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Utilizing force-velocity profiling to improve performance in collegiate American football players

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Abstract
Introduction. **Force-velocity-power (FVP) profiling has yet to be studied in American football.** Aim of Study. **To determine (1) if optimized training based upon vertical FVP profiling could correct FVP imbalances (%FV_{imb}); (2) if optimized training over a 6-week training program could translate into performance metrics in American football players. Secondary aims: To determine if optimized training would translate into horizontal FVP metrics and provide exploratory observations on position-specific changes.** Material and Methods. **Forty-seven collegiate American football athletes (20.7 ± 1.5 years, mean ± SD) underwent pre- and post FVP profile and performance testing (countermovement vertical jump [CMJ], flying 10's speed, 1-repetition maximum [1-RM] barbell back squat, 1-RM power clean). Based upon individualized FVP profiles, the subjects were allocated to a force-deficient (FD), velocity-deficient (VD), or well-balanced (WB) group and received 6 weeks of optimized training. Paired t-tests with Bonferroni adjustments were used.** Results. **Post-intervention, %FV_{imb} of the VD and FD groups moved toward the well-balanced category. Vertical theoretical maximum velocity (V0) was significantly improved in the VD group (21.9%, p = 0.0023), but remained unchanged in the FD and WB groups. CMJ improved by 4.2% in the FD group (p = 0.0009), but not in the VD or WB groups (p > 0.05). The optimized training improved 1-RM back squat by 5.4% in the FD group (p < 0.0001) and tended to be improved in the WB group (7.0%, p = 0.0042). Flying 10's performance was unchanged in all groups (p > 0.05). Horizontal theoretical maximal force output and theoretical maximal power output improved in the WB and FD groups (38.3-47.0%, p < 0.0042), while the VD group tended to have improvements (26.5%, p = 0.0118).** Conclusions. **Six weeks of individualized training was sufficient to correct %FV_{imb}, but training did not enhance sprinting. While the FVP profiling is a feasible field-based approach in American football, learning how to best apply the FVP profiling to optimize performance is needed.**

KEYWORDS: optimization, strength, vertical jump, power.

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Introduction

Success in American football requires strength, power, and speed [12, 13], with mechanical power output forming a foundation for explosive sport movements [15]. Thus, optimizing power production capabilities of athletes could translate to enhanced sport performance. One training approach is to design training programs based upon athletes' force-velocity imbalances, or an imbalance between force production and muscle contractions velocity. Mathematically, power is a product of force and velocity, and peak power is attained when force and velocity are optimized. Maximum force production of a concentric contraction occurs at submaximal velocity. In contrast, maximum contraction velocity is dependent on a load and slows at the end of a movement [8]. A deceleration at the end of the movement is a result of a muscle reaching its maximal physical limit. Thus, peak power cannot be easily ascertained as interplay between force and velocity; peak power requires optimization of both factors.
One approach to measuring and optimizing performance is to use force-velocity-power (FVP) profiling. Jimenez-Reyes et al. previously demonstrated that athletes with the smallest FVP imbalances (%FV_{imb}) had the greatest

maximal power (P_{max}) [14]. Research has shown both theoretically [23] and experimentally [22] that for given maximal power output, athletes with a vertical FVP profile closer to an optimal value, holding other variables equal, had better vertical jump performance. Thus, optimized training can be achieved by first assessing vertical FVP profiles and then designing tailored training regimens to address deficiencies. Knowledge about imbalance magnitude and its direction could be used to design off-season and preseason training interventions. In fact, previous research suggests that quantifying vertical $\%FV_{imb}$ of an athlete and adapting a training prescription to individual's baseline fitness is a more effective approach to optimizing power when compared to a generalized approach [14]. This method has been used to assess and improve performance in sports such as rugby [17, 25], soccer [16], and futsal [16]. However, this approach has not been applied to American football, which has different in-game and position-specific demands than the previously tested sports. American football metrics are centered around vertical performance movements (vertical countermovement jump [CMJ] height, 1-repetition maximum [1-RM] power clean, and 1-RM back squat, with the only horizontal metric being sprint speed [flying 10]). Ironically, these metrics may not directly translate into this intermittent, high-intensity sport, where a game is played in three- to five-second all-out bursts, separated by 20- to 40-second rest periods [26]. American football has position-specific demands and, as a result, a team is composed of athletes with diverse athletic capabilities and heterogenous physical characteristics [24]. A wide range of physical abilities and characteristics in an American football team contrasts with those in rugby, soccer, and futsal. Furthermore, it is unknown whether this scientific approach can be realistically applied during preseason training in conjunction with usual training assessments, using a field-based approach with commercially available equipment while adhering to the National Collegiate Athletic Association (NCAA) guidelines for training duration.

Deficits in force or velocity are determined by a ratio between a measured FV slope and optimal FV slope [22]. Velocity deficit (VD) is defined as a percentage imbalance ($\%FV_{imb}$) > 110%, force deficit (FD) is defined as $\%FV_{imb}$ < 90% and athletes that have $\%FV_{imb}$ of 90-110% are considered well-balanced (WB), which is deemed optimal. FVP profiling results can be used to design training regimens and help to group athletes with similar characteristics. For example, an FD athlete would benefit from high-load, low-repetition strength training, whereas a VD athlete would benefit from speed training, reduced or no external load, and faster movements. Theoretically, by addressing identified deficiency, maximal power output should increase. Grouping athletes into one of the three categories facilitates a training regimen, in which each group works toward a common goal of improving force production (FD), velocity (VD), or maintaining their well-balanced force output and velocity (WB).

Utilizing the FVP profiles to group athletes into designated training programs has shown to decrease a within-group response variation of one overarching and generalized program for the entire team to follow [14]. This optimized training approach has been used in semi-professional soccer and rugby players, where a 9-week deficiency-assigned group intervention was shown to be more effective in improving vertical jump performance than traditional resistance training [14]. However, research suggests that improvements in vertical FVP metrics may not translate into improvements in horizontal FVP, implying that vertical and horizontal FVP are independent. While the FVP profiling has been studied in athletes from field-based sports, it was unknown whether optimized training could be achieved in a 6-week period and within NCAA guidelines in an American football team.

Since the FVP profiling is not commonly used in American football, but rather performance metrics are used to identify the top performing athletes, it is important to understand a relationship between the FVP profiles and these metrics. Thus, the main purposes of this study were to: 1) determine if optimized training based upon the vertical FVP profiling could correct $\%FV_{imb}$, and 2) determine if this optimized training over a 6-week training program could translate into performance metrics in American football players (i.e., vertical CMJs, flying 10's sprint speed, 1-RM barbell back squats, 1-RM power cleans). Secondary aims were to determine if vertically optimized training would translate into horizontal FVP metrics and to provide exploratory observations on position-specific changes in $\%FV_{imb}$. It was hypothesized that the vertically optimized training would correct vertical $\%FV_{imb}$ and that – program design derived from the vertical FVP profile would improve vertical performance metrics. However, it is unclear if changes in the vertical FVP metrics and performance will translate into changes in the horizontal FVP metrics and performance.

