FORCE-VELOCITY PROFILES IN COLLEGIATE AMERICAN FOOTBALL PLAYERS

A THESIS SUBMITTED TO THE GRADUATE DIVISIONS OF THE UNIVERSITY OF HAWAI'I AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

KINESIOLOGY AND REHABILITATION SCIENCE

MAY 2023

By

Parker J Hill

Thesis Committee:

Paulette M. Yamada, Chairperson

Brett G Freemyer

Kyoko Shirahata

Keywords: Football, Force, Velocity, Profiles, Collegiate

Acknowledgements

First off I would like to thank my committee chairperson, Dr. Paulette Yamada for all her time and support in creating this research study, learning about force velocity profiling, running statistics, editing manuscript drafts and just taking a genuine interest in my academic success. I would like to thank Dr. Freemyer and Dr. Shirahata for participating in my thesis committee and their countless hours of support. Thank you for continually checking in with me to see how things were progressing and for having a new and different perspective on the study. I would also like to highlight the role that Trevor Short played in the development of this study, and that I would not have been successful without his expertise, knowledge and support. I extend a special thanks to Coach Kody Cooke and Coach Timmy Chang for providing the time in the athletes’ training schedule to participate in the study and trusting that the study findings would be beneficial to improving the athletic performance of the players involved. I must also thank Ryan Ishihara for collaborating with me on the study, always being in my corner and for being the best hype man. Finally, but most importantly, thank you to my wife Gabby and kids Ellie and Jace. I appreciate their love and support during my time as a student and the sacrifices they have made in order for me to pursue my degree and carry out this study.

Abstract

American football is a intermittent high-intensity sport played in 3-5 seconds bursts with 20-40 seconds rest between each play. The athletic demands are position specific, but all positions require speed, agility, strength and power. Typically, strength and conditioning coaches rely on subjective observations of the athletes' pre-season fitness or playing experience to design a training regimen. In this study, we aimed to use force-velocity profiling (FV profiling) to objectively measure performance. The first aim of this study was to determine horizontal and vertical F0(N), F0(N/kg), V0(m/s), Pmax(W), and Pmax(W/kg) in collegiate American football players and compare them between position groups. The second aim was to see if force velocity profiling could predict countermovement jump (CMJ) height and flying-10 performance. To investigate these aims we assessed 82 collegiate American football players horizontal and vertical force velocity profiles via a 30 meter sprint, unloaded jumps and loaded jumps as described by Morin and Samozino. We also assessed CMJ height, flying-10 times, squat 1-repetition max (RM) and clean 1-RM. Our results showed a moderate and positive correlation between horizontal V0(m/s) and flying-10 times. We observed a moderate and positive relationship between vertical F0(N) and squat 1-RM, clean 1-RM and CMJ. When controlling for body mass, Pmax (W/kg) had a moderate and positive correlation with CMJ in both vertical and horizontal FV profiles. Both vertical and horizontal Pmax (W/kg) also saw a moderate and negative correlation with Flying-10 performance. Horizontal and vertical FV profiling along with traditional measurements of American Football athletic performance allows the coaching staff to make better informed decisions about which training modalities should be used to improve performance.

Table of Contents

List of Tables

List of Figures

Introduction

American football is a intermittent high-intensity sport played in 3-5 seconds bursts with 20-40 seconds rest between each play.[34] The athletic demands during these 3-5 seconds are position specific, but all positions require speed, agility, strength and power.[15,27,38] Strength and conditioning coaches are responsible for creating training programs which optimize these position dependent skills. This training is important because enhanced athletic performance can improve team based and individual success. This translates to improved on field play as a team, or it can be vital in determining college athletes' draft order based on combine testing results. Specifically, straight sprint time and jump performance are valued the most when it comes to National Football League Draft decisions.[16,28] There are approximately 16,000 draft eligible college football athletes every year, but only a total of 254 draft picks. Therefore, elite performance in sprinting and jumping are vital for team and individual American football success. The common denominator of successful game play or combine type events is the ability to generate power.

Power is defined as the product of force and velocity. Athletes can optimize their maximal power output (Pmax) by either increasing force or increasing velocity.[15] Force velocity (FV) profiles are used to identify whether force or velocity should be improved for the optimization of power. An athlete who can produce a sufficient amount of force, but lacks the ability to create that force quickly, would be classified as velocity deficient. The athlete who produces force quickly, but is unable to produce high amounts of force, would be force deficient. Training programs should target a deficiency, which should correct the imbalance between force and velocity, which can maximize Pmax and athletic performance.[7,10]

Typically, strength and conditioning coaches rely on subjective observations of the athletes' pre-season fitness or playing experience to design a training regimen (i.e., hypertrophy, strength or power focus).[30] FV profiling is a validated and objective measure that determines the relationship between an athletes' force and velocity producing capabilities in both horizontal and vertical planes of movement.[7,9,10,11,12,13,18,21]

It has been used to enhance athletic performance in sports like soccer, rugby and ice hockey.[10,12,18] To our knowledge, the use of FV profiles to assess performance and inform the training program design has not been applied to American football.

Therefore, the first aim of this exploratory, cross-sectional study was to use FV profiling to determine the maximal force (F0), maximal velocity (V0) and Pmax outputs in both the vertical and horizontal planes of movement in collegiate American football players and to compare these performance measures between position groups. We hypothesized that the big athletes of the offensive and defensive line will have the highest F0 in both the vertical and horizontal FV profiles, and thus their resultant program should focus on velocity development. We also hypothesize that the athletes in the "skills group" (i.e., quarterback, wide receiver, defensive backs) will have the highest vertical V0 and the resultant training program should focus on strength or force development.

The second aim of this study was to calculate the correlations between the horizontal or vertical FV profiles with traditional performance measures used in collegiate strength and conditioning settings (e.g., flying-10 time, 1-repetition maximum (RM) power clean, and 1-RM back squat). We hypothesized that horizontal V0 will have a strong and positive correlation with the flying-10 speed and that vertical F0 would have a strong and positive correlation with CMJ height.

Methods

Participants

This study incorporated a convenience sample of 82 division 1 American football players. Participants were categorized into one of the following groups according to their position: 1) Big (offensive lineman and defensive line), 2) Big Skill (linebacker, tight end, running back, and safety), 3) Skill (quarterback, wide receiver, cornerback), or 4) Specialist (kicker, punter, long snapper).

Table 1 shows the number of players studied in each group with their average height and weight.

Table 1. Participant characteristics (mean ± SD)

	N	Weight (kg ± SD)	Height (cm ± SD)
Big	27	124.6 ± 16.1	188.9 ± 6.5
Big Skill	21	93.9 ± 10.3	179.7 ± 5.8
Skill	31	80.4 ± 16.3	182.2 ± 5.5
Specialist	3	94.4 ± 7.1	184.3 ± 12.1
Overall	82	98.1 ± 23.8	183.8 ± 7.1

Note: Big= Offensive/Defensive lineman; Big skill= Linebacker/Tight end/Running back, safety; Skill= Quarterback, Wide receiver, cornerback; Specialist= Kicker, Punter, Long snapper

Prior to study initiation, participants were deemed healthy and injury free by their assigned sports medicine staff and all participants provided informed consent (Appendix 1). All participants previously engaged in structured collegiate strength and conditioning protocols prior to study inclusion and had familiarity with the prescribed sprint and jumping protocols. One participant was excluded from the vertical FV profile assessment because he was not cleared to perform this test as determined by the sports medicine staff. This study was approved by the University's Human Studies Program (IRB# 2022-00845).

