +10 yards). All offensive and defensive skills players, including quarterbacks, wide receivers, tight ends, running backs, linebackers, defensive backs, and specialists were given a 20 yard lead-in (20 yards +10 yards). The same verbal instructions, cues, and encouragement were provided to all participants. Three successful flying 10s trials were performed and the fastest time was used.

Countermovement jumps (CMJ) were conducted using a JustJump! mat, which measured vertical jump height.. Each athlete was given 3 trials and the best CMJ trial was used in the analyses. All participants were instructed to jump as high as possible, to not to kick back or out

and to jump straight up without tucking their knees. If an athlete failed to adhere to these guidelines, the trial was not counted as a successful trial. Each participant had at least two minutes rest between jump trials.

For the full clean 1-RM, athletes used an Olympic barbell and rubber plated weights. The lift started from the ground, and the athletes were instructed to catch the bar at the bottom position of a front squat. All subjects were asked to execute the lift to their maximum effort to establish their 1-RM, gradually adding load after the warm up. The lift was considered to be completed only if the athlete reached full hip extension upon standing from the bottom catch position. All subjects were given 3 sets to achieve their 1-RM after clearing through submaximal warm-up sets. The weight of the heaviest executed lift would be used in alignment with training protocols. All full clean trials were done using the same equipment. All subjects were previously recorded for their 1-RMs on the lift. Weight was added based on the previously recorded 1-RM, current proficiency and successful executions, and strength coach's recommendations for subsequent attempts. The weight was gradually increased to achieve the 1-RM by the 6th set of the exercise.

For the 1-RM back squat, athletes were tested using an Olympic barbell and iron plated weights. The lift started from a standing position after unracking the bar from a resting position on the squat rack. Athletes were asked to provide maximal effort to lower the back-racked weight down to a 90º knee angle and stand up unassisted. If the athletes failed to lift the weight, the lift was not recorded. Three spotters were used, positioned at either side outside of the barbell and one behind the athlete. Spotters were not allowed to touch the bar or assist in the lift unless the athlete could not safely finish the lift themself. All lifts were supervised by a certified athletic performance coach with the CSCS, Certified Strength and Conditioning Specialist, designation.

Weight was added based on the previously recorded 1-RM, current proficiency and successful executions, and strength coach's recommendations for subsequent attempts. The weight was gradually increased to achieve the 1-RM by the 6th set of the exercise.

Training Program Design

After the initial horizontal and vertical force-velocity profile testing, individualized FV profiling was computed. Subjects were assigned to a force-deficient (FD), a velocity-deficient (VD), or a well-balanced (WB) group. The WB group consisted of athletes who did not exhibit large FV imbalances according to their theoretical optimal calculation and had FV imbalance percentages ranging from 90% to 110%.[14] Subjects in the FD group had FV imbalances percentages of less than 90% while the VD group had FV imbalances percentages greater than 110%.

Training programs were designed to reduce the FV imbalance. The pre-testing performance metrics of each athlete were used to design the individualized training intervention (i.e., 1-RM measurements were used to determine training load based on created training programs). Each training program for the groups varied in terms of volume and intensity to match the individual athlete's profile. The force-deficit training program used a minimum of 6 exercises each week that addressed strength, strength-power, and power (i.e., power clean, front squats, trap bar deadlift, rear foot elevated split squat, back squat, and barbell hip lift). Due to the deficiency in force production, the program focused on strength gains more so than power.[14] Appendix E provides examples of training programs for the force-deficient group.

The velocity-deficit program included speed-focused exercises in addition to power-speed, and power exercise variations. For example, dynamic effort back squat with

resistance band accommodation, weighted countermovement jumps, snatch grip high pulls, rear foot elevated split squat, power clean, and back squat were some of the exercises that were used. Appendix F shows the training program for the velocity-deficient group.

The well-balanced intervention incorporated exercises that focused equally on strength, strength-power, power, power-speed, and speed. Exercises for the WB group included power clean, dynamic effort back squat with resistance band accommodation, unloaded box jumps, clean pulls from the hang position, block cleans from below the knee, and back squat. Appendix G reflects the training program for the WB group.

Since 3 of the 4 performance metrics rely on force production in the vertical plane, the vertical FV profile was used to design the training program. The horizontal FV profile could have been used to design the training intervention, but using the principle of specificity, which states that training should mimic the targeted movement, we opted to use the vertical FV profile. The training programs relied heavily on vertical movements, for example, squats which require lifting a load in the vertical plane rather than pushing a sled in the horizontal plane.

STATISTICAL ANALYSIS

Descriptive statistics were performed for all measurements including performance metrics and the outcome variables both horizontal and vertical force-velocity profiles. Mean delta and Cohen's effect sizes (ES) were also calculated to assess the size of change in the variable metrics. Ranges of Cohen's d of up to 0.2, 0.5, and 0.8 reflected small, medium, and large effect sizes.[7] 2 x 3 ANOVAs (Time [pre, post] x Group [force deficient, velocity deficient, well-balanced]) were used to determine the presence of significant main effects or interactions for each dependent variable. If a main effect was detected, Tukey's post-hoc statistical analyses

were used to determine which, if any, groups were statistically different from each other. Dependent variables included the 4 performance metrics (flying 10's, 1-RM barbell back squat, 1-RM power clean, CMJ), vertical FVP variables (F0, V0, P_{max}, %FV imbalance), and horizontal FVP variables (F0, V), P_{max}, horizontal rate of decrease in ratio of force (DRF). Within-group and between-group differences in pre and post-training were assessed for performance variables and vertical force-velocity profile measurements. The statistical significance was set at a p-value of 0.05. SPSS software (MacOS, New York, United States) was used for statistical analyses.