Methods

Participants

Eighty-two male, collegiate Division I American football athletes (20.7 ± 1.5 years, mean ± SD) provided written informed consent to participate in this study. Based upon previously published data showing improvements in maximum power with the use of FVP profiling, and assuming statistical power of 0.8 and an alpha level of 0.05, a total of 47 subjects was required to detect a significant difference in power after a 9-week training regimen [14]. To account for subject attrition and the fact that the current study would use a 6-week training intervention, an entire football team was included in this study to maximize statistical power. Data from the subjects who participated in all pre- and post-testing, and those who completed at least 80% of the training intervention was included in the analysis.

The subjects had a training age (number of years of proper resistance training) ranging from 0 to 5 years. All subjects were deemed eligible by the NCAA regulations. Prior to testing, all participants were familiarized with testing/training procedures and the training program. Athletes who had injuries during the study and/or those who did not obtain clearance from athletic training staff were excluded. This study was approved by the University of Hawai‘i Institutional Review Board (#2022-00845).

Protocol

This study was conducted over a 9-week period. During week one, FVP profiling and performance metrics were measured, which was followed by 6 weeks of optimized training for the three groups determined by the FVP profiling (FD, VD, WB). The eighth week was a tapering period, in which 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 tapering period, which allows for recovery (e.g., intramuscular substrate replenishment, skeletal muscle repair), is a usual part of collegiate football preseason training in preparation for fall camps. This ensured that the athletes were able to perform at maximum effort during post-assessments. Following the tapering period (week nine), the athletes were retested using the same pretraining assessments.

All testing took place between 6:00 and 10:00 AM. Sprints took place on an outdoor, artificial turf field. The remaining performance measures were conducted in an air-conditioned weight room. All lifts were supervised by a certified athletic performance coach with the Certified Strength and Conditioning Specialist designation. The 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 the horizontal and vertical FVP profiling. Then, defensive athletes were tested; the FVP profiling of the entire football team was completed on the first day. The following day, sprint speed was evaluated with flying 10s, and 1-RM power cleans was measured. Either 24 or 48 hours later, two additional performance metrics were measured: CMJs (vertical jump height) and 1-RM back squats.

Prior to all testing and training sessions, the 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. All athletes were instructed with the same verbal script by the same administrator prior to each testing session. All individual performance and testing measures completed the pre- and post-training intervention and were cued and performed in the same way. Verbal encouragement was provided by test administrators.

The vertical [7, 11, 14] and horizontal FVP tests [14, 16] detailed in Appendix A were performed as previously described. The vertical FVP profiles were computed using individual limb length measurements, initial jump height measurements, jump height results, and a publicly available spreadsheet that automates FVP profiling calculations [22]. The spreadsheet determines a graphical slope of a subject’s actual vertical FVP relationship and their theoretical optimal FVP profile [18, 19]. The benefit of using this method is that a jump mat is commercially available and does not require force plate measurements, which would be inaccessible to most football teams. Vertical theoretical maximal force output (F0), vertical theoretical maximum velocity (V0), and vertical theoretical maximal power output (P_{max}) were calculated using the validated MySprint app [11, 21]. F0 and P_{max} were normalized to body weight at the time of measurement, i.e., post-training F0/post-training body weight.

Horizontal F0, horizontal V0, P_{max}, and a horizontal rate of decrease in ratio of force (DRF) were calculated with the MySprint app using validated predictive equations [15]. Explanations of the derived equations have been previously described and a reader is referred to the original work validating this approach [14, 16]. DRF is the rate of decrease in ratio of force during acceleration in sprinting and is attributed to a loss of mechanical effectiveness at increasing speeds [5, 18]. The more negative the DRF, the faster the loss of force application during acceleration [18]. F0 and P_{max} were normalized to body weight.

The performance metrics that were measured pre- and post-training intervention were the flying 10s, vertical CMJs, 1-RM power cleans, and 1-RM back squats (see Appendix A for detailed methodological descriptions). These variables were selected as they are the same metrics used in previous training seasons for the collegiate football team, so all participants were familiar with the testing procedures.

After the FVP profile testing, the individualized FVP profiles were computed for each subject and they were assigned to the FD, VD, or WB group. From an operational perspective, grouping and training athletes based on both their vertical and horizontal $\%FV_{imb}$ was not possible. Since three of the four performance metrics rely on force production in a vertical plane and the training programs heavily relied on vertical movements, e.g., squats which require lifting a load in the vertical plane, the vertical FVP profile was used to design the training program.

The pretesting performance metrics of each athlete were used to individualize the training intervention. Each training program varied in terms of volume and intensity to match the individual athlete's profile. If the athletes were unable to attend training sessions due to sickness, they were allowed to make up a session before a start of a next training week. The WB group consisted of athletes who did not exhibit high $\%FV_{imb}$ according to their theoretical optimal calculation ($\%FV_{imb}$ = 90% to 110%) [11, 13, 15]. They engaged in a blend of higher loads with lower velocities and performed fewer sets in order to serve both qualities. They used exercises that focused equally on strength, strength-power, power, power-speed, and speed. The subjects in the FD group ($\%FV_{imb} < 90\%$) focused on high loads, strength, strength-power, and power. The VD group ($\%FV_{imb} > 110\%$) used speed-focused exercises in addition to power-speed and power exercise variations with low loads.

Specifically, the FD group engaged in lower body exercises with 70 to 85% 1-RM loads. The VD group performed dynamic lifts that encompassed upper and lower body exercises (i.e., hang snatches) at loads ranging from 20 to 40% 1-RM. The WB group was prescribed a range of 45 to 60% 1-RM for dynamic lower body exercises. The VD group utilized the hang snatch exercise to target velocity, whereas the FD and WB groups used the power clean variations instead. The VD and WB groups were prescribed band-assisted jumps to train overspeed, while the FD group did weighted jumps progressing in difficulty and load from a concentric starting point to countermovement. The FD group used a trap bar deadlift exercise to target strength, whereas the other groups did not. Also, while both the VD and WB groups executed dynamic effort back squats, the WB group used higher loads. Appendix B provides the example training programs for each group.

Statistical analysis

To determine if the optimized training corrected the $\%FV_{imb}$ value, descriptive statistics were used to evaluate if the imbalance in the FD and VD groups moved closer to the WB category. To show proof of concept (e.g., the FD group should have improved F0 after the intervention), 18 paired t-tests were performed for each dependent variable within each group for both vertical and horizontal FVP metrics (vertical: relative F0, V0, relative P_{max}, $\%FV_{imb}$; horizontal: relative F0, V0, relative P_{max}, DRF). After applying a Bonferroni adjustment, significance was set at $p < 0.0028$ (0.05/18). To determine if the FVP profiling optimized performance after the intervention, paired (two-tailed) t-tests were performed for each of the four metrics (CMJ, 1-RM back squat, 1-RM power clean, and flying 10's speed) for each group (FD, VD, WB). The Bonferroni adjustment was used, and significance was set at $p < 0.0042$ (0.05/12). Descriptive statistics were performed for all measurements, including the performance metrics and the outcome variables of both horizontal and vertical FVP profiles. Mean delta and Cohen's d (effect sizes) were also calculated to assess a size of change in the variable metrics. Cohen's d ranges of 0.2, 0.5, and 0.8 reflected small, medium, and large effect sizes [3]. The GraphPad Prism 10.2 software (Boston, MA) was used for statistical analyses.