Testing Procedures

Anthropometric measurements were collected the week prior to performance testing. Body mass 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. 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 align with the midline of the thigh and midline of the shin.

Participants were tested 3 times over 4 days, and were given 24-48 hours of rest between each testing day. Testing took place on a turf field and in a weight room, which participants were accustomed to sprinting and jumping training, respectively. The first day of testing consisted of both the horizontal and vertical FV profile testing.The second day of testing consisted of flying-10 sprints and 1-RM power clean testing. On the third day, participants performed the CMJ and 1-RM back squat. Testing schedule was based on position group and can be found in appendix 2.

Horizontal force-velocity profile

All participants began the session with a familiar warm-up that they had routinely performed prior to maximum velocity training days. The warm-up exercises are listed in appendix 3. Participants were given at least 5 minutes after the warm-up prior to the sprint trial testing.

The FV profiling was conducted using methods described in previous studies.(30,32,33) Sprints were recorded using the camera of an iPad (Apple, 6th generation) and a dedicated iOS app called MySprint (Pedro Jimenez Reyes, Madrid, Spain). Speed sticks were set up at the 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m distances and were used as markers to measure the time it took for each athlete to cover each 5 m distance (see figure 1). Participants started from a two-point, staggered stance and were verbally instructed to self-select which foot was in front. Verbal encouragement was given to all participants and they were instructed to run as fast as they could for the entire duration of the 30 m sprint. Video analysis was used to determine the split times for each 5 m distance based on when the participants' midline of the pelvis is in-line with the speed stick. The video based timer was started on the first propulsive movement and, each 5 m split was determined and entered into the MySprint app. This process and prediction equations have been previously validated by Samozino et al.(10,12,31) From these predictive equations, horizontal F0, horizontal V0 and FV imbalance (FVimb) was calculated by the My Sprint app. A FVimb value <60, 60-90, >90-100, >110-140 or>140 indicates that the athlete scored in the category of high force deficit, low force deficit, well-balanced, low velocity deficit or high velocity deficit, respectively.(11)

Vertical force-velocity profile

All athletes were given 20-25 minutes of rest time to transition from the sprint testing to the jump assessment. The vertical force-velocity profile assessment consisted of a series of 10-15 unloaded and loaded squat jumps (SJ). Participants were verbally cued to squat to 90° of knee flexion, hold this position for 2 seconds (and then jump (verbally cued with "press") as forcefully and quickly as possible. Participants were not allowed to use a countermovement and trials were visually confirmed to follow these guidelines. Jump height was measured using JustJump! mats (PerformBetter, West Warwick, RI). Participants were instructed to maintain leg extension during the jump and not flex their knees, as this would alter jump height. Similar methods were used for each jump trial for both unloaded and loaded conditions. Any deviation from this protocol required the participants to repeat the trial. In order to ensure consistency of body position, the unloaded SJ were performed with unweighted wooden dowels (0.2 kg, which were included in calculations). Participants were instructed to keep their hands on the dowel or bar throughout the entirety of each trial. Jumps were tested unloaded, and with 20 kg, 40 kg, 60 kg and 80 kg of additional weight. Weight was added by use of an olympic bar and plates. A minimum of two successful jumps were required at each load and 2-3 minutes of rest was given between each jump trial. The highest recorded jump height was used in the subsequent analyses. An open source spreadsheet (https://jbmorin.net/2017/10/01/a-spreadsheet-for-jump-force-velocity-power-profiling/), which is pre-populated with prediction equations, was used to determine vertical F0, vertical V0 and vertical Pmax.[11,21,30,32,33]

Flying 10

Warm-ups identical to the horizontal FV profile test day (see appendix 3) were used prior to flying 10 testing. Following the warm-up, participants were given 5-7 minutes of recovery, in which flying-10 instructions were given. All participants were familiar with flying-10 sprints but were reminded to build up to maximal running velocity during the initial 10 or 20 yards, and then maintain their maximal velocity through the end of the timing gates (over the next 10 yards) (Brower, Draper, UT). Three trials were collected, with the best time used in data analyses. Five minutes of recovery time were provided between trials. All "bigs" (offensive and defensive lineman) were given 10 yards to build up to their top sprinting speed, while all other positions were given 20 yards.

Power clean

Participants had a minimum of 8-weeks of collegiate strength and conditioning training prior to the study, which included power clean training. Based on their previous lifts, all participants were instructed to build up to a 1-RM. They completed 2 repetitions at 60% and 70% of their estimated 1-RM, and 1 repetition at their estimated 75%, 80%, 85%, and 90% 1-RM. Based on their attempt at 90% 1-RM, the designated strength coach at the participants rack assigned the next weight to attempt by adding 5-10% to the last lifted weight. Participants were given 3 attempts to achieve their 1-RM.

Countermovement Jump

All participants were familiar with the CMJ testing procedures and performed a warm-up and CMJ preparation protocol (see appendix 4). Vertical jump height was measured with an electronic mat (JustJump!, Probiotics INC, Huntsville, AL). Participants were instructed to jump as high as possible, 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 2-3 minutes rest between jump trials and the highest of 3 trials was used in subsequent analyses.

Squat

All participants were instructed to squat so that their hips dipped below their knee alignment and their thighs were at least parallel to the ground, which was visually confirmed by a strength and conditioning coach. Based on the previous weight lifted during their 8-week training period, all participants were instructed to build up to a 1-RM. They were instructed to lift 2 repetitions at 60%, 70% of their estimated 1-RM, and then lift 1 repetition of their estimated 77%, 82%, 87%, and 92% 1-RM. Based on the load lifted at their 92%-1RM, the strength coach estimated an additional 8% weight for the athlete to attempt. Participants were given 3 sets to achieve their 1-RM and were allowed to attempt the lift no more than 3 times. The subject was spotted by 3 spotters, one located behind and 2 placed at either side of the athlete.

Statistical Analysis

Descriptive statistics were calculated for all measures and are presented as mean ± SD in table 2. Normality was tested and confirmed using the Shapiro-Wilk test, which was non-significant across groups. A one-way ANOVA was performed to determine if there FV profiling differences exist between position groups of American Football players. Tukey's post-hoc statistical analysis test was used to determine which post hoc groups differences. Statistical significance was with an alpha level set to $P \leq 0.05$. The magnitude of group differences in horizontal and vertical FV profiles in F0, V0 and Pmax were assessed using Cohen's d effect sizes (ES) of small = 0.2, moderate = 0.5, and large = 0.8. Pearson's correlation coefficients were calculated to examine the relationships between measures of horizontal and vertical F0, V0, Pmax with traditional performance measures (1-RM clean and back squat, flying-10, and CMJ). A Pearson's r of 0.2-0.39, 0.4-0.59 and 0.6-0.79 and > 0.8 were used to denote weak, moderate, strong and very strong relationships. GraphPad Prism version 9.2 for MacOS was used for statistical analyses (GraphPad Software, San Diego, California USA).

Results

Table 2 shows position groups performance measures from vertical and horizontal FV profiling.