RESULTS

Of the convenience sample of 82 division I American football players at the University of Hawaii at Manoa, 50 subjects satisfied the adherence requirement, which was minimum of 80% training intervention attendance and completion of all pre- and post-testing. As such, 50 complete datasets were included in the statistical analyses. The vertical FV profiling revealed that 9 athletes were velocity-deficient, 16 athletes were well-balanced, and 25 athletes were force-deficient. Table 2 shows the breakdown of each FV group based on the position group played for football. The bigs represented subjects who played offensive and defensive line. There were 11 FD, 1 VD, and 3 WB. The big skills category consisted of linebackers, running backs, tight ends, and specialists. There were 5 FD, 2 VD, and 6 WB. Meanwhile the wide receivers, cornerbacks, safeties, and quarterbacks made up the skills position. There were 9 FD, 6 Vd, and 7 WB. Table 2 also reflects each position group's height, pre- and post-body weight, and pre- and post-%FVimb. The first 4 columns in Table 3 provide pre- and post-training results (means ± SD), delta changes, and effect sizes for each FV group as a whole.

The 2x3 ANOVAs revealed a significant main effect of Time in all performance metrics except for the Flying 10s (see Table 2's three columns on the right). After the 6-week training intervention, there were significant improvements in the 1-RM back squat, 1-RM full clean, and countermovement jump across all three groups ($p< 0.001$). The performance metrics movements that improved from pre- to post-training were vertically based. There were no significant main effects of group or interaction for any of the performance metrics. As noted in Table 2, there was a small effect size for the mean 1-RM barbell back squat (d=0.26), 1-RM power clean (d=0.24) and CMJ (d=0.26). Notably, the force-deficient group exhibited the greatest improvements in the strength-dependent performance metrics among the 3 groups, such as 1-RM barbell back squat (d=0.34, 5.34% improvement) and 1-RM power clean (d = 0.30, 4.00% improvement).

Table 3 shows the horizontal force-velocity profiling data. 2x3 ANOVAs showed significant main effects of time for all dependent variables, including F0 (absolute and relative), P_{max} (absolute and relative) and horizontal DRF. However, it was found that all three groups significantly reduced V0 over time. Cohen's d showed large effect sizes in all FV profiling groups of F0 (absolute and relative), V0, P_{max} (absolute and relative), and DRF from pre- to post-intervention. Also, there were no significant group main effects or interaction for the horizontal FVP metrics.

Of great interest, as outlined in Table 4, descriptive statistics show that the %FV imbalance of the velocity- and force-deficient groups decreased or increased, respectively, and each group's imbalance moved toward the well-balanced category (90-110%). The velocity-deficient group had a %FV imbalance of 134.3 ±11.1% prior to training and after training, the imbalance decreased to 96.8 ± 22.4%, placing this group in the well-balanced category. The force-deficient group had a %FV imbalance of 68.2 ± 15.5% prior to training and

after training, imbalance increased to 86.2 ± 38.1%, which is just 4% shy of the well-balanced category. Post-training intervention, the well-balanced group scored remained in the well-balanced category. Results indicate that %FV imbalances improved as a result of the training in the velocity- and force-deficient groups, and the well-balanced group retained its well-balanced standing.

Table 4 contains the results of the statistical analyses of the vertical FVP. This table can be best interpreted by understanding that the data reflects the impact of change imposed by the group-specific training programs that were designed based upon vertical FV imbalances designations. The 2x3 ANOVA revealed significant main effects of Group for F0 (relative), V0, P_{max} (absolute) and % FV imbalance. With regard to absolute F0, Tukey's post hoc test revealed that the force-deficient group was significantly weaker than the velocity-deficient group (p= 0.012). Although the well-balanced group tended to have a greater F0 than the force-deficient group, it was not significantly different according to Tukey's post hoc test (p= .074). The velocity-deficient group had a significantly lower V0 than the force-deficient group (p= .002). The well-balanced group tended to have a greater V0 than the velocity-deficient group, however it wasn't significant (p= .098). For the measure of absolute P_{max}, the force-deficient group tended to have more power than the velocity-deficient group, but this was not significant (p= .054). However, there was a significant difference found between the force-deficient group and the well-balanced group for absolute P_{max} (p= .013). Tukey's post hoc test showed a significant difference between the velocity-deficient group and the force-deficient group for %FV imbalance (p< .001). There was also a statistically significant difference between the well-balanced group and the force-deficient group for %FV imbalance (p< .001).

Cohen's d showed moderate and large effect sizes for F0 and V0 in the velocity-deficient group, concomitant with a 800% increase in V0. Despite these large changes, there was no main effect of time as each group had divergent outcomes (some showed improvement while others showed decrement), washing out the main effect of time across groups.

Table 2. SUBJECT MEASURABLES BY POSITION GROUP AND FORCE-VELOCITY GROUP

Table 2. Subject measurables by position group and force-velocity profile group (n=50)

	FD	VD	WB
BIGS			
n	11	1	3
Height (m)	1.88 ± 0.06	1.84	1.90 ± 0.14
PRE-Weight (kg)	124.7 ± 18.33	114.3	126.25 ± 18.01
POST-Weight (kg)	125.4 ± 18.06	114.76	121.11 ± 11.41
PRE %FVimb	69.27 ± 9.34	131	96 ± 1.73
POST %FVimb	57.73 ± 24.17	83	70.67 ± 28.54
BIG SKILLS			
n	5	2	6
Height (m)	1.87 ± 0.09	1.75 ± 0.02	1.82 ± 0.03
PRE-Weight (kg)	93.98 ± 12.6	98.66 ± 0.32	94.27 ± 4.8
POST-Weight (kg)	93.53 ± 11.65	98.2 ± 3.53	94.65 ± 4.61
PRE %FVimb	66.60 ± 16.53	135 ± 0.00	98.33 ± 6.77
POST %FVimb	100.6 ± 36.53	89.5 ± 41.72	126.83 ± 25.56
SKILLS			
n	9	6	7
Height (m)	1.86 ± 0.03	1.82 ± 0.09	1.80 ± 0.04
PRE-Weight (kg)	88.2 ± 8.55	84.37 ± 8.63	74.97 ± 7.35
POST-Weight (kg)	88.3 ± 9.47	84.37 ± 9.58	75.3 ± 7.27
PRE %FVimb	71.22 ± 20.74	134.67 ± 13.89	103.43 ± 6.78
POST %FVimb	113.11 ± 29.83	101.5 ± 19.22	106.57 ± 19.28

Note. Data are expressed as mean ± standard deviation. FD = force-deficient. VD = velocity-deficient. WB = well-balanced. Bigs = offensive linemen and defensive linemen. Big skills = linebackers, running backs, tight ends, and specialists. Skills = Wide receivers, cornerbacks, safeties, and quarterbacks. m = meters, kg = kilograms, %FVimb = Vertical force-velocity imbalance percentage.