Results

A total of 47 athletes completed the intervention (height, mean ± SD, FD [n = 24]: 1.9 ± 0.1 m, VD [n = 9]: 1.8 ± 0.1 m, WB [n = 14]: 1.8 ± 0.04 m; pretraining body mass, FD: 106.4 ± 22.6 kg, VD: 91.4 ± 12.6 kg, WB: 88.9 ± 17.5 kg; post-training body mass, FD: 106.6 ± 22.8 kg, VD: 93.5 ± 12.2 kg, WB: 89.2 ± 18.0 kg). As outlined in Table 1, $\%FV_{imb}$ of the VD and FD groups decreased or increased, respectively, and each group's imbalance moved toward the well-balanced category (90-110%). Prior to the training the velocity-deficient group had the $\%FV_{imb}$ value of 132.0 ± 13.7%, and after training the imbalance decreased to 92.3 ± 18.1%, placing this group in the well-balanced category. The FD group had the $\%FV_{imb}$ value of 68.2 ± 15.5% prior to the training and the score increased to 86.2 ± 38.1% after the training. Following the training intervention, the WB group scored remained in the well-balanced category. The results indicate that $\%FV_{imb}$ improved as a result of the training in the VD and FD groups, and the WB group maintained its well-balanced status.

As a result of the training, the VD group that focused on speed training exhibited a significant 13.8% decrease in normalized F0 ($p = 0.0018$, Cohen's d = –1.36, Table 1). The V0 value significantly improved by 21.9% (Cohen's d = 1.9, $p = 0.0026$) and relative P_{max} tended to increase (4.0% improvement) but did not reach statistical significance ($p = 0.05$). The FD group did not have any significant differences in the vertical FVP variables, although relative F0 tended to increase ($p = 0.0431$), resulting in a 7.3% improvement with a moderate effect size (Cohen's d = 0.50). The WB group did not show significant changes in any of the vertical FVP profile metrics.

Table 2 shows the pre-to-post changes in the performance metrics for each FVP group. The FD group that trained for strength exhibited significant improvements in the barbell back squat 1-RM ($p < 0.001$, 5.4% improvement, Cohen's d = 0.34) and CMJ height ($p = 0.0009$, 4.2% improvement, Cohen's d = 0.25). The CMJ tended to improve in both the VD and WB groups, but these changes were not statistically significant ($p = 0.0767$, $p = 0.0783$, Cohen's d = 0.8, 0.27, respectively). While

Table 1. Vertical force-velocity profile before and after the training intervention

Variable	Pre-training	Post-training	p-value	Mean ± SD Δ%	Effect size (Cohen's d)	95% confidence interval
F0 (N/kg)						
velocity deficit (n = 9)	56.0 ± 5.8	48.1 ± 5.8	0.0018*	–13.8 ± 8.8%	–1.36	–11.84 to –3.911
well-balanced (n = 14)	51.4 ± 6.4	54.2 ± 11.3	0.1821	4.9 ± 14.9%	0.32	–1.483 to 7.055
force deficit (n = 24)	44.5 ± 3.3	48.0 ± 9.9	0.0431	7.3 ± 17.5%	0.50	0.1175 to 6.816
mean	48.8 ± 6.7	49.9 ± 9.9		2.2 ± 0.13%	0.13	
V0 (m/s)						
velocity deficit (n = 9)	3.0 ± 0.2	3.6 ± 0.5	0.0026*	21.9 ± 15.4%	1.9	0.3010 to 0.9923
well-balanced (n = 14)	3.5 ± 0.2	3.5 ± 0.6	0.901	1.1 ± 20.6%	0.06	–0.3770 to 0.4242
force deficit (n = 24)	4.1 ± 0.56	4.2 ± 1.8	0.8404	–9.6 ± 16.7%	0.07	–0.7366 to 0.8974
mean	3.7 ± 0.6	3.9 ± 1.4		0.1 ± 21.1%	0.17	
P_{max} (Watts/kg)						
velocity deficit (n = 9)	41.4 ± 5.7	43.2 ± 7.4	0.050	4.0 ± 5.0%	0.27	–0.002140 to 3.558
well-balanced (n = 14)	44.6 ± 6.3	46.1 ± 6.5	0.100	3.6 ± 7.6%	0.24	–0.3372 to 3.380
force deficit (n = 24)	46.10 ± 7.8	47.5 ± 9.0	0.5153	0.2 ± 13.9%	0.16	–2.876 to 5.576
mean	44.8 ± 7.1	46.2 ± 8.1		2.0 ± 10.9%	0.2	
% imbalance at 90 degrees						
velocity deficit (n = 9)	132.0 ± 13.7	92.3 ± 18.1	0.0006*	–29.4 ± 15.4%	–2.29	–56.61 to –22.72
well-balanced (n = 14)	99.6 ± 6.5	108.9 ± 31.8	0.281	9.2 ± 31.5%	0.48	–8.494 to 26.92
force deficit (n = 24)	68.2 ± 15.5	86.2 ± 38.1	0.0232	19.7 ± 45.6%	0.58	2.685 to 33.40
mean	90.8 ± 26.3	93.4 ± 34.4		7.2 ± 41.3%	0.09	

Note: F0 (N) – theoretical absolute maximal force output, F0 (N/kg) – theoretical maximal force output relative to bodyweight, V0 (m/s) – theoretical maximal vertical velocity, P_{max} (Watts) – theoretical absolute maximal power output, P_{max} (Watts/kg) – theoretical maximal power output relative to bodyweight, $\%FV_{imb} > 110\%$, VD; $\%FV_{imb} < 90\%$, FD; $\%FV_{imb}$ = 90-110%, WB

Data is expressed as mean ± standard deviation. Mean Δ% = [(Post – Pre)/Pre] × 100. 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. Paired 2-tests (double tailed) were performed for each dependent variable. Significance was set at $p < 0.00277$ (0.05/18).