Table 2. Results and Effect sizes from the Horizontal and Vertical Force-Velocity Profile

	Variable	BIG (27) (mean ± SD)	BIG SKILL (21) (mean ± SD)	SKILL (31) (mean ± SD)	SPEC (3) (mean ± SD)	Overall (82) (mean ± SD)	Effect Size (Cohen's d) BIG VS BIG SKILL	BIG VS SKILL	BIG SKILL VS SKILL
Horizontal FV Profile	F0 (N)	685.7 ± 188.8	610.3 ± 167.6	562.1 ± 96.6	579.9 ± 103.7	615.8 ± 157.7	0.4	0.8	0.4
	F(N/kg)	5.5 ± 1.3	6.6 ± 1.5	6.8 ± 1.1	6.1 ± 1.0	6.3 ± 1.4	0.8	1.1	0.2
	V0 (m/s)	8.6 ± 1.0	9.1 ± 0.9	9.3 ± 0.9	8.0 ± 0.4	9.0 ± 1.0	0.5	0.7	0.2
	Pmax (W)	1434.6 ± 275.1	1364.4 ± 287.6	1291.3 ± 166.2	1153.4 ± 157.1	1352.2 ± 246.4	0.2	0.6	0.3
	P(W/kg)	11.6 ± 2.3	14.9 ± 2.5	15.7 ± 2.4	12.2 ± 12.3	13.9 ± 2.9	1.4	1.7	0.3
Vertical FV Profile	F0 (N)	5240.4 ± 627.0	4968.5 ± 1047.6	4313.5 ± 634.9	4297.0 ± 113.0	4791.7 ± 848.3	0.3	1.5	0.8
	F(N/kg)	42.5 ± 5.9	52.9 ± 8.2	54.0 ± 8.3	45.8 ± 45.9	49.4 ± 8.9	1.5	1.6	0.1
	V0 (m/s)	3.9 ± 0.7	3.7 ± 0.7	3.0 ± 4.4	3.3 ± 0.2	3.8 ± 1.0	0.3	0.1	0.1
	Pmax (W)	5032.9 ± 605.6	4541.5 ± 974.3	4005.9 ± 1027.1	3576.0 ± 213.2	4471.1 ± 979.3	0.6	1.2	0.5
	Pmax (W/kg)	40.8 ± 5.9	48.4 ± 7.6	46.6 ± 7.0	38.0 ± 38.0	45.0 ± 7.6	1.1	0.9	0.2
	%IMB	74.6 ± 21.9	96.2 ± 27.6	99.6 ± 29.0	95.3 ± 11.6	90.2 ± 27.9	0.9	1.0	0.1

Note: BIG= offensive/defensive lineman; BIG SKILL= linebacker/tight end/running back/safeties; SKILL= quarterback, wide reciever, cornerback; SPEC= kicker, punter, long snapper; F0=maximum theoretical force output; V0= maximum theoretical velocity output; Pmax= maximum power output; %IMB= imbalance between optimal FV profile and measured

Table 3 shows the breakdown of how many participants from each position group are in either force-deficient, velocity-deficient or well-balanced based on FV profile results.

Table 3. Position groups and category of FV profile

	Force-deficient	Velocity-deficient	Well-balanced
Big	21	2	4

Big Skill	11	9	10
Skill	9	7	5
Spec	1	0	2

Figure 2 shows selected scatter plots illustrating the association between horizontal FV profile metrics and performance metrics.

Figure 2

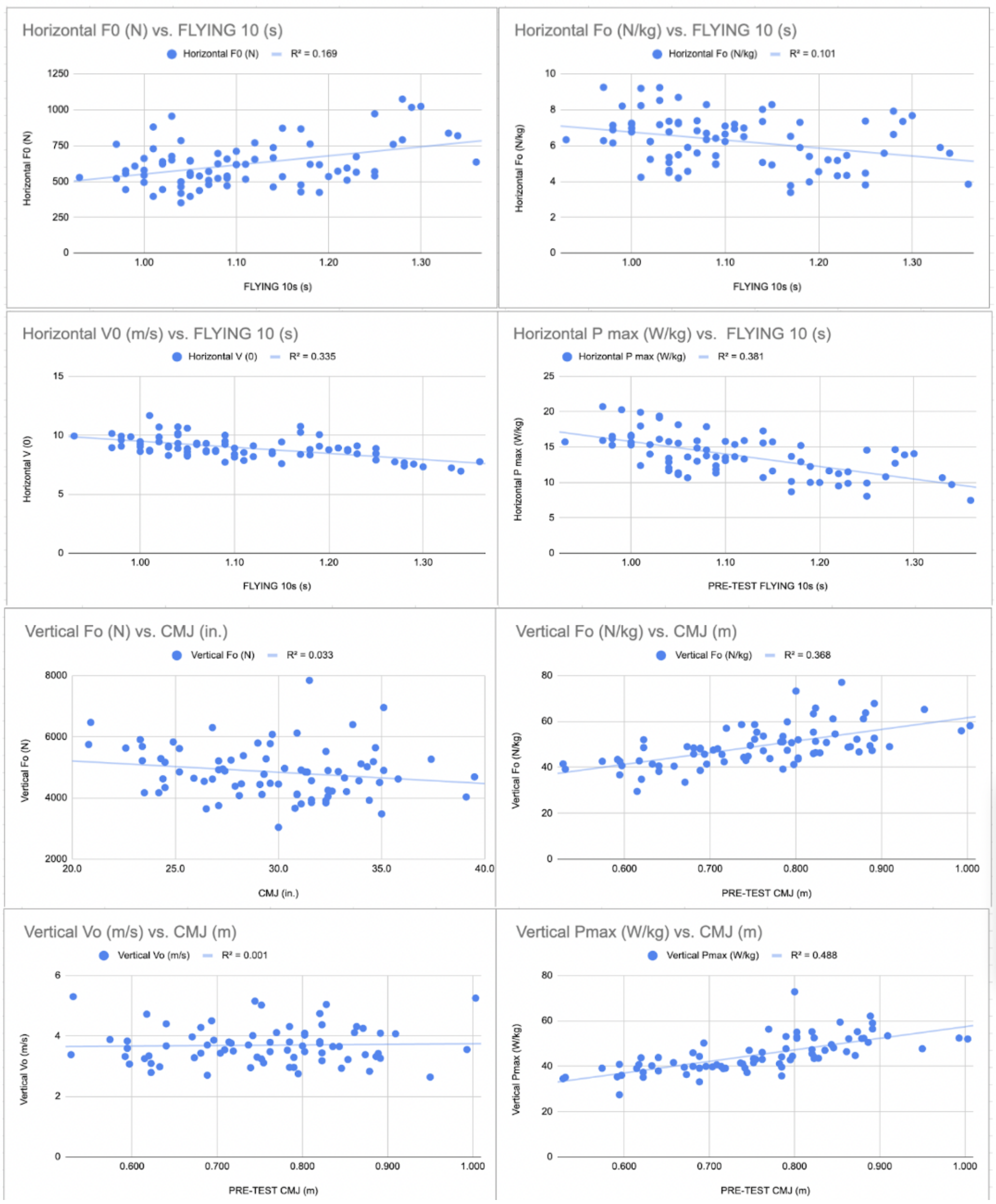


Table 4 contains the one-way ANOVA statistical analysis results between position groups of football players and F0, V0 and Pmax results from both horizontal and vertical FV profile assessments. There were significant differences between groups in horizontal V0 (F(3, 78)=4.24, P=0.0079, and R^2=0.14), F0 (F(3, 28)=3.28, P=0.025), F0 (N/kg) (F(3, 78)=4.51, P=0.0057, and R^2=0.15), and Pmax (W/kg) (F(3,78)=14.56, P<0.0001, and R^2=0.36). With regard to the vertical FV profile, there were statistically significant differences between position groups in F0 (F(3, 77)=8.00, P=0.0001), F0 (N/kg) (F(3,77)=12.72, P<0.0001, and R^2=0.33), Pmax (F(3, 77)=7.42, P=0.0002) and Pmax (W/kg) (F(3,77)=7.29, P=0.0002, and R^2=0.22).