Table 3. PERFORMANCE VARIABLES BEFORE AND AFTER THE TRAINING INTERVENTION

Variable	Pre-training	Post-training	Δ%	Effect Size (Cohen's d)	MANOVA p (ηp2) Time	Group	Group x Time
Flying 10 (s)					.472 (.011)	.121 (.086)	.622 (0.20)
Velocity Deficient	1.05 ± .07	1.05 ± .07	0.00%	0.00			
Well-Balanced	1.08 ± .10	1.08 ± .09	0.00%	0.00			
Force Deficient	1.13 ± .11	1.12 ± .11	-0.88%	-0.09			
Mean	1.10 ± .10	1.09 ± .10	-0.91%	-0.10			
Barbell Backsquat 1-RM (kg)					**<.001 (.273)**	.466 (.032)	.251 (.057)
Velocity Deficient	180.30 ± 29.68	182.95 ± 33.85	1.47%	0.08			
Well-Balanced	168.47 ± 30.95	177.04 ± 37.80	5.09%	0.25			
Force Deficient	180.09 ± 26.75	189.69 ± 29.87	5.33%	0.34			
Mean	176.41 ± 28.60	184.43 ± 33.01	4.55%	0.26			
Power Clean 1-RM (kg)					**<.001 (.239)**	.326 (.047)	.856 (.007)
Velocity Deficient	116.1 ± 13.1	119.4 ± 9.50	2.87%	0.29			
Well-Balanced	108.4 ± 20.6	112.3 ± 20.40	3.51%	0.19			
Force Deficient	115.6 ± 14.5	120.2 ± 16.53	4.01%	0.30			
Mean	113.4 ± 16.6	117.5 ± 17.01	3.65%	0.25			
Countermovement Jump Height (m)					**<.001 (.272)**	.585 (.023)	.765 (.011)
Velocity Deficient	.78 ± .10	.81 ± .13	3.85%	0.26			
Well-Balanced	.77 ± .09	.80 ± .12	3.90%	0.28			
Force Deficient	.74 ± .11	.77 ± .12	4.05%	0.26			
Mean	.76 ± .11	.79 ± .12	3.95%	0.26			

Note. Data are expressed as mean ± standard deviation. Mean Δ% = [(Post - Pre)/Pre]*100. A Cohen's d of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥ 0.80 represent trivial, small moderate, and large effects, respectively. A partial eta squared (ηp2) ≥ 0.01 indicates a small effect, ≥ 0.059 is a medium effect, and ≥ 0.138 is a large effect. Repeated measures univariate ANOVAs results are in the 3 columns to the right, where an ANOVA was run for each dependent variable. s = seconds, kg = kilograms, m = meters

Table 4. HORIZONTAL FORCE-VELOCITY PROFILE BEFORE AND AFTER THE TRAINING INTERVENTION

Variable		Pre-training	Post-training	Mean Δ%	Effect Size (Cohen's d)	MANOVA p (ηp2) Time	Group	Group x Time
F0 (N)						**< .001 (.528)**	.298 (.05)	.818 (.009)
	Velocity Deficient	588.42 ± 67.4	768.30 ± 129.19	30.57%	1.82			
	Well-Balanced	583.00 ± 142.84	807.91 ± 187.69	38.57%	1.36			
	Force Deficient	651.13 ± 183.32	873.78 ± 258.59	34.19%	1.01			
	Mean	618.04 ± 156.79	833.71 ± 219.28	34.90%	1.15			
F0 (N/kg)						**< .001 (.553)**	.703 (.02)	.864 (.006)
	Velocity Deficient	6.55 ± .88	8.64 ± 2.15	31.91%	1.38			
	Well-Balanced	6.52 ± 1.63	8.88 ± 2.39	36.20%	1.17			
	Force Deficient	6.27 ± 1.52	8.31 ± 1.92	32.54%	1.19			
	Mean	6.40 ± 1.45	8.55 ± 2.09	33.60%	1.21			
V0 (m/s)						**< .001 (.650)**	.733 (.013)	.689 (.016)
	Velocity Deficient	8.97 ± .61	8.23 ± .35	-8.25%	-1.54			
	Well-Balanced	8.94 ± .71	7.98 ± .44	-10.74%	-1.67			
	Force Deficient	8.85 ± 1.04	7.93 ± .70	-10.40%	-1.06			
	Mean	8.90 ± .86	8.00 ± .57	-10.11%	-1.26			
Pmax (Watts)						**< .001 (.440)**	.425 (.036)	.894 (.005)
	Velocity Deficient	1317.89 ± 144.47	1579.10 ± 261.72	19.82%	1.29			
	Well-Balanced	1289.82 ± 268.69	1610.78 ± 380.93	24.88%	0.99			
	Force Deficient	1405.38 ± 277.07	1695.79 ± 372.39	20.66%	0.89			
	Mean	1352.66 ± 256.97	1647.59 ± 354.99	21.80%	0.96			
Pmax (Watts/kg)						**< .001 (.484)**	.434 (.035)	.595 (.022)
	Velocity Deficient	14.71 ± 2.24	17.70 ± 4.48	20.33%	0.89			
	Well-Balanced	14.49 ± 3.44	18.13 ± 4.67	25.12%	0.90			
	Force Deficient	13.72 ± 3.09	16.37 ± 3.69	19.31%	0.78			
	Mean	14.14 ± 3.05	17.17 ± 4.16	21.43%	0.84			
Horizontal DRF (Rate of Decrease in Ratio of Force)						**< .001 (.645)**	.208 (.813)	.703 (.015)
	Velocity Deficient	-.07 ± .01	-0.1 ± .02	42.86%	-2.00			
	Well-Balanced	-.07 ± .02	-0.1 ± .02	42.86%	-1.50			
	Force Deficient	-.07 ± .02	-0.1 ± .03	42.86%	-1.20			
	Mean	-.07 ± .02	-0.1 ± .02	42.86%	-1.50			