Table 2. Performance variables before and after the training intervention

Variable	Pre-training	Post-training	p-value	Δ% Mean ± SD	Effect size (Cohen's d)	95% confidence interval
Flying 10 (s)						
velocity deficit (n = 9)	1.06 ± 0.06	1.07 ± 0.06	0.5776	0.5 ± 2.1%	0.07	–0.01321 to 0.02210
well-balanced (n = 14)	1.06 ± 0.080	1.07 ± 0.08	0.6674	–0.3 ± 2.2%	–0.04	–0.01690 to 0.01118
force deficit (n = 24)	1.13 ± 0.11	1.12 ± 0.11	0.3471	–0.5 ± 2.6%	–0.05	–0.01840 to 0.006737
mean	1.10 ± 0.10	1.09 ± 0.10		–0.2 ± 2.4%	–0.03	
Barbell back squat 1-RM (kg)						
velocity deficit (n = 9)	176.3 ± 29.5	177.7 ± 35.4	0.6968	0.5 ± 5.5%	0.04	–6.563 to 9.351
well-balanced (n = 14)	168.5 ± 33.1	180.5 ± 39.3	0.0054	7.0 ± 8.1%	0.33	4.203 to 19.71
force deficit (n = 24)	180.9 ± 27.0	190.7 ± 30.1	<0.0001*	5.4 ± 3.8%	0.34	6.886 to 12.77
mean	185.2 ± 33.8	184.7 ± 33.5		4.9 ± 6.0%	0.28	
Power clean 1-RM (kg)						
velocity deficit (n = 9)	115.0 ± 13.5	118.3 ± 10.0	0.2191	3.4 ± 7.5%	0.28	–2.432 to 9.098
well-balanced (n = 14)	108.9 ± 21.9	118.3 ± 21.6	0.0046	4.3 ± 4.9%	0.20	1.606 to 7.109
force deficit (n = 24)	116.7 ± 13.8	121.3 ± 16.0	0.0061	4.0 ± 6.5%	0.31	1.453 to 7.797
mean	114.0 ± 16.6	118.3 ± 17.0		4.0 ± 6.2%	0.26	
Countermovement jump height (m)						
velocity deficit (n = 9)	0.77 ± 0.10	0.79 ± 0.12	0.0767	2.4 ± 3.6%	0.18	
well-balanced (n = 14)	0.78 ± 0.08	0.81 ± 0.11	0.0783	3.3 ± 6.6%	0.27	
force deficit (n = 24)	0.74 ± 0.12	0.77 ± 0.13	0.0009*	4.2 ± 4.9%	0.25	
mean	0.76 ± 0.11	0.79 ± 0.12		3.6 ± 5.2%	0.25	

Data is expressed as mean ± standard deviation. Mean Δ% = [(Post – Pre)/Pre] × 100.
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. Paired 2-tests (double tailed) were performed for each dependent variable. Significance was set at p < 0.00416 (0.05/12).

there was a small trend toward improvement in the power clean 1-RM in the WB and FD groups, this was not significant (p = 0.0046, p = 0.006; Cohen's d = 0.20, 0.30, respectively). The WB group tended to have an improvement in the barbell back squat 1-RM, but this did not reach significance (p = 0.0054, 7.0% improvement, Cohen's d = 0.33). There were no significant changes in flying 10's performance in any group.

Table 3 shows the horizontal FVP data. In the horizontal plane, the FD athletes had significant and large improvements in F0 and P_{max} ($p < 0.0001$, 38.3% improvement, Cohen's d = 1.24; 22.9% improvement, Cohen's d = 0.82, respectively). The WB group had similar results as the FD group, showing large improvements in relative F0 and P_{max} (p = 0.0007), with F0 increasing by 47% and P_{max} increasing by 35.1% (Cohen's d = 1.37, 1.11, respectively). Although the VD group exhibited a similar trend, improvements were not statistically significant, likely due to the smaller sample size (F0: 26.5% improvement, p = 0.0118, Cohen's d = 1.10; P_{max}: 16.0% improvement, p = 0.035, Cohen's d = 0.72).

Despite the improvements in horizontal F0 and P_{max}, all groups exhibited a significant decrease in V0 ($p \leq 0.0002$). The decrement ranged from 7.4% in the VD group to 11.4% in the WB group. Cohen's d indicated that all groups had large effects ranging from –1.10 to –2.23. This decrement in V0 corresponds to a decrement in DRF. The FD and WB groups had significant decreases in DRF ($p < 0.0001$), corresponding to a 54.4% and 68.8% decrease in the ability to maintain acceleration during sprinting (Cohen's d = –1.46, –2.07,

Table 3. Horizontal force-velocity profile before and after the training intervention

Variable	Pre-training	Post-training	p-value	Δ% mean ± SD	Effect size (Cohen's d)	95% confidence interval
F0 (N/kg)						
velocity deficit (n = 9)	6.5 ± 0.9	8.3± 2.4	0.0118	26.5 ± 23.7%	1.10	0.5245 to 3.105
well-balanced (n = 14)	6.6 ± 1.7	9.3 ± 2.2	0.0007*	47.0 ± 46.0%	1.37	1.369 to 4.009
force deficit (n = 24)	6.2 ± 1.5	8.4 ± 1.9	<0.0001*	38.3 ± 31.3%	1.24	1.527 to 2.788
mean	6.4 ± 1.5	8.6 ± 2.1		38.6 ± 35.2%	1.26	
V0 (m/s)						
velocity deficit (n = 9)	8.8 ± 0.4	8.2 ± 0.3	0.0002*	–7.4 ± 3.1%	–1.74	–0.9074 to –0.4282
well-balanced (n = 14)	9.0 ± 0.6	8.0 ± 0.4	<0.0001*	–11.6 ± 5.8%	–2.23	–1.392 to –0.7081
force deficit (n = 24)	8.9 ± 1.1	7.9 ± 0.7	<0.0001*	–10.4 ± 5.7%	–1.10	–1.234 to –0.6894
mean	8.9 ± 0.8	8.0 ± 0.5		–10.1 ± 5.4%	–1.34	
P_{max} (Watts/kg)						
velocity deficit (n = 9)	14.4 ± 2.23	16.9 ± 4.7	0.035	16.0 ± 18.5%	0.72	0.2258 to 4.799
well-balanced (n = 14)	14.9 ± 3.5	19.1 ± 4.1	0.0007*	35.1 ± 31.1%	1.11	2.148 to 6.284
force deficit (n = 24)	13.67 ± 3.1	16.4 ± 3.7	<0.0001*	22.9 ± 23.6%	0.82	1.756 to 3.892
mean	14.1 ± 3.1	17.3 ± 4.1		24.1 ± 25.3%	0.88	
Horizontal DRF (rate of decrease in ratio of force)						
velocity deficit (n = 9)	–0.07 ± 0.01	–0.09 ± 0.025	0.006	–36.1 ± 29.3%	–1.47	–0.04082 to –0.009845
well-balanced (n = 14)	–0.07 ± 0.02	–0.11 ± 0.02	<0.0001*	–68.8 ± 53.9%	–2.07	–0.05441 to –0.02673
force deficit (n = 24)	–0.07 ± 0.02	–0.10 ± 0.03	<0.0001*	–54.5 ± 40.3%	–1.46	–0.04120 to –0.02430
mean	–0.07 ± 0.02	–0.10 ± 0.02		–53.3 ± 43.7%	–1.62	

Note: F0 (N) – theoretical absolute maximal force output, F0 (N/kg) – theoretical maximal force output relative to bodyweight, V0 (m/s) – theoretical maximal velocity, P_{max} (Watts) – theoretical absolute maximal power output, P_{max} (Watts/kg) – theoretical maximal power output relative to bodyweight, horizontal DRF – rate of decrease in ratio of force in horizontal plane when running velocity increases. As DRF becomes more positive, this relates to improved technical capacity to accelerate; negative mean changes and effect size in this table reflect a decreased technical capacity to accelerate.
Data is expressed as mean ± standard deviation. Mean Δ% = [(Post – Pre)/Pre] × 100. 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. Paired 2-tests (double tailed) were performed for each dependent variable. Significance was set at p < 0.00277 (0.05/18).

respectively). The VD group had the smallest decrease in DRF (–6.1%, Cohen's d = –1.47, p = 0.006), but this did not reach statistical significance. Taking the experimental design into consideration, the authors recognize that without a control group, the changes in performance should be interpreted with caution.