Table 4. One way ANOVA analysis between position groups and FV Profile Results. (n=82)

		F	P value	P value summary	Significant diff. among means (P < 0.05)?
Horizontal	V0 (m/s)	4.24	0.0079	**	Yes
	F0 (N)	3.28	0.0253	*	Yes
	F0 (N/kg)	4.51	0.0057	**	Yes
	Pmax (W)	2.43	0.0718	ns	No
	Pmax (W/kg)	14.56	<0.0001	****	Yes
Vertical	V0 (m/s)	0.37	0.7738	ns	No
	F0 (N)	8.00	0.0001	***	Yes
	F0 (N/kg)	12.72	<0.0001	****	Yes
	Pmax (W)	7.42	0.0002	***	Yes
	Pmax (W/kg)	7.29	0.0002	***	Yes

Table 5 contains results from Tukey's post hoc statistical analysis. From the horizontal FV profile results, significant differences between the Big and Skill position groups were found in V0 (Mean diff=-0.7 m/s, P=0.0203 with 95% CI of diff.= -1.351 to -0.02821), F0 (Mean diff=123.6, P=0.0141 with 95% CI of diff.= 18.89 to 228.2), F0 (N/kg) (Mean diff=-1.30, P=0.0076 with CI of diff.=-2.32 to -0.27) and Pmax (W/kg) (Mean diff=-4.06, P<0.0001 with CI of diff.=-5.87 to -2.25). A significant difference between Big and Big Skill was found in F0 (N/kg) (Mean diff=-1.06, P=0.0188 with CI of diff.=-1.99 to -0.13) and Pmax (W/kg) (Mean diff=-3.27, P<0.0001 with CI of diff.=-4.91 to -1.63) From the vertical FV profile we found statistically significant differences in F0 between Big and Skill and Big Skill and Skill (Mean diff=654.9 N, P<0.0001 with 95% CI of diff.= 401.0 to 1453 and Mean diff=926.9, P=0.0163 with 95% CI of diff.= 90.87 to 1219 respectively). Vertical Pmax was significantly different between the Big and Skill groups (Mean diff=1027 W, P=0.0002 with 95% CI of diff.= 416.6 to 1637). Statistically significant differences were found in the measures of F0 and Pmax relative to body mass between Big vs. Big Skill (Mean diff=-10.34, P<0.0001 with CI of -15.53 to -5.16 and Mean diff=-7.55, P=0.0004 with CI of -12.29 to -2.81 respectively) and Big vs. Skill (Mean diff=-11.44, P<0.0001 with CI of 416.60 to 1637.00 and Mean diff=-5.75, P=0.0243 with CI of -10.95 to -0.55 respectively).

Table 5. Tukey's Post Hoc Analysis between position groups and FV Profile Results. (n=82)

			Mean Diff.	95% CI of diff.	Below threshold?	Summary	Adjusted P Value
Horizontal	V0 (m/s)	Big vs. Skill	-0.70	-1.35 to -0.08	Yes	*	0.0203
	F0 (N)	Big vs. Skill	123.60	18.89 to 228.20	Yes	*	0.0141
	F0 (N/kg)	Big vs Big Skill	-1.06	-1.99 to -0.13	Yes	*	0.0188
		Big vs Skill	-1.30	-2.32 to -0.27	Yes	**	0.0076
	Pmax (W/kg)	Big vs Big Skill	-3.27	-4.91 to -1.63	Yes	****	<0.0001
		Big vs Skill	-4.06	-5.87 to -2.25	Yes	****	<0.0001
Vertical	F0 (N)	Big vs. Skill	926.9	401.00 to 1453.00	Yes	****	<0.0001
		Big Skill vs. Skill	654.9	90.87 to 1219.00	Yes	*	0.0163
	F0 (N/kg)	Big vs Big Skill	-10.34	-15.53 to -5.16	Yes	****	<0.0001
		Big vs. Skill	-11.44	-17.13 to -5.76	Yes	****	<0.0001
	Pmax (W)	Big vs. Skill	1027	416.60 to 1637.00	Yes	***	0.0002

Pmax (W/kg)	Big vs. Big Skill	-7.55	-12.29 to -2.81	Yes	***	0.0004
	Big vs. Skill	-5.75	-10.95 to -0.55	Yes	*	0.0243

Table 6 shows the Pearson coefficient analysis and simple linear regression results comparing the horizontal FV profile and performance results. Absolute values of horizontal FV profiling showed significant, positive correlations with V0 (CMJ, r=0.58, R^2=0.33, p<0.05); F0 (Squat, r=0.33, R^2=0.11, p<0.05; flying-10, r=0.42, R^2=0.18, p<0.05) and Pmax (Clean, r=0.31, R^2=0.09, p<0.05; Squat, r=0.34, R^2=0.12, p<0.05). Horizontal FV profiling showed significant, negative correlations with V0 (Flying-10, r=-0.58, R^2=0.34, p=0.35), F0 (CMJ, r=-0.39, R^2=0.15 p<0.05; %IMB, r=-0.27, R^2=0.07, p<0.05), and Pmax (%IMB, r=-0.23, R^2=0.05, p<0.05). Relative to body mass, horizontal FV profiling showed significant, positive correlation with Pmax (W/kg) (CMJ, r=0.51, R^2=0.26, p<0.000; %IMB, r=0.28, R^2=0.08, p=0.0127). It also showed significant, negative correlation with F0 (N/kg) (Flying-10, r=-0.32, R^2=0.10, p=0.0051) and Pmax (W/kg) (Squat, r=-0.32, R^2=0.10, p=0.006; Flying-10, r=-0.62, R^2=0.38, p<0.0001)

Table 6. Simple Linear Regression and Pearson Correlation Analysis, Horizontal FV Profile and Performance metrics Results (n=82)

	Variable	r	95% CI	R squared	P Value
V0 (m/s)	Clean 1-RM (kg)	0.10	-0.13 to 0.32	0.01	0.4044
	Squat 1-RM (kg)	-0.14	-0.36 to 0.09	0.02	0.2224
	CMJ (m)	0.58	0.41 to 0.71	0.33	<0.0001*
	Flying-10 (s)	-0.58	-0.71 to -0.41	0.34	<0.0001*
	%IMB	0.08	-0.14 to 0.30	0.01	0.4792
F0 (N)	Clean 1-RM (kg)	0.20	-0.03 to 0.41	0.04	0.0896
	Squat 1-RM (kg)	0.33	0.11 to 0.52	0.11	0.0035*