Note. Data are expressed as mean ± standard deviation. Mean Δ% = [(Post - Pre)/Pre]*100. A Cohen's d of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥ 0.80 represent trivial, small, moderate, and large effects, respectively. A partial eta squared (ηp2) ≥ 0.01 indicates a small effect, ≥ 0.059 is a medium effect, and ≥ 0.138 is a large effect. Repeated measures univariate ANOVAs results are in the 3 columns to the right, where an ANOVA was run for each dependent variable. s = seconds, kg = kilograms, m = meters, N = newtons. F0 (N) = theoretical absolute maximal force output, F0 (N/kg) = theoretical maximal force output relative to bodyweight, V0 (m/s) = theoretical maximal velocity, Pmax (Watts) = theoretical absolute maximal power output, Pmax (Watts/kg) = theoretical maximal power output relative to bodyweight, Horizontal DRF = the rate of the decrease in ratio of force in the horizontal plane when running velocity increases.

Table 5. VERTICAL FORCE-VELOCITY PROFILE BEFORE AND AFTER THE TRAINING INTERVENTION

Variable	Pre-training	Post-training	Mean Δ%	Effect Size (Cohen's d)	MANOVA p (ηp2) Time	Group	Group x Time
F0 (N)					.570 (.007)	.680 (.016)	**.007 (.191)**
Velocity Deficient	5321.67 ± 910.41	4617.78 ± 893.87	-13.22%	-0.78			
Well-Balanced	4588.44 ± 978.48	4761.19 ± 1173.41	3.76%	0.16			
Force Deficient	4614.64 ± 817.58	4934.28 ± 693.52	6.93%	0.42			
Mean	4733.52 ± 912.92	4821.92 ± 895.96	1.87%	0.10			
F0 (N/kg)					.821 (.001)	**.008 (.186)**	**.001 (.242)**
Velocity Deficient	58.74 ± 8.85	51.49 ± 11.49	-12.34%	-0.70			
Well-Balanced	50.54 ± 7.00	52.90 ± 11.16	4.67%	0.26			
Force Deficient	44.17 ± 3.68	48.26 ± 9.77	9.26%	0.55			
Mean	48.83 ± 8.03	50.33 ± 10.54	3.07%	0.16			
V0 (m/s)					.086 (.061)	**.003 (.215)**	.063 (.111)
Velocity Deficient	0.42 ± 7.43	3.56 ± 0.53	748%	0.79			
Well-Balanced	3.42 ± 0.22	3.46 ± 0.60	1.17%	0.10			
Force Deficient	4.38 ± 1.35	4.16 ± 1.77	-5.02%	-0.14			
Mean	3.36 ± 3.47	3.83 ± 1.34	13.99%	0.20			
Pmax (Watts)					.472 (.011)	**.007 (.190)**	.998 (.000)
Velocity Deficient	3926.89 ± 777.29	4084.00 ± 842.42	4.00%	0.19			
Well-Balanced	3913.63 ± 838.15	4061.19 ± 955.76	3.77%	0.16			
Force Deficient	4911.04 ± 960.76	5038.32 ± 1880.80	2.59%	0.09			
Mean	4414.72 ± 1008.55	4553.86 ± 1538.72	3.15%	0.11			
Pmax (Watts/kg)					.596 (.006)	.307 (.049)	.715 (.014)
Velocity Deficient	43.42 ± 8.30	45.28 ± 9.16	4.28%	0.21			
Well-Balanced	43.31 ± 7.26	44.86 ± 7.19	3.58%	0.21			
Force Deficient	47.96 ± 12.05	47.17 ± 8.96	-1.65%	-0.08			
Mean	45.66 ± 10.20	46.10 ±8.37	0.96%	0.05			
% Imbalance at 90 degrees					.428 (.013)	**< .001 (.427)**	**< .001 (.287)**
Velocity Deficient	134.33 ± 11.06	96.78 ± 22.41	-27.95%	-2.24			
Well-Balanced	100.13 ± 6.62	107.44 ± 29.94	7.30%	0.40			
Force Deficient	68.20 ± 15.47	86.20 ± 38.06	26.39%	0.67			
Mean	90.32 ± 28.06	94.92 ± 34.00	5.09%	0.15			

Note. Data are expressed as mean ± standard deviation. Mean Δ% = [(Post - Pre)/Pre]*100. A Cohen's d of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥ 0.80 represent trivial, small, moderate, and large effects, respectively. A partial eta squared (ηp2) ≥ 0.01 indicates a small effect, ≥ 0.059 is a medium effect, and ≥ 0.138 is a large effect. Repeated measures univariate ANOVAs results are in the 3 columns to the right, where an ANOVA was run for each dependent variable. s = seconds, kg = kilograms, m = meters, N = newtons. F0 (N) = theoretical absolute maximal force output, F0 (N/kg) = theoretical maximal force output relative to bodyweight, V0 (m/s) = theoretical maximal vertical velocity, Pmax (Watts) = theoretical absolute maximal power output, Pmax (Watts/kg) = theoretical maximal power output relative to bodyweight.

DISCUSSION

The main finding of this study was that 6 weeks of an individualized training intervention which was designed in relation to the athlete's respective FV profile improved in % FV imbalances in both force- and velocity- deficient groups. The well-balanced group tested within 90-100% range prior to the training intervention and again achieved scores consistent with the well-balanced category after the intervention. This indicates that the training intervention delivered a “well-balanced” stimulus which resulted in this group retaining their well-balanced status. While the %FV imbalances of the velocity- and force-deficient groups converged toward the well-balanced category, the force deficient group did not reach the targeted 90-110%, suggesting that while 6 weeks provided ample time to measure changes, additional training may have been necessary for optimal results. In fact, previous studies showed that 9 weeks of training based upon FV profiling improved imbalances in soccer,[12] rugby,[17] and ballet,[6] suggesting that an additional 3 weeks of training could have been beneficial.