Table 4 provides mean heights and weights of the athletes, grouped by position and the FVP profile group, as well as the pre-to-post-test change in $\%FV_{imb}$ by position. The athletes were grouped as "bigs" (offensive and defensive line athletes), "big skills" (linebackers, running backs, tight ends, specialists), or "skills" (wide receivers, cornerbacks, safeties, quarterbacks). Unexpectedly, there were three groups (FD "bigs", WB "bigs", WB "big skills") that moved away from their target FVP profile. The $\%FV_{imb}$ value of the FD "bigs" group started in a low FD category and finished in a high FD category ($\%FV_{imb} < 60\%$). The WB "big skills" started as WB, but moved into a low VD category. The WB "bigs" started as WB, but moved into the low FD category.

The $\%FV_{imb}$ value of the VD "big" athletes moved in an expected direction, but overshot a correction from

Table 4. Subject characteristics by position

	FD (n = 24)	VD (n = 9)	WB (n = 14)
BIGS (n = 13)			
n	10	1	2
height (m)	1.88 ± 0.06	1.84	1.90 ± 0.14
pre-training body mass (kg)	124.70 ± 18.33	114.31	126.25 ± 18.01
post-training body mass (kg)	125.40 ± 18.06	114.76	121.11 ± 11.41
pre-training $\%FV_{imb}$	69.3 ± 9.3	131.0	96.00 ± 1.7
post-training $\%FV_{imb}$	57.7 ± 24.2	83.0	70.67 ± 28.5
BIG SKILLS (n = 14)			
n	6	2	6
height (m)	1.87 ± 0.09	1.75 ± 0.02	1.82 ± 0.03
pre-training body mass (kg)	93.98 ± 12.60	98.66 ± 0.32	94.27 ± 4.80
post-training body mass (kg)	93.53 ± 11.65	98.20 ± 3.53	94.65 ± 4.61
pre-training $\%FV_{imb}$	66.6 ± 16.5	135.0 ± 0.00	98.33 ± 6.8
post-training $\%FV_{imb}$	100.6 ± 36.5	89.5 ± 41.7	126.83 ± 25.6
SKILLS (n = 20)			
n	8	6	6
height (m)	1.86 ± 0.03	1.82 ± 0.09	1.80 ± 0.04
pre-training body mass (kg)	88.20 ± 8.55	84.37 ± 8.63	74.97 ± 7.35
post-training body mass (kg)	88.30 ± 9.47	84.37 ± 9.58	75.30 ± 7.27
pre-training $\%FV_{imb}$	71.2 ± 20.7	134.7 ± 13.9	103.4 ± 6.8
post-training $\%FV_{imb}$	113.1 ± 29.8	101.5 ± 19.2	106.6 ± 19.3

Note: 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; $\%FV_{imb}$ – vertical force-velocity imbalance percentage; $\%FV_{imb}$ > 110%, VD; $\%FV_{imb}$ < 90%, FD; $\%FV_{imb}$ = 90-110%, WB
Data is expressed as mean ± standard deviation.

131.0% to 83.0% (90% was the target). A similar event occurred happened in the FD "skills" group, which slightly overshot a correction from 71.2% to 113.1% (110% was the target). The remaining four groups exhibited the optimized FVP profiles with post-intervention $\%FV_{imb}$ scores ranging from 90 to 110%.

Discussion

The main finding is that 6 weeks of the individualized training intervention designed in relation to the athletes' respective FVP profile overall corrected the $\%FV_{imb}$ value. The WB group tested within 90-100% range prior to the training intervention and again after the intervention achieved scores consistent with the WB category. This suggests that the training intervention provided a "well-balanced" stimulus which resulted in this group maintaining their well-balanced status. While the $\%FV_{imb}$ value of the VD and FD groups converged toward the well-balanced category, the FD group did not reach the targeted 90-110% score, suggesting that although 6 weeks were sufficient to measure changes, additional training may have been necessary for optimal results. In fact, previous studies have shown that 8 to 9 weeks of training based upon the FVP profiling enhanced $\%FV_{imb}$ in rugby athletes and sprint performance [17]. The improved $\%FV_{imb}$ was related to an improvement in vertical jumps in trained athletes [8, 14], indicating that more time may have allowed for greater improvement.

A different study applied the FVP profiling to futsal, rugby, and soccer athletes and demonstrated that a number of weeks needed to correct $\%FV_{imb}$ was correlated to magnitude of an initial imbalance [16]. The mean $\%FV_{imb}$ values of FD and VD groups (68%, 132%, respectively) were equidistant from the target of 90-110% (i.e., 22% above or below in either case), suggesting the magnitude was not an issue. Instead, it is plausible that the FD's group size (n = 24 vs 9 athletes) could have amounted to greater variance in the group, and a smaller mean change, as evidenced by a slightly larger standard deviation.

Among all groups, the correction in $\%FV_{imb}$ was associated with the overall improvement in horizontal F0 and P_{max}, but decreased horizontal V0 and DRF. Thus, the program design based upon the vertical FVP profiling was effective in increasing horizontal force and power, but resulted in the decrease in speed and ability to accelerate. Vertical and horizontal V0 decreased, which was associated with no change in flying 10's performance. All groups showed a small effect size for absolute vertical P_{max}, which is comparable to trivial or small changes found in previous research [18]. These results suggest that while the training stimulus was effective in improving power, applying newly gained power into acceleration and maintaining sprint speed was not addressed by the intervention. The training intervention did not improve flying 10's performance and was detrimental to horizontal V0 and DRF. These results are consistent with the training intervention, which focused on external load gains and not moving body weight in the horizontal plane. The present research implies that vertical and horizontal FVP are independent, and that optimization of the vertical profiles does not directly translate into enhanced horizontal performance. The only significant difference occurred in the VD group which showed a decrease in vertical F0. This result was expected since this group trained for velocity. This was associated with a 23.7% improvement in V0 in the vertical plane and a trend for improved F0 in the horizontal plane. However, this did not translate into horizontal V0, where the VD group exhibited a decline. The FD group had significant improvements in F0 in the horizontal plane and tended to have improved F0 in the vertical plane. This was associated with significant improvements in the barbell back squat 1-RM and a trend for the improved power clean 1-RM. Still, the FD group had a decreased V0 value in the horizontal plane, suggesting that overall running performance in this group was not improved. Since vertical and horizontal F0 performance was enhanced, these results coincide with the finding that the CMJ height was significantly improved.