	CMJ (m)	-0.39	-0.56 to -0.19	0.15	0.0004*
	Flying-10 (s)	0.42	0.22 to 0.59	0.18	0.0001*
	%IMB	-0.27	-0.46 to -0.06	0.07	0.0134*
F0 (N/kg)	Clean 1-RM (kg)	-0.19	-0.41 to 0.04	0.04	0.1115
	Squat 1-RM (kg)	-0.19	-0.40 to 0.04	0.04	0.0982
	CMJ (m)	0.22	-0.002 to 0.42	0.05	0.0528
	Flying-10 (s)	-0.32	-0.50 to -0.10	0.10	0.0051*
	%IMB	0.14	-0.08 to 0.35	0.02	0.2051
Pmax (W)	Clean 1-RM (kg)	0.31	0.08 to 0.50	0.09	0.0084*
	Squat 1-RM (kg)	0.34	0.13 to 0.53	0.12	0.0024*
	CMJ (m)	-0.19	-0.39 to 0.03	0.04	0.0932
	Flying-10 (s)	0.21	-0.01 to 0.41	0.05	0.0586
	%IMB	-0.23	-0.42 to -0.01	0.05	0.0389*
Pmax (W/kg)	Clean 1-RM (kg)	-0.17	-0.39 to 0.07	0.03	0.1619
	Squat 1-RM (kg)	-0.32	-0.51 to -0.10	0.10	0.006*
	CMJ (m)	0.51	0.32 to 0.66	0.26	<0.0001*
	Flying-10 (s)	-0.62	-0.74 to -0.46	0.38	<0.0001
	%IMB	0.28	0.06 to 0.47	0.08	0.0127*

Note: F0=maximum force output; V0= maximum velocity output; Pmax= maximum power output; 1-RM= 1 rep max; CMJ= countermovement jump; Flying-10= 10 yard split (s); %IMB= force-velocity imbalance from non-countermovement vertical jump with 90° of knee flexion.

Table 7 shows the results of the Pearson coefficient analysis and simple linear regression between the vertical FV profile and performance results. Absolute values of vertical FV profiling showed significant, positive correlations with F0 (Clean, r=0.58, R^2=0.33, $p<0.05$; Squat, r=0.58, R^2=0.34, $p<0.05$; CMJ, r=0.60, R^2=0.36, $p<0.05$; flying 10, r=0.36, R^2=0.13, $p<0.05$); Pmax (Clean, r=0.41, R^2=0.17, $p<0.05$; Squat, r=0.52,

R^2=0.27, p<0.05; flying 10, r=0.34, R^2=0.11, p<0.05). Vertical FV profiling showed no significant, positive correlations with V0 (clean 1-RM, r=-0.003, R^2=0.00001, p=0.9795), F0 (%IMB, r=0.21, R^2=0.04, p=0.05760, and Pmax (CMJ, r=-0.11, R^2=0.01, p=0.3336). Relative to body mass, vertical FV profiling showed significant, positive correlation with F0 (CMJ, r=0.61, R^2=0.37, p<0.0001; %IMB, r=0.71, R^2=0.51, p<0.0001) and Pmax (CMJ, r=0.70, R^2=0.49 and p<0.0001). It also showed significant, negative correlation with F0 (Flying-10, r=-0.62, R^2=0.39, p<0.0001) and Pmax (Flying-10, r=-0.53, R^2=0.28, p<0.0001).

Table 7. Simple Linear Regression and Pearson Correlation Analysis between Vertical FV Profile and Performance metrics Results (n=82)

	Variable	r	95% confidence interval	R squared	P Value
	Clean 1-RM	0.00	-0.23 to 0.23	0.00001	0.9795
	Squat 1-RM	0.05	-0.18 to 0.27	0.002	0.6886
V0 (m/s)	CMJ	-0.11	-0.32 to 0.11	0.01	0.3347
	Flying-10	0.11	-0.17 to 0.32	0.01	0.3429
	%IMB	-0.37	-0.54 to -0.17	0.14	0.0006*
	Clean 1-RM	0.08	-0.15 to 0.31	0.01	0.4878
	Squat 1-RM	-0.07	-0.29 to 0.17	0.00	0.5774
F0 (N/kg)	CMJ	0.61	0.44 to 0.73	0.37	<0.0001*
	Flying-10	-0.62	-0.74 to -0.46	0.39	<0.0001*
	%IMB	0.71	0.58 to 0.80	0.51	<0.0001*
	Clean 1-RM	0.58	0.40 to 0.71	0.33	<0.0001*
	Squat 1-RM	0.58	0.41 to 0.71	0.34	<0.0001*
	CMJ	0.60	0.44 to 0.72	0.36	<0.0001*
	Flying-10	0.36	0.15 to 0.54	0.13	0.0011*
F0 (N)	%IMB	0.21	-0.007 to 0.41	0.04	0.0576
	Clean 1-RM	0.41	0.20 to 0.59	0.17	0.0003*
	Squat 1-RM	0.52	0.33 to 0.67	0.27	<0.0001*
Pmax (W)	CMJ	-0.11	-0.32 to 0.11	0.01	0.3336
	Flying-10	0.34	0.12 to 0.52	0.11	0.0026*
	%IMB	-0.61	-0.73 to -0.46	0.38	<0.0001*

Pmax (W/kg)	Clean 1-RM	0.18	-0.06 to 0.40	0.03	0.1409
	Squat 1-RM	0.05	-0.19 to 0.27	0.002	0.6985
	CMJ	0.70	0.56 to 0.80	0.49	<0.0001*
	Flying-10	-0.53	-0.68 to -0.35	0.28	<0.0001*
	%IMB	-0.10	-0.31 to 0.12	0.01	0.3797

Note: F0=maximum force output; V0= maximum velocity output; Pmax= maximum power output; 1-RM= 1 rep max; CMJ= countermovement jump; Flying-10= 10 yard split (s); %IMB= force-velocity imbalance from non-countermovement vertical jump with 90° of knee flexion.

Discussion

The first aim of this study was to use horizontal and vertical FV profiling to determine and compare F0, V0 and Pmax outputs between position groups in collegiate American football players. We hypothesized that the big athletes of the offensive and defensive line would have the highest F0 in both the vertical and horizontal FV profiles, and thus their resultant program should focus on velocity development. Our study found that while the mean F0 for Bigs was the highest among all position groups for both horizontal and vertical, 21 of 27 Big athletes were still force-deficient. This may be explained by the observation that these athletes needed greater force to propel themselves forward when sprinting or upwards when jumping, relative to their body mass. Having higher levels of body fat will negatively impact sprint speed.(2) We also hypothesized that the athletes in the “skills group” (i.e., quarterback, wide receiver, defensive backs) would have the highest vertical V0 and the resultant training program should focus on strength or force development. The skills athletes’ mean vertical V0 was the highest of any position group, but the results of the FV profile evenly distributed them into each training program focused on force development, velocity development and the well-balanced group.(29)

Our study found that there was a moderate and positive correlation between horizontal velocity and CMJ. Previous studies have demonstrated that higher running velocities correlate with an elevated capacity for generating force.(1,4,6,14,17,22,23,26,36) We also saw this when looking at horizontal force relative to body mass. There was a significant, negative correlation between horizontal F0 (N/kg) and Flying-10 performance. This is explained by the primary factors that dictate velocity are the forces exerted on the ground and the duration of foot-ground contact. In other words, achieving higher velocities necessitates the application of stronger support forces within shorter contact intervals.[8,20,36]

There was a statistically significant moderate, negative correlation between horizontal velocity and flying-10 times. This shows that as horizontal velocity increases, flying-10 times decreases. With the availability of increased support forces, shorter contact times could be used to provide the necessary impulses and aerial times, resulting in higher speeds.[20]

We saw a small positive correlation between horizontal Pmax and Squat 1-RM. Comfort et al. (2014) reported similar results, where squat strength relative to body weight yielded stronger relationship with 20-m sprint compared to absolute squat strength.[3]

Vertical F0 had positive correlation with Squat 1RM, Clean 1-RM, and CMJ. All of these metrics are dependent on high force production, which has been seen across many studies, and correlate to improving maximal force proves to improve squat, clean and CMJ performance.[3,4,5,24,26,35,37]

Of the collegiate strength and conditioning performance measures such as CMJ, flying-10 time, 1-RM power clean, and 1-RM back squat, our study showed that vertical F0force explained 36% of the variance in CMJ. This fits the narrative in strength and conditioning that as squat strength increases so does jump height.[3,4,5,19,24,25,35,37] Vertical F0 also accounted for at least 33% of both power clean 1RM and back squat variance. This is also supported by previous studies and in practical application in the weight room.[4,5,24,25,26] Together these observations suggest that these common performance measures are reliable in predicting maximum force and velocity development.