Secondly, three vertically oriented performance metrics were significantly improved after the training intervention, while one horizontally-based performance metric was not different. This finding is not surprising as the training intervention was designed based upon the vertical FV profiles and utilized exercises which challenged the athlete in the vertical plane. The barbell back squat and power clean are tenured exercises well known to football and sport coaches to measure and examine athletes. With the addition of the countermovement jump, the three vertically-emphasized movements are convenient for coaches and practitioners to use and reference. However, the application of all three exercises is what matters most for sport performance in the sport setting. Thus, the three vertically-improved movements did not translate to making a positive impact on the flying 10 measurement metrics over the course of the study.

Previous research states that force-deficient subjects should implement training that focuses on increasing P_{max} by increasing F0 capabilities.[14] Similarly, subjects deemed as velocity deficient should work to increase P_{max} by improving their V0 capabilities. This model has been applied to improve jumping ability.[20] Although absolute P_{max} did not improve significantly over time as measured in the vertical FVP, (table 4) there were significant differences between-groups for absolute P_{max}. Additionally, all groups showed small effect size changes for absolute P_{max} (VD ES = 0.19, WB ES = 0.16, FD ES = 0.09). Interestingly enough, the lack of significance in change in relative P_{max} (in vertical FVP) after the intervention is comparable to the trivial or small changes found in previous research.[14] While normalizing P_{max} to body weight is a scientific technique that is often utilized in research, absolute P_{max} is a better measure to use when gauging game performance. Using relative P_{max} would be best used to compare changes in performance within-subjects to gauge the effect of training, independent of the athlete's body mass or resulting training-induced hypertrophy. In these types of studies, it is important to consider the value of using absolute or relative performance variables when applying it to specific scenarios.

The effect of the training is evidenced by the changes in vertical FVP variables. For example, the mean percent change in F0 for the velocity-deficient group decreased 13.22%. Since this group's training was a velocity-based program, it makes sense that velocity would improve at the expense of force production. In this group, V0 improved 800%, achieving a well-balanced FV profile score and a 4% increase in P_{max}. Thus, the velocity-concentrated training was effective in correcting the %FV imbalance and improving P_{max}. Likewise, the force-deficient group who trained for strength gains exhibited a 9.28% increase in relative F0, while V0 decreased by 4.55%. Altogether, their %FV imbalance improved, moving this group closer to the well-balanced category. These observations suggest that in order to improve FV

imbalances, resistance training programs designed specifically for velocity- or force-deficient athletes are as beneficial for improving %FV imbalances and performance metrics in the vertical plane.

In this study, vertically-oriented performance variables significantly improved over time within-groups. Moreover, each variable of the horizontal FVP tended to improve after the intervention, i.e., absolute and relative F0, V0, absolute and relative Pmax and DRF. These observations spur the question of why flying 10 performance improvements were not observed, as well as the decrease in V0, especially because previous research found that increased lower-body strength transferred positively to sprint performance.[14] Further considering that previous research has also reported that the squat and/or jump squat were associated with running speed improvements, it is surprising that no significant improvements in flying 10s performance and V0 were detected.[3] Horizontal DRF, the rate of decrease in ratio of force may explain this observation. DRF can be examined in horizontal and vertical planes, where horizontal DRF corresponds to the acceleration phase, and vertical DRF would be measured during upright sprinting posture. A positive DRF would indicate an improved ability to accelerate and efficiently run while a decrease in DRF would signal a loss or reduction in ability to accelerate. Since horizontal DRF is a measure of the ability to accelerate and sustain the quality of sprinting biomechanics, a decrement in horizontal DRF suggests that the athletes could not translate improved strength to horizontal force production, or acceleration.[1]

This corresponds to the vertically-focused training regimen as we would not expect improvements in horizontal performance metrics. In other words, the current study showed that subjects were not able to increase and/or maintain their force application at higher speeds while running the 30 meter sprint during the post-test.[14] One factor that could have hindered optimal

results is technical proficiency in sprinting, or how to apply the new strength gains in horizontal F0. The original focus of the sprinting instruction was to apply more force into the testing surface or ground in a shorter time period.[24] This would result in enhanced acceleration and an improved ability to to generate higher running velocities.[4] Competency and quality repetitions with optimal mechanics are necessary for proprioception for running at greater speeds.[11] This provides a plausible explanation of why significant improvements in horizontal F0 were not accompanied by improvements in flying 10 performance. Thus, teaching athletes how to optimize the biomechanics of sprinting should be incorporated secondary to the training intervention to ensure translation of new F0 gains to sprinting performance.[5]

LIMITATIONS

The current study utilized a convenience sample (a university football team) with a limited training age, suggesting results may not be applicable to samples with a wider range of training ages. Also, since this study required multiple testing from each athlete, logistically it was not feasible to ensure equal rest times for all study participants. Still, the rest periods for testing were within ± 24 hours. While these methods may not have been optimal, this methodology enabled this study to be completed within a (6 week) training period as regulated by the National Collegiate Athletics Association (NCAA). Secondly, the creation of the vertical FV profile relied on the electronic JustJump! mats. Force plates may have provided more accurate measurements of each subject's vertical FV outputs, but this would have hindered the speed of data collection. Also, athletic teams may not have access to force plates, limiting the practicality and application of the current study's findings. Lastly, reviewing the video of the 30 m sprints interjected subjectivity. Determining the first propulsive movement during the 30 m

sprint was subjective and could heavily influence the horizontal FV profile. This limitation was minimized by utilizing the vertical FVP to determine imbalances between force and velocity production.

CONCLUSION

Six weeks of individualized training was sufficient to improve performance metrics in collegiate American football players and notably, correct FV imbalances. The optimized training for each grouping addressed the identified needs and provided sufficient training stimuli. Utilization of FV profiling catered to the individual needs of athletes as opposed to a one-size-fits-all approach, where all athletes utilize the same training program. Utilizing FV profiling is a realistic and effective model for training collegiate football players. These methods can be replicated and applied to the various time frames of the athletic calendar year for team training.

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APPENDIX

Appendix A. Weight room warm-up routines.