Although the VD group had corrected their $\%FV_{imb}$, their performance metrics were not significantly improved. In this group, the CMJ was the only metric which showed a trend for improvement. The training program aligned with appropriate %1-RM loads which target maximum velocity, speed-strength, and peak power. However, this study did not measure movements' velocity or rely solely on unweighted jumps, which could account for the observed weak effects on performance. The WB group that started and ended with the optimized FVP profiles, tended to have improvements in the barbell back squat 1-RM, power clean 1-RM, and CMJ. Overall, with regard to the first aim of this paper, the intervention corrected $\%FV_{imb}$, but this did not coincide with the improved performance metrics across the board.

Jimenez-Reyes et al. [14] showed that using individualized training programs based upon $\%FV_{imb}$ was more effective in improving jumping performance than a general resistance training program common to all subjects. Specifically, after tailored interventions, a FD group exhibited large increases in F0, and a VD group exhibited large increases in velocity [14]. Both groups showed correction of their $\%FV_{imb}$ values and had large improvements in jump height [14]. Similarly, in the current study, the CMJ trended upward after the training, but these changes were small. In contrast to Jimenez-Reyes et al. [14], the current study showed the increase in V0 in the vertical plane, but the decrease in V0 in the horizontal plane.

Previous research showed low correlations between vertical FVP variables and mechanical movements in the horizontal plane; these relationships weaken as a level of practice increases [15]. Thus, vertical FVP should not be used to infer mechanical characteristics of athletes performing multidirectional tasks [15]. The current study results confirm this finding, where the vertical profiles improved, while the decrements in horizontal V0 and DRF were observed.

The traditional exercises utilized in this study (barbell back squats and power cleans) have the capacity to be manipulated to achieve desired shifts across an FVP continuum and ultimately enhance vertically oriented athletic performance. However, without specific training designed to improve DRF (such as heavy sled towing), no improvement in sprint speed was observed. DRF represents a capacity to maintain mechanical effectiveness of force application despite increases in running velocity, a reflection of technical proficiency. More positive DRF would indicate an improved ability to accelerate and efficient application of downward force at increased velocities, while a decrease in DRF would signal a loss or reduction in an ability to accelerate. Since horizontal DRF is a measure of the ability to accelerate and sustain sprinting biomechanics quality, a decrease in horizontal DRF suggests that the athletes could not translate their improved strength into horizontal force production or acceleration [1].

Acceleration and an ability to generate higher running velocities would be enhanced [4] by a concentration on applying more force into a ground in shorter time [20]. Competency and quality repetitions with optimal mechanics are necessary to develop proprioception for running at higher speeds [9, 22]. This provides a plausible explanation for why the significant improvements in horizontal F0 were not accompanied by improvements in flying 10's performance. Thus, teaching athletes how to optimize sprinting biomechanics should be incorporated secondary to a training intervention to ensure a translation of new F0 gains into sprinting performance [5].

This phenomenon represents importance of developing physical capacity and technical proficiency together. Furthermore, the results of the current study suggest that horizontal FVP profiling imbalances should be addressed in future research. Specifically, future studies should place more emphasis on horizontal FVP profiling and emphasize training this component with sled towing, assisted sprinting and technical sprinting proficiency [2, 5].

Another aspect that should be examined is how field position affects an athlete's responsiveness to individualized training based upon the FVP profiles. Out of the three positional groups, the "bigs" exhibited an unexpected effect on $\%FV_{imb}$, where the FD athletes' scores decreased further, moving them away from the WB category. Also, a $\%FV_{imb}$ score of the WB "bigs" decreased, moving them into the FD category even when provided with the WB training program. Similarly, when the WB training program was prescribed, a $\%FV_{imb}$ score of the WB "big skills" increased, moving them in the VD category. Overall, these results suggest that the "bigs" may have the least benefit (particularly those who are in the FD or WB groups), while the "skills" group may have the biggest benefit from the FVP profiling. Additional research is needed focusing on an effect of the FVP profiling and program design by position.

A major limitation of this study is that there was no comparison or control condition. The study was conducted with the Division 1 collegiate athletes, with the intent to maximize performance, which precluded our capacity to have a control group, and the authors needed to have the coaches' approval to conduct this study. The current study utilized a convenience sample with a limited training age, suggesting that the results may not be applicable to samples with a wider range of training ages. Logistically, it was not feasible to ensure equal rest periods for all study participants. However, 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 NCAA. Secondly, the creation of the vertical FVP profile relied on electronic mats. Force plates may have provided more accurate measurements of each subject's vertical FVP outputs, but this would have hindered a speed of data collection. Also, teams may not have access to force plates, limiting practicality and a pragmatic application of the current study's findings.

Additionally, subjectivity was used to determine the first propulsive movement during video analysis of a 30-m sprint, which may have influenced the resultant horizontal FVP profile. This limitation was minimized by utilizing the vertical FVP to determine the imbalances between force and velocity production. Lastly, grouping the athletes into specific box heights resulted in marginal differences in the initial jump height. This sacrifice was made to provide a practical and efficient testing process for a collegiate football teams' training schedule. Complete individualization of box heights would make this project impractical to recreate in a large team-based setting. Also, although there were 47 completing subjects in the study, who should have provided ample power, the authors had no control over the grouping of the subjects. The majority of the subjects were within the FD score, resulting in the small VD sample. This probably limited statistical power in determining differences after the intervention. Nevertheless, this study demonstrates that the utilization of the FVP profiling is a feasible field-based approach that can be applied with commercially available equipment in American football.

Conclusions

The optimized training for each group (FD, VD, WB) addressed the identified needs and provided the sufficient training stimuli to correct $\%FV_{imb}$, which enhanced the vertical performance metrics (1-RM and CMJ). However, the vertically optimized training did not translate into improvements in horizontal V0 and sprint speed observed in flying 10. These findings highlight the independent nature of the vertical and horizontal FVP profiles. Thus, future research should explore efficacy of concurrently correcting $\%FV_{imb}$ in both vertical and horizontal planes. The inclusion of load velocity profiling to determine an appropriate training prescription for sled-towing, and an emphasis on technical sprinting proficiency to enhance DRF may lead to desired performance adaptations. Additional work in this area is needed to determine the best way to apply FVP in training collegiate American football players.

Conflict of Interest

The authors declare no conflict of interest.