Practical application

Strength and conditioning coaches should continue to use sprint and jump performance as proxy measures for vertical and horizontal F0 in American football players. These metrics had significant implications for CMJ and sprinting performance in our study. The positive relationship between horizontal F0 and sprint time and vertical F0 and CMJ suggest that training for improved sprint times and jump heights should improve performance or maximal power output.

Also, our results suggest that the subjective rating that coaches use to design the training program may not be optimal. For instance, the assumption that velocity-deficient athletes (Bigs) would need to only train for velocity may not optimize performance as our data showed that these athletes were still force deficient. Likewise, assuming that the skills group would need to solely focus on strength is not an ideal strategy, as our data showed that these players were a mixed group of force-deficient, velocity deficient, or well-balanced athletes. As such, when training American Football athletes, we recommend that FV profiling be used to determine which training program could optimize power and performance.

Limitations to our study

The primary limitation of this study was the testing equipment used for FV profiling. Vertical FV profile was determined by using electronic jump mats, where force plates would have been a more accurate measurement of FV profiles. Still, we followed Morin and Samozino's protocol for vertical FV profiles which has been previously validated. Also, using the iOS app for the horizontal FV profile is subjective to when the first propulsion action of the sprint occurred and when the speed sticks were at the center midline of the hip.

Practitioners should utilize force velocity profiling to identify how to best improve power outputs in their athletes. It is just another tool to help create the most optimal training for athletes based on their individual needs.

Conclusion

The significant relationships between F0, V0 and Pmax with metrics such as CMJ, Flying-10, Squat 1RM, and Clean 1RM indicate that strength and conditioning coaches and other sports performance practitioners are using measures which reliably track and predict performance. It is advantageous to utilize horizontal and vertical FV profiling along with traditional measurements of American Football athletic performance. Use of FV profiling allows the coaching staff to make better informed decisions about which training modalities should be used to improve performance. In the end, this helps the coaches to hone in on individualized training strategies to maximize improvement and optimize athletic performance.

Appendix 1.

UNIVERSITY of HAWAI'I®

Consent to Participate in a Research Project
Paulette Yamada Principal Investigator
Project title: “Force-Velocity Profiles in Collegiate American Football Players.*”*

Aloha! My name is Paulette Yamada and I am an Assistant Professor at the University of Hawai'i (UH) at Mānoa in the Department of Kinesiology and Rehabilitation Science. I will be conducting this study with the help of Ryan Ishihara and Parker Hill who are also in the same department as graduate students. This research project will serve to fulfill their requirements towards their graduate degrees.

What am I being asked to do?
The goal is to learn how to optimize training protocols for American football players in order to maximize the athletic potential. In other words, does separating football players into force or velocity training-specific emphasis improve power and ultimately sport performance? This will take place at the beginning of regularly scheduled off-season training. Pre and post-performance results will be compared and evaluated to determine the effectiveness of the training.

Taking part in this study is your choice.
Your participation in this project is completely voluntary. You may stop participating at any time. If you stop being in the study, there will be no penalty or loss to you. Your choice to participate or not participate will not affect your rights to training with the Hawaii Football Strength and Conditioning program.

Why is this study being done?
The first aim of this cross-sectional study is to determine the maximal force (Fo), maximal velocity (Vo) and Pmax outputs among American football players and determine if these parameters are dependent upon position and/or level of experience. The second aim of this study is to determine if any correlations exist between horizontal and vertical FV profiles and common performance measures used in collegiate S&C settings such as flying-10 (maximum velocity 10 yard split) times, 1 rep maximum (RM) power clean, 1RM back squat. The 3rd aim is to determine if optimized training results in improvement in the FV profiles.

What will happen if I decide to take part in this study?
Testing will take place at the beginning of off-season training (March, 2023) and will consist of 3, 30-meter sprints, with split times being taken every 5 meters by MySprint app video recording. The best of the 3 repetitions will be used for the profile. After taking 30 minutes rest, the second part is a squat jump assessment. This portion will consist of 2-3 jumps unloaded, and loaded with an additional 20kg, 40kg, and 60 kg. Then, you will be placed into a training group specific to your baseline performance. You will be asked to undergo 5 weeks of training + 1 week of a deloaded training period (which is training similar to your usual pre-season training). Then at the end of the training period, you will be asked to complete the same assessments that were completed prior to the training.

1

UNIVERSITY of HAWAI'I

Consent to Participate in a Research Project
Paulette Yamada Principal Investigator
Project title: "Force-Velocity Profiles in Collegiate American Football Players."

With your permission, we will record data from these two assessments and create a force-velocity profile. Profiles will be separated by athletes position as a football player and years experience playing collegiate football.

What are the risks and benefits of taking part in this study?
As with any training or sporting event, there is potential for minor injuries such as spraining an ankle or pulling a hamstring due to the high velocity sprints. The methods used in this study will not put you at an increased risk of injury compared to the usual risk associated with participating in football strength and conditioning activities.

The benefit to you for participation in this study is knowing how your performance as an athlete compares to other athletes that play your same position, and the training program could potentially improve your athletic performance.

Privacy and Confidentiality: We will keep all study data secure in a password locked google sheet in a locked office/encrypted on a password protected computer. No one outside the Hawaii Football Performance staff and Hawaii Football Coaching staff will have access to this information. Other agencies that have legal permission have the right to review research records. The University of Hawai'i Human Studies Program has the right to review research records for this study.
Records of force-velocity profiles will be stored and used for the duration of your time as a Hawaii Football athlete. When we report the results of our research project, We will not use your name. We will not use any other personal identifying information that can identify you. We will use pseudonyms (not your real names) and report our findings in a way that protects your privacy and confidentiality to the extent allowed by law. Side view video will be used to conduct horizontal FV profiling, there will not be a clear shot of the face. Video will be used for analysis as part of the study, kept on the iPad owned by UH Strength and Conditioning for no longer than the athlete's tenure as a student-athlete at the University of Hawaii.

Compensation:
No compensation will be given for participating in this study. However, participants will receive an optimized training program that will be scientifically developed, which could improve performance.

Conflict of Interest
We have graduate assistantship through the UH Athletics program (as strength and conditioning graduate assistants.) Our goal is to maximize our athlete's performance. We will not be provided

2

extra compensation for improved performance of their athletes. As such, there is little to no risk of our positions as graduate assistants affecting research outcomes.

Disclaimer
The Head Strength Coach of the Hawaii Football program, Kody Cooke, has given his full support to this study and training intervention. This is also supported by the Head Football Coach, Timmy Chang and his staff. For the duration of this study, Coach Chang and his coaching staff will let the study run its course without interference by not being involved in any way.