TEAM UPPER BODY WARM UP	
PLATFORMS	
QUICK STEP R. FT LEAD	
QUICK STEP L. FT LEAD	
SCISSORS	
2 FT HOP	
ALL TOGETHER	
SHOULDER CAR	X 5
ISO Y/T/W	X 10 SEC EA
WARRIOR PUSH UPS (ISO)	X PERFECT

TEAM LOWER BODY WARM UP	
WARRIOR SQUAT (ISO)	X PERFECT

JUMP TESTING WARM UP	
BW SQUAT	X 10
POGOS FOR HEIGHT	X 5

TEAM LOWER BODY WARM UP (CLEAN/SQUAT)	
PLATFORMS	
QUICK STEP R. FT LEAD	
QUICK STEP L. FT LEAD	
2 FT LATERAL HOP	
2 FT LATERAL HOP	
90/90 HIP ROTATIONS + HEEL TAP	X:30 + :15EA
ISO LUNGE	X :20
WARRIOR SQUAT	X PERFECT

Note. Team warm up done on the platforms. Quick step right foot lead exercise. Quick step left foot lead exercise. Scissors exercise. 2 feet hop exercise. Shoulder controlled articular rotation (CAR) exercise. Isometric Y, T, W hold exercise. Isometric warrior push-ups exercise. Isometric warrior squat exercise. BW = bodyweight. Pogos = pogo jumps for height. 2 feet lateral hop exercise. 90/90 hip rotation stretch and heel tap exercise. X:30 = 30 seconds. :15 = 15 seconds each side. Isometric lunge. X:20 = 20 seconds.

Appendix B. Acceleration day warm-up routine.

DAY 1: ACCELERATION DYNAMIC WARM-UP	
STRIDE	x H/S
WALKING QUAD	x N
HAMSTRING SCOOPS	x N
WALKING LEG SWING	x N
SL TOE TOUCH	x N
SPRINTER LUNGE	x N
A-MARCH	x N
A-SWITCH	x H
A-BOUNCE	x S
BOOM-BOOMS	2 x 5
3 STEP BURST	x H
5 STEP BURST	x S

Note. Day 1: Acceleration dynamic warm-up. Stride. Walking quad stretch. Hamstring scoops stretch. Walking leg swing stretch. Single leg toe touch stretch. Sprinter lunge exercise. A-March exercise. A-Bounce exercise. Boom-booms exercise. 3 step burst run. 5 step burst run. x H (Do the exercise to the hash mark on the football field). x N (Do the exercises to the top of the numbers mark painted on the turf field). x S (Do the exercises to the sideline on the turf field).

Appendix C. Max velocity day warm-up routine.

DAY 2: MAX VELOCITY DYNAMIC WARM-UP	
FWD SKIP	x H
BWD SKIP	x S
WALKING QUAD + LEG CRADLE	x H
HAMSTRING SCOOPS	x N
WALKING LEG SWING	x N
SL TOE TOUCH	x N
LEG SWING SKIP	x H
BIG BOUNDS	x S
A-MARCH	x N
A-SKIP	x S
A-3s	x N
A-Pops (R)	x S
A-Pops (L)	x H
DRIBBLES: A-C-K	x S
FLOAT-SPRINT-FLOAT	x OS

Note. Day 2: Max velocity dynamic warm-up. FWD skip (forward skip) exercise. BWD skip (backward skip) exercise. Walking quad stretch into leg cradle stretch. Hamstring scoops stretch. Walking leg swing stretch. Single leg toe touch stretch. Leg swing skip exercise. Big bounds exercise. A-march exercise. A-skip exercise. A-3s exercise. A-pops right leg exercise. A-pops left leg exercise. Dribbles exercise: ankle, calf, knee. Float-sprint-float exercise. x H (Do the exercise to the hash mark on the football field). x N (Do the exercises to the top of the numbers mark painted on the turf field). x S (Do the exercises to the sideline on the turf field). x OS (Do the exercise to the opposite sideline).

Appendix D. Change of direction day warm-up routine.

DAY 3: C.O.D. DYNAMIC WARM-UP	
STRIDE	x H/S
WALKING QUAD	x N
ALTERNATING SIDE LUNGES	x N
SPRINTER LUNGE	x N
WALKING LEG SWING	x N
SL TOE TOUCH	x N
SIDE SHUFFLES	x S/H
SLOW CARIOCA	x S/H
FAST CARIOCA	x N/N
REPEAT 3 STEP BURST: 2x	x H/S

Note. Day 3: Change of direction dynamic warm-up. Stride. Walking quad stretch. Alternating side lunges stretch. Sprinter lunge stretch. Walking leg swing stretch. Single leg toe touch stretch. Side shuffles exercise. Slow carioca exercise. Fast carioca exercise. Repeat 3 step burst exercise, twice. x H (Do the exercise to the hash mark on the football field). x N (Do the exercises to the top of the numbers mark painted on the turf field). x S (Do the exercises to the sideline on the turf field).

Appendix E. Force-Deficient (FD) group's optimized training program: weeks 1 and 5.