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Appendix A

Methods of assessing squat jumps and vertical FVP profiles

Body weight was assessed using an analog scale (Toledo Scale Company, OH), while lower limb length (distance from anterior superior iliac spine [ASIS] to toes at ankle plantarflexion with shoes on) and initial hip height (distance from ASIS to a floor with knees flexed 90° while seated on a plyometric box) were measured with a tape measure. For each subject's initial jump height, knee flexion at 90° was determined by aligning a square on a lateral side of a right knee joint, with arms of the square aligned with a midline of a thigh and a midline of a shin. Using their initial jump height and assigned plyometric box, athletes were asked to stand on a Just Jump Mat (Probotics Inc., 8692 Esslinger Court, Huntsville, AL), lower down to the box by bending their knees, and jump as high as possible while maintaining leg extension during the jump [6].

For squat jumps, the individuals performed vertical, maximal effort squat jumps with no load and against four external loads (20 kg, 40 kg, 60 kg, and 80 kg). A range of external loads remained constant regardless of the subjects' body weight. The loads were placed through a back-rack position using a 20 kg Olympic barbell. The protocol used in this study is the same as that used in previous FVP profiling studies [7, 11, 15]. An unloaded jump consisted of using a 0.4 kg dowel, which ensured that a posture of the jumps was equalized across weighted conditions. The athletes were asked to lower into their individual starting position with knees flexed to a 90º angle, and hold this position for 2 seconds before exploding into a maximal jump and landing on a Just Jump Mat. Countermovements were not allowed, and the subjects were instructed to maintain leg extension during the jumps. The subjects performed two trials at each load, and the highest jump was recorded. For each attempt, the athletes were given 2 minutes of recovery between the trials, and 4 minutes between each load condition.

Briefly, each subject's force and velocity were modeled with linear least squares regression to determine individual FVP profiles. The linear model provides a slope which describes a relationship between force and velocity produced by an athlete. The program also models the athlete's optimized relationship between force and velocity, and uses the linear least squares regression to determine the slope corresponding to the optimized relationship. A $\%FV_{imb}$ value is a difference between the theoretical optimized and actual slope, or how much the athlete's actual power generation deviates from their potential optimal power output.

The graphical slope represents the individuals' ratio between the maximum theoretical force and velocity capabilities [17]. Each theoretical optimum FVP profile is athlete specific, which dictates an exercise prescription [23]. A $\%FV_{imb}$ value of ≤90%, 90-110%, or ≥110% corresponds to FD, WB, or VD, respectively. For $\%FV_{imb}$ that deviate further from the WB category, a classification of high-FD and high-VD is defined as $\%FV_{imb}$ < 60% and > 140%, respectively [15].

Horizontal FVP profile testing methods

FVP testing was conducted using an unloaded 30-meter sprint for horizontal FVP testing. The testing was performed on artificial turf and the athletes wore football cleats. Prior to the testing, the subjects performed a standardized dynamic warm-up. The dynamic warm-up included a progressive sequence of speed improvement drills, which was intended to prime the athletes for a maximum velocity workout. Speed sticks were placed 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 each athlete to cover each 5 m distance. The subjects started from a two-point, staggered stance with a self-selected front foot and ran as fast as they could for the entire 30 m sprint. To set up their start, all subjects were required to hold their stance for 2 seconds to designate when they took off and started the run. Each sprint was filmed using a camera of a 6th generation iPad (Apple Inc., Cupertino, CA) and a dedicated iOS app called My Sprint [11, 21]. One valid trial was required for each subject.

Subsequently, video analysis was used to determine split times for each 5 m distance. Each individual's sprint time was calculated from the subject's first propulsive movement with a video timer, and each 5 m split was determined and entered into the My Sprint app containing previously validated prediction equations as reported by Romero-Franco et al. [21].

Performance metrics measurements

Flying 10 is a timed sprint that measures running velocity over a 10-yard distance. Two timing gates were placed 10 yards apart and used to determine sprint speed (Brower Timing Systems, Draper, UT). Timing gates are an effective and efficient way to measure sprint velocity and have been validated against radar guns and a GPS software (11, 23). 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). A difference in the lead-in distances was based upon position specificity. The same verbal instructions, cues, and encouragement were provided to all participants. Three successful flying 10's trials were performed, and the fastest time was used.

CMJ were conducted using the Just Jump Mats. Each athlete performed three trials and the best CMJ trial was used. All participants were instructed to jump as high as possible, not to kick back or out, and to jump straight up without tucking their knees. Each participant had at least 2 minutes of rest between the jump trials.

For 1-RM power cleans, the athletes used an Olympic barbell and rubber-coated weights. All power clean trials were completed in accordance with the National Strength and Conditioning testing procedures [10]. Lifting began from a ground, and the athletes were instructed to catch the bar at a bottom position of a front squat. All subjects were asked to execute the lift to their maximum effort to establish their 1-RM, with loads gradually added after the warm-up. Weight was added based on the previously recorded 1-RM, and strength coach's recommendations so that the 1-RM was achieved by the 6th set. A successful lift required the athlete to reach full hip extension upon standing. All subjects were given three sets to achieve their 1-RM and this weight was used in creating the training protocols.

For 1-RM back squats, the athletes were tested using an Olympic barbell and iron-plated weights. Lifting began from a standing position after unracking the bar from a resting position on a squat rack. The athletes were asked to provide maximal effort to lower back-racked weight down to a 90º knee angle, with a top of their thighs were parallel to a ground, and to stand up unassisted. If the athletes failed to lift the weight, the lift was not recorded. Three spotters were used, positioned on either side of the barbell and one behind the athlete. The spotters were not allowed to touch the bar or assist in the lift unless the athlete could not safely finish the lift unassisted. Weight was added based upon the previously recorded 1-RM, proficiency and successful executions, and the weight was gradually increased to achieve the 1-RM by the 6th set.

Appendix B. Example training programs for each group

Force-deficient group (week 1)

Day 1		Day 2		Day 3		Day 4		Day 5	
clean	4 × 2, 80%	bench press	4 × 5, 75%	seated box jump WTD	5 × 1, 10 lb MB	OH press	4 × 5, 70%	HAK clean	3 × 3, 70%
front squat	3 × 6, 55%	pull-up skills/BS	4 × 10	Trap bar deadlift	3 × 5/4/3, 70%/75%/80%	ALT DB bench	3 × 8 each	back squat	4 × 5, 80%
RDL	4 × 5	big man LPD	4 × 5 NG	DB/KB RFE split squat	3 × 5 each	partner KB seal row	3 × 8	BB hip lift	4 × 5
SA KB/DB farmers walk	3 × 30 yd	dips	3 × 8	KB pull through (crawl)	2 × 4 each	BB shrug	3 × 30	hollow hold	3 × 15 sec.
		DB rear lateral raise	3 × :30			DB hammer curl	3 × :30		
		fat grip BB curl	3 × :30			band Tri	3 × :30		
		Russian twist	3 × :30						

Force-deficient group (week 5)