Questions:
If you have any questions about this study, please call or email Parker Hill at (801) 641-9515 & hill33@hawaii.edu) or Ryan Ishihara at (808) 292-6907 & ryannki@hawaii.edu. You may also contact our advisor, Dr. Paulette Yamada, at (808) 956-3638 & pyamada@hawaii.edu). You may contact the UH Human Studies Program at (808) 956-5007 or uhirb@hawaii.edu. to discuss problems, concerns and questions; obtain information; or offer input with an Iinformed individual who is unaffiliated with the specific research protocol. Please visit http://go.hawaii.edu/jRd for more information on your rights as a research participant.

If you agree to participate in this project, please sign and date the following signature page and return it to: *Parker Hill or Ryan Ishihara.*

A copy of the informed consent will be emailed to you for your records and reference.

Signature(s) for Consent:

I give permission to join the research project entitled, "Force-Velocity Profiles in Collegiate American Football Players."

Please initial next to either "Yes" or "No":

_____ Yes _____ No

Name of Participant (Print): ______________________________

Participant's Signature: ______________________________

Signature of the Person Obtaining Consent: ______________________________

Date: ______________________

Appendix 2.

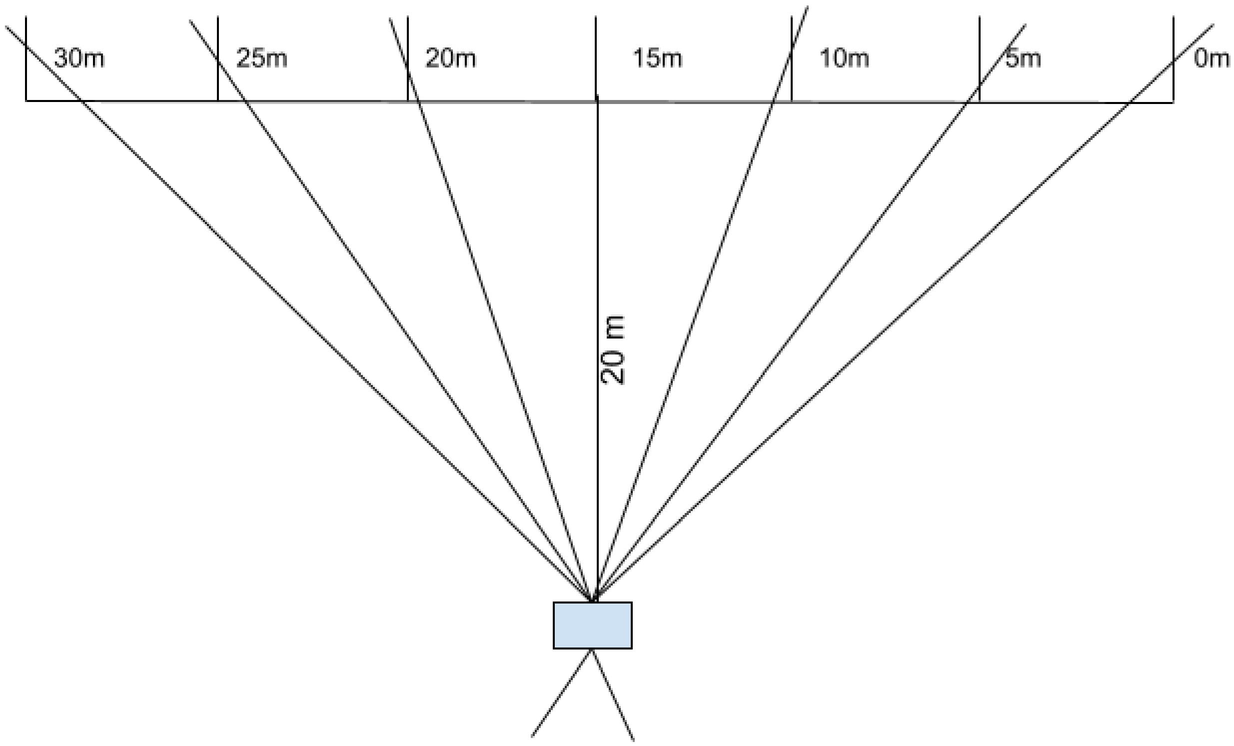
Monday (30m sprint + Vertical FV assessment)	Tuesday (Flying-10 + Clean 1RM)	Wednesday (Flying-10 + Clean 1RM)	Thursday (CMJ + Squat 1RM)
ALL OFFENSE	OL	RBs	ALL OFFENSE
	QBs	WRs	
	TEs	SPEC	
ALL DEFENSE	DL	Safeties	ALL DEFENSE
	LBs	CBs	

Appendix 3.

HI-SPEED DYNAMIC WARM-UP	
FWD SKIP	x HASH
BWD SKIP	x SIDELINE
WALKING QUAD + LEG CRADLE	x HASH
SL TOE TOUCH	x NUMBERS

HAMSTRING SCOOPS	x NUMBERS
WALKING LEG SWING	x NUMBERS
LEG SWING SKIP	x HASH
BIG BOUNDS	x SIDELINE
A-MARCH	x NUMBERS
A-SKIP	x SIDELINE
A-3s	x NUMBERS
A-Pops (R)	x SIDELINE
A-Pops (L)	x HASH
DRIBBLES: A-C-K	x SIDELINE
FLOAT-SPRINT-FLOAT	x OPPOSITE SIDELINE

Figure 1.



Appendix 4.

Body weight squat	**x10**
Pogo jump for height	**x10**
Max effort vertical jump	**x5**

References

1. Arampatzis A, Brüggemann GP, Metzler V. The effect of speed on leg stiffness and joint kinetics in human running. *J Biomech*. 1999;32(12):1349-1353. doi:10.1016/s0021-9290(99)00133-5
2. Barbieri D, Zaccagni L, Babić V, Rakovac M, Mišigoj-Duraković M, Gualdi E. Body composition and size in sprint athletes. *The Journal of sports medicine and physical fitness*. 2017;57. doi:10.23736/S0022-4707.17.06925-0
3. Comfort P, Stewart A, Bloom L, Clarkson B. Relationships Between Strength, Sprint, and Jump Performance in Well-Trained Youth Soccer Players. *The Journal of Strength & Conditioning Research*. 2014;28(1):173. doi:10.1519/JSC.0b013e318291b8c7
4. Cronin J, Ogden T, Lawton T, Brughelli M. Does Increasing Maximal Strength Improve Sprint Running Performance? *Strength & Conditioning Journal*. 2007;29(3):86.
5. Cronin J, Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Med*. 2005;35(3):213-234. doi:10.2165/00007256-200535030-00003
6. Cross M, Brughelli M, Brown S, et al. Mechanical Properties of Sprinting in Elite Rugby Union and Rugby League. *International Journal of Sports Physiology and Performance*. 2014;10:695-702. doi:10.1123/ijspp.2014-0151
7. Haugen T, Breitschädel F, Samozino P. Power-Force-Velocity Profiling of Sprinting Athletes: Methodological and Practical Considerations When Using Timing Gates. *The Journal of Strength and Conditioning Research*. 2018;34. doi:10.1519/JSC.0000000000002890
8. Hunter JP, Marshall RN, McNair PJ. Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *J Appl Biomech*. 2005;21(1):31-43. doi:10.1123/jab.21.1.31
9. Jimenez-Reyes P, Samozino P, Brughelli M, Morin JB. Effectiveness of an Individualized Training Based on Force-Velocity Profiling during Jumping. *Frontiers in Physiology*. 2017;7. doi:10.3389/fphys.2016.00677
10. Jimenez-Reyes P, Samozino P, García Ramos A, Cuadrado V, Brughelli M, Morin JB. Relationship between vertical and horizontal force-velocity-power profiles in various sports and levels of practice. *PeerJ*. 2018;6:e5937. doi:10.7717/peerj.5937
11. Jimenez-Reyes P, Samozino P, Morin JB. Optimized training for jumping performance using the force-velocity imbalance: Individual adaptation kinetics. *PLOS ONE*. 2019;14:e0216681. doi:10.1371/journal.pone.0216681