Week 1: 3/20/23			Week 5: 4/17/2023		
FORCE DEFICIENT TRAINING PLAN (WHITE GROUP)					
DAY 1			DAY 1		
1	CLEAN	4 X 2 @ 80%	1	CLEAN	2 X 1 @ 95%/ 1 X 1 @ OPEN
2	FRONT SQUAT	3 X 6 @ 55% OF BS	2	FRONT SQUAT	2 X 2 @ 60% OF BS
3	RDL	4 X 5	3	ASSISTED SL DB RDL	3 X 3EA (60#+)
4	SA KB/DB FARMER'S WALK	3 X 30YD	4	KB WAITER'S CARRY	3 X 30YD
DAY 2			DAY 2		
1	BENCH PRESS	4 X 5 @ 75%	1	BENCH PRESS	2 X 1 @ 90%/1 X 1 @ 95%
2A	PULL UP- SKILL/BS	4 X 10	2A	PULL UP- SKILL/BS	3 X 3
2A	BIG MAN LAT PULLDOWN	NG - 4 X 5	2A	BIG MAN LAT PULLDOWN	PRO. - 3 X 5
2B	DIPS	3 X 8	2B	DIPS	3 X 5
3A	DB REAR LATERAL RAISE	3 X :30	3A	10# SNOW ANGEL	3 X :30
3B	FAT GRIP BB CURL	3 X : 30	3B	BAND CURL	3 X : 30
3C	RUSSIAN TWIST	3 X :30	3C	BAND PULL APART	3 X :30
DAY 3			DAY 3		
1	SEATED BOX JUMP WTD	5 X 1 (10# MB)	1	BB CM WTD JUMP	4 X 1 (25% SQT) SR
2	TRAP BAR DEADLIFT	3 X 5/4/3 (70%/75%/80%)	2	CLEAN PULL	2 X 2 @ 115%
3	DB/KB RFE SPLIT SQUAT	3 X 5EA	3A	DB/KB REV. LUNGE	3 X 4EA
4	KB PULL THROUGH (CRAWL)	2 X 4EA	3B	KB PULL THROUGH (P. UP)	3 X 4EA
DAY 4			DAY 4		
1	OH PRESS	4 X 5 @ 70%	1	OH PRESS	3 X 3 @ 55% OF BENCH
2A	ALT. DB BENCH	3 X 8EA	2A	DB BENCH	3 X 5
2B	PARTNER KB SEAL ROW	3 X 8	2B	WTD INV. ROW	4 X 8
3A	BARBELL SHRUG	3 X :30	3A	SNATCH GRIP OH SHRUG	3 X :30
3B	DB HAMMER CURL	3 X :30	3B	KB TOWEL CURL	3 X :30
3C	BAND TRI	3 X :30	3C	BENCH DIPS	3 X :30
DAY 5			DAY 5		
1	HAK CLEAN	3 X 3 @ 70%	1	BACK SQUAT	1 X 1 @ 90%
2	BACK SQUAT	4 X 5 @ 80%			
3	BARBELL HIP LIFT	4 X 5			
4	HOLLOW HOLD	3 X 15 SEC			

Note. SA = single arm. KB = kettlebell. DB = dumbbell. BS = big skill. NG = narrow grip. MB = medicine ball. BB = barbell. WTD = weighted. RFE = rear foot elevated. EA = each. OH = overhead. ALT. = alternating. TRI = tricep. HAK = hang above the knee. SL = single leg. BS = back squat. # = pounds. YD = yards. P. UP = push-up position. INV = inverted. REV. = reverse. SEC = seconds. CM = countermovement. SR = single response. PRO. = pronated. RDL = romanian deadlift.

Appendix F. Velocity-deficient (VD) group's optimized training program: weeks 1 and 5.

Week 1: 3/20/23			Week 5: 4/17/2023		
VELOCITY DEFICIENT TRAINING PLAN (GREEN GROUP)					
DAY 1			DAY 1		
1	CLEAN	4 X 2 @ 76%	1	CLEAN	2 X 1 @ 95%/ 1 X 1 @ OPEN
2	DE BACK SQUAT	6 X 2 @ 20% (GREEN BAND)	2	DE BACK SQUAT	5 X 2 @ 30% (GREEN BAND +)
3	RDL	4 X 5	3	ASSISTED SL DB RDL	3 X 3EA (60#+)
4	SA KB/DB FARMER'S WALK	3 X 30YD	4	KB WAITER'S CARRY	3 X 30YD
DAY 2			DAY 2		
1	BENCH PRESS	4 X 5 @ 75%	1	BENCH PRESS	2 X 1 @ 90%/1 X 1 @ 95%
2A	PULL UP- SKILL/BS	4 X 10	2A	PULL UP- SKILL/BS	3 X 3
2A	BIG MAN LAT PULLDOWN	NG - 4 X 5	2A	BIG MAN LAT PULLDOWN	PRO. - 3 X 5
2B	DIPS	3 X 8	2B	DIPS	3 X 5
3A	DB REAR LATERAL RAISE	3 X :30	3A	10# SNOW ANGEL	3 X :30
3B	FAT GRIP BB CURL	3 X : 30	3B	BAND CURL	3 X : 30
3C	RUSSIAN TWIST	3 X :30	3C	BAND PULL APART	3 X :30
DAY 3			DAY 3		
1	DB CM WTD JUMP	5 X 1 (10% SQT) SR	1	BAND ASSISTED JUMP	3 X 3 MR
2	HANG SNATCH PULL	2 X 3 @ 80%	2	HANG SNATCH	3 X 2 @ 40% OF CLEAN
3	DB/KB RFE SPLIT SQUAT	3 X 5EA	3A	DB/KB REV. LUNGE	3 X 4EA
4	KB PULL THROUGH (CRAWL)	2 X 4EA	3B	KB PULL THROUGH (P. UP)	3 X 4EA
DAY 4			DAY 4		
1	OH PRESS	4 X 5 @ 70%	1	OH PRESS	4 X 3 @ 55% OF BENCH
2A	ALT. DB BENCH	3 X 8EA	2A	DB BENCH	3 X 5
2B	PARTNER KB SEAL ROW	3 X 8	2B	WTD INV. ROW	4 X 8
3A	BARBELL SHRUG	3 X :30	3A	SNATCH GRIP OH SHRUG	3 X :30
3B	DB HAMMER CURL	3 X :30	3B	KB TOWEL CURL	3 X :30
3C	BAND TRI	3 X :30	3C	BENCH DIPS	3 X :30
DAY 5			DAY 5		
1	POWER CLEAN	3 X 3 @ 76%	1	BACK SQUAT	1 X 1 @ 90%
2	BACK SQUAT	4 X 3 @ 76%			
3	BARBELL HIP LIFT	4 X 5			
4	HOLLOW HOLD	3 X 15 SEC			

Note. SA = single arm. KB = kettlebell. DB = dumbbell. BS = big skill. NG = narrow grip. MB = medicine ball. BB = barbell. WTD = weighted. RFE = rear foot elevated. EA = each. OH = overhead. ALT. = alternating. TRI = tricep. HAK = hang above the knee. SL = single leg. BS = back squat. # = pounds. YD = yards. P. UP = push-up position. INV = inverted. REV. = reverse. SEC = seconds. CM = countermovement. SR = single response. PRO. = pronated. RDL = romanian deadlift. MR = multiple response. DE = dynamic effort. SQT = squat.