Day 1		Day 2		Day 3		Day 4		Day 5	
clean	2 × 1, 95% 1 × 1 OPEN	bench press	2 × 1, 90% 1 × 1, 95%	BB CM WT jump	4 × 1, 25% SQT SR	OH press	3 × 3, 55%	back squat	1 × 1, 90%
front squat	2 × 2, 60%	pull-up skills/BS	3 × 3	clean pull	2 × 2, 115%	DB bench	3 × 5		
assisted SL DB RDL	3 × 3 each 60 lb+	big man LPD	3 × 5 PRO	DB/KB REV lunge	3 × 4 each	WTD INV row	4 × 8		
KB waiter's carry	3 × 30 yd	dips	3 × 5	KB pull through (P. UP)	3 × 4 each	snatch grip OH shrug	3 × :30		
		10 lb snow angel	3 × :30			KB towel curl	3 × :30		
		band curl	3 × :30			bench dips	3 × :30		
		band pull-apart	3 × :30						

Notes: :30 – 30 seconds, ALT – alternating, BB – barbell, BS – back squat, CM WT – countermovement weighted, DB – dumbbell, HAK – hang above knee, KB – kettlebell, lb – pound, LPD – latissimus dorsi pull-down, MB – medicine ball, NG – neutral grip, OH – overhead, OPEN – open set, up to a lifter depending on how previous sets went, P.UP – push up position, PRO – pronated, RDL – Russian deadlift, REV – reverse, RFE – rear foot elevated, SA – single arm, SL – single leg, SQT SR – squat single response, Trap – trapezius, Tri – triceps, WTD – weighted, WTD INV – weighted inverted row, yd – yard
Example training program, repetitions × sets and percentage of baseline lift are provided.

Velocity-deficient group (week 1)

Day 1		Day 2		Day 3		Day 4		Day 5	
clean	4 × 2, 76%	bench press	4 × 5, 75%	BB CM WT jump	5 × 1, 10% SQT SR	OH press	4 × 5, 70%	power clean	3 × 3, 76%
DE back squat	6 × 2, 20% (green band)	pull-up skill/BS	4 × 10	hang snatch pull	2 × 3, 80%	ALT DB bench	3 × 8 each	back squat	4 × 3, 76%
RDL	4 × 5	big man LPD	4 × 5 NG	DB/KB RFE split squat	3 × 5 each	partner KB seal row	3 × 8	BB hip lift	4 × 5
KB waiter's carry	3 × 30 yd	dips	3 × 8	KB pull through (crawl)	2 × 4 each	BB shrug	3 × :30	hollow hold	3 × :15
SA KB/DB farmers walk	3 × 30 yd	DB rear lateral raise	3 × :30			DB hammer curl	3 × :30		
		fat grip BB curl	3 × :30			band Tri	3 × :30		
		Russian twist	3 × :30						

Velocity-deficient group (week 5)

Day 1		Day 2		Day 3		Day 4		Day 5	
clean	2 × 1, 95% 1 × 1 OPEN	bench press	2 × 1, 90% 1 × 1, 95%	band assisted jump	3 × 3 MR	OH press	4 × 3, 55% of bench	back squat	1 × 1, 90%
DE back squat	5 × 2, 30% (green band +)	pull-up skills/BS	3 × 3	hang snatch	3 × 2, 40% of clean	DB bench	3 × 5		
assisted SL DB RDL	3 × 3 each 60 lb+	big man LPD	3 × 5 PRO	DB/KB REV lunge	3 × 4 each	WTD INV row	4 × 8		
KB waiter's carry	3 × 30 yd	dips	3 × 5	KB pull through (P. UP)	3 × 4 each	snatch grip OH shrug	3 × :30		
		10 lb snow angel	3 × :30			KB towel curl	3 × :30		
		band curl	3 × :30			bench dips	3 × :30		
		band pull apart	3 × :30						

Notes: :30 – 30 seconds, ALT – alternating, BB – barbell, BS – back squat, CM WT – countermovement weighted, DB – dumbbell, DE – dynamic effort, KB – kettlebell, lb – pound, LPD – latissimus dorsi pull-down, MR – multiple response, NG – neutral grip, OH – overhead, OPEN – open set, up to a lifter depending on how previous sets went, P.UP – push up position, PRO – pronated, RDL – Russian deadlift, REV – reverse, RFE – rear foot elevated, SA – single arm, SL – single leg, SQT SR – squat single response, Tri – triceps, WTD INV – weighted inverted row, yd – yard
Example training program, repetitions × sets and percentage of baseline lift are provided.

Well-balanced group (week 1)

Day 1		Day 2		Day 3		Day 4		Day 5	
clean	4 × 2, 82%	bench press	4 × 5, 75%	seated box jump (no weight)	5 × 1 SR	OH press	4 × 5, 70%	BAK clean	3 × 3, 70%
band back squat	6 × 2, 45% (orange band)	pull-up skill/BS	4 × 10	HAK clean pull	4 × 3, 70%	ALT DB bench	3 × 8 each	back squat	4 × 3, 76%
RDL	4 × 5	big man LPD	4 × 5 NG	DB/KB RFE split squat	3 × 5 each	partner KB seal row	3 × 8	BB hip lift	4 × 5
KB waiter's carry	3 × 30 yd	dips	3 × 8	KB pull through (crawl)	2 × 4 each	BB shrug	3 × 30	hollow hold	3 × :15
SA KB/DB farmers walk	3 × 30 yd	DB rear lateral raise	3 × :30			DB hammer curl	3 × :30		
		fat grip BB curl	3 × :30			band Tri	3 × :30		
		Russian twist	3 × :30						

Well-balanced group (week 5)

Day 1		Day 2		Day 3		Day 4		Day 5	
clean	2 × 1, 95% 1 × 1 OPEN	bench press	2 × 1, 90% 1 × 1, 95%	band assisted jump	3 × 3 MR	OH press	4 × 3, 55% of bench	back squat	1 × 1, 90%
band back squat	5 × 1, 50% (orange band)	pull-up skills/BS	3 × 3	HAK clean pull + clean	3 × 1 + 2, 65%	DB bench	3 × 5		
assisted SL DB RDL	3 × 3 each 60 lb+	big man LPD	3 × 5 PRO	DB/KB REV lunge	3 × 4 each	WTD INV row	4 × 8		
KB waiter's carry	3 × 30 yd	dips	3 × 5	KB pull through (P. UP)	3 × 4 each	snatch grip OH shrug	3 × :30		
		10 lb snow angel	3 × :30			KB towel curl	3 × :30		
		band face pull	3 × :30			bench dips	3 × :30		
		band pull apart	3 × :30						

Notes: :30 – 30 seconds, ALT – alternating, BAK – block above knee, BB – barbell, BS – back squat, DB – dumbbell, HAK – hang above knee, KB – kettlebell, lb – pound, LPD – latissimus dorsi pull-down, MR – multiple response, NG – neutral grip, OH – overhead, OPEN – open set, up to a lifter depending on how previous sets went, P.UP – push up position, PRO – pronated, RDL – Russian deadlift, REV – reverse, RFE – rear foot elevated, SA – single arm, SL – single leg, SR – single response, Tri – triceps, WTD INV – weighted inverted row, yd – yard
Example training program, repetitions × sets and percentage of baseline lift are provided.