12. Juan EA, Fuentes J, Conceicao F, Jimenez-Reyes P. Association between vertical and horizontal force-velocity-power profiles in netball players. *Journal of Human Sport and Exercise*. 2022;17:83-92.
13. Junge N, Lundsgaard A, Hansen MF, et al. Force-velocity-power profiling of maximal effort sprinting, jumping and hip thrusting: Exploring the importance of force orientation specificity for assessing neuromuscular function. *J Sports Sci*. 2021;39(18):2115-2122. doi:10.1080/02640414.2021.1920128
14. Keller TS, Weisberger AM, Ray JL, Hasan SS, Shiavi RG, Spengler DM. Relationship between vertical ground reaction force and speed during walking, slow jogging, and running. *Clin Biomech (Bristol, Avon)*. 1996;11(5):253-259. doi:10.1016/0268-0033(95)00068-2
15. Knudson DV. Correcting the Use of the Term “Power” in the Strength and Conditioning Literature. *The Journal of Strength & Conditioning Research*. 2009;23(6):1902-1908. doi:10.1519/JSC.0b013e3181b7f5e5
16. Kuzmits FE, Adams AJ. The NFL Combine: Does It Predict Performance in the National Football League? *The Journal of Strength & Conditioning Research*. 2008;22(6):1721-1727. doi:10.1519/JSC.0b013e318185f09d
17. Kyröläinen H, Belli A, Komi PV. Biomechanical factors affecting running economy. *Med Sci Sports Exerc*. 2001;33(8):1330-1337. doi:10.1097/00005768-200108000-00014
18. Lahti J, Jimenez-Reyes P, Cross M, et al. Individual Sprint Force-Velocity Profile Adaptations to In-Season Assisted and Resisted Velocity-Based Training in Professional Rugby. *Sports*. 2020;8. doi:10.3390/sports8050074
19. McBride J, Kirby TJ, Haines T, Skinner J. Relationship Between Relative Net Vertical Impulse and Jump Height in Jump Squats Performed to Various Squat Depths and With Various Loads. *International journal of sports physiology and performance*. 2010;5:484-496. doi:10.1123/ijspp.5.4.484
20. Mero A, Komi PV. Force-, EMG-, and elasticity-velocity relationships at submaximal, maximal and supramaximal running speeds in sprinters. *Eur J Appl Physiol Occup Physiol*. 1986;55(5):553-561. doi:10.1007/BF00421652
21. Morin JB, Samozino P. Interpreting Power-Force-Velocity Profiles for Individualized and Specific Training. *International journal of sports physiology and performance*. 2015;11. doi:10.1123/ijspp.2015-0638
22. Munro CF, Miller DI, Fuglevand AJ. Ground reaction forces in running: a reexamination. *J Biomech*. 1987;20(2):147-155. doi:10.1016/0021-9290(87)90306-x

23. Nigg BM, Bahlsen HA, Luethi SM, Stokes S. The influence of running velocity and midsole hardness on external impact forces in heel-toe running. *J Biomech*. 1987;20(10):951-959. doi:10.1016/0021-9290(87)90324-1
24. Peterson MD, Alvar BA, Rhea MR. The contribution of maximal force production to explosive movement among young collegiate athletes. *J Strength Cond Res*. 2006;20(4):867-873. doi:10.1519/R-18695.1
25. Peterson M, Rhea M, Alvar B. Maximizing Strength Development in Athletes: A Meta-Analysis to Determine the Dose-Response Relationship. *Journal of strength and conditioning research / National Strength & Conditioning Association*. 2004;18:377-382. doi:10.1519/R-12842.1
26. Randell AD, Cronin JB, Keogh JWL, Gill ND. Transference of Strength and Power Adaptation to Sports Performance—Horizontal and Vertical Force Production. *Strength & Conditioning Journal*. 2010;32(4):100. doi:10.1519/SSC.0b013e3181e91eec
27. Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc*. 2003;35(3):456-464. doi:10.1249/01.MSS.0000053727.63505.D4
28. Robbins DW. The National Football League (NFL) Combine: Does Normalized Data Better Predict Performance in the NFL Draft? *The Journal of Strength & Conditioning Research*. 2010;24(11):2888. doi:10.1519/JSC.0b013e3181f927cc
29. Robbins DW, Goodale TL, Kuzmits FE, Adams AJ. Changes in the athletic profile of elite college American football players. *J Strength Cond Res*. 2013;27(4):861-874. doi:10.1519/JSC.0b013e3182610be2
30. Samozino P, Edouard P, Sangnier S, Brughelli M, Gimenez P, Morin JB. Force-Velocity Profile: Imbalance Determination and Effect on Lower Limb Ballistic Performance. *International journal of sports medicine*. 2013;35. doi:10.1055/s-0033-1354382
31. Samozino, Pierre, Giuseppe Rabita, Sylvain Dorel, Jean Slawinski, Nicolas Peyrot, Eduardo Sáez de Villarreal, and Jean-Benoît Morin. A Simple Method for Measuring Power, Force, Velocity Properties, and Mechanical Effectiveness in Sprint Running: Simple Method to Compute Sprint Mechanics. *Scandinavian Journal of Medicine and Science in Sports* Article first published online (May 21, 2015). https://doi.org/10.1111/sms.12490.
32. Samozino P, Morin JB, Hintzy F, Belli A. A simple method for measuring force, velocity and power output during squat jump. *Journal of Biomechanics*. 2008;41(14):2940-2945. doi:10.1016/j.jbiomech.2008.07.028

33. Samozino P, Rejc E, Prampero P, Belli A, Morin JB. Optimal Force–Velocity Profile in Ballistic Movements—Altius. *Medicine and science in sports and exercise*. 2011;44:313-322. doi:10.1249/MSS.0b013e31822d757a
34. Smith RA, Martin GJ, Szivak TK, et al. The Effects of Resistance Training Prioritization in NCAA Division I Football Summer Training. *The Journal of Strength & Conditioning Research*. 2014;28(1):14. doi:10.1519/JSC.0b013e3182977e56
35. Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, Newton RU. Relationship of maximum strength to weightlifting performance. *Med Sci Sports Exerc*. 2005;37(6):1037-1043.
36. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J Appl Physiol (1985)*. 2000;89(5):1991-1999. doi:10.1152/jappl.2000.89.5.1991
37. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med*. 2004;38(3):285-288. doi:10.1136/bjsm.2002.002071
38. Yamashita D, Asakura M, Ito Y, Yamada S, Yamada Y. Physical Characteristics and Performance of Japanese Top-Level American Football Players. *Journal of Strength and Conditioning Research*. 2016;31:1. doi:10.1519/JSC.0000000000001714