Appendix G. Well-balanced (WB) group's optimized training program: weeks 1 and 5.

Week 1: 3/20/23			Week 5: 4/17/2023		
BALANCED TRAINING PLAN (BLACK GROUP)					
DAY 1			DAY 1		
1	CLEAN	4 X 2 @ 82%	1	CLEAN	2 X 1 @ 95%/ 1 X 1 @ OPEN
2	BAND BACK SQUAT	6 X 2 @ 45% (ORANGE BAND)	2	BAND BACK SQUAT	5 X 1 @ 50% (ORANGE BAND)
3	RDL	4 X 5	3	ASSISTED SL DB RDL	3 X 3EA (60#+)
4	SA KB/DB FARMER'S WALK	3 X 30YD	4	KB WAITER'S CARRY	3 X 30YD
DAY 2			DAY 2		
1	BENCH PRESS	4 X 5 @ 75%	1	BENCH PRESS	2 X 1 @ 90%/1 X 1 @ 95%
2A	PULL UP- SKILL/BS	4 X 10	2A	PULL UP- SKILL/BS	3 X 3
2A	BIG MAN LAT PULLDOWN	NG - 4 X 5	2A	BIG MAN LAT PULLDOWN	PRO. - 3 X 5
2B	DIPS	3 X 8	2B	DIPS	3 X 5
3A	DB REAR LATERAL RAISE	3 X :30	3A	10# SNOW ANGEL	3 X :30
3B	FAT GRIP BB CURL	3 X : 30	3B	BAND CURL	3 X : 30
3C	RUSSIAN TWIST	3 X :30	3C	BAND PULL A PART	3 X :30
DAY 3			DAY 3		
1	SEATED BOX JUMP (NO WEIGHT)	5 X 1 SR	1	BAND ASSISTED JUMP	3 X 3 MR
2	HAK CLEAN PULL	4 X 3 @ 70%	2	HAK CLEAN PULL + CLEAN	3 X 1 + 2 @ 65%
3	DB/KB RFE SPLIT SQUAT	3 X 5EA	3A	DB/KB REV. LUNGE	3 X 4EA
4	KB PULL THROUGH (CRAWL)	2 X 4EA	3B	KB PULL THROUGH (P. UP)	3 X 4EA
DAY 4			DAY 4		
1	OH PRESS	4 X 5 @ 70%	1	OH PRESS	4 X 3 @ 55% OF BENCH
2A	ALT. DB BENCH	3 X 8EA	2A	DB BENCH	3 X 5
2B	PARTNER KB SEAL ROW	3 X 8	2B	WTD INV. ROW	4 X 8
3A	BARBELL SHRUG	3 X :30	3A	SNATCH GRIP OH SHRUG	3 X :30
3B	DB HAMMER CURL	3 X :30	3B	KB TOWEL CURL	3 X :30
3C	BAND TRI	3 X :30	3C	BENCH DIPS	3 X :30
DAY 5			DAY 5		
1	BAK CLEAN	3 X 3 @ 70%	1	BACK SQUAT	1 X 1 @ 90%
2	BACK SQUAT	4 X 3 @ 76%			
3	BARBELL HIP LIFT	4 X 5			
4	HOLLOW HOLD	3 X 15 SEC			

Note. SA = single arm. KB = kettlebell. DB = dumbbell. BS = big skill. NG = narrow grip. MB = medicine ball. BB = barbell. WTD = weighted. RFE = rear foot elevated. EA = each. OH = overhead. ALT. = alternating. TRI = tricep. HAK = hang above the knee. SL = single leg. BS = back squat. # = pounds. YD = yards. P. UP = push-up position. INV = inverted. REV. = reverse. SEC = seconds. CM = countermovement. SR = single response. PRO. = pronated. RDL = romanian deadlift. MR = multiple response. DE = dynamic effort. SQT = squat.

Appendix H. Running program for all training groups: weeks 1 and 5.

WEEK 1

DAY 1		ACCELERATION	
		BIG SKILLS/SKILLS	BIGS
A1	HEAVY SLED MARCHES - 2P	4 x 10 yards	
A2	SPEED BOUNDS	4 x 30 yards	
	SLED BOUNDS		4 x 20 yards
A3	MR BROAD JUMP - 3x	4 x 3	
	MR BROAD JUMP - 2x		4 x 2
B	COMPETITION SPRINTS	4 x 15 yards	4 x 10 yards

DAY 2		MAX VELOCITY	
		BIG SKILLS/SKILLS	BIGS
A1	WICKETS + FORM RUN	3 x 8 + 5 yards	3 x 8 + 15 yards
A2	FLYING 10s	3x 10+10	3x 5+10
B	PRIMETIMES	2 x 30 yards	2 x 20 yards
C	MR HURDLE HOPS: 3x	4x3	

DAY 3		ACCELERATION/COD	
		BIG SKILLS/SKILLS	BIGS
A	1/2 KNEELING COMP. LATERAL START	4 x 15 yards	4 x 10 yards
B	SR DL 90° SQUARE HOPS - DISTANCE	4 x 4	4 x 4
C	RABBIT SPRINT DECEL: 2 MOVES	4 x 20 yards	4 x 10 yards
D	RABBIT SHUFFLE	4 x 10 yards	4 x 10 yards

WEEK 6

DAY 1		ACCELERATION	
		BIG SKILLS/SKILLS	BIGS
A1	SLED TOWS - 10% of 300#/250#/200#	2 x 15 yards (30#/25#20#)	
A2	TRIPLE JUMP	2 x 1	
	MR SLED BROAD JUMP @ 45#		2 x 4
B	COMPETITION SPRINTS	2 x 30 yards	2 x 20 yards

DAY 2		MAX VELOCITY	
		BIG SKILLS/SKILLS	BIGS
A1	WICKETS	2 x 10	
A2	FLYING 10s	2 x 15+10	2 x 8+10
B	PRIMETIMES TO SPRINTS	2 x 15+20	2 x 15+10

DAY 3
OFF

Note. 2P = two plates. MR = multiple response. 3x = three jumps. 2x = two jumps. COMP. = competition. SR = single response. DL = double leg. DECEL = deceleration.