Running head: The Importance of the Force-Vector Predominance

Influence of Vertical-Oriented vs. Horizontal-Oriented Combined Strength Training in Young Basketball Players

Q1

All changes will be reviewed by the production team to ensure they are consistent with the journal's style.

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Abstract

Sánchez-Sabaté, J, Gutiérrez, H, Marco-Contreras, LA, Younes-Egana, O, Gonzalo-Skok, O, and Piedrafita, E. Influence of vertical-oriented vs. horizontal-oriented combined strength training in young basketball players. *J Strength Cond Res* XX(X): 000–000, 2024—This study aimed to compare the effects of 8-week combined vertical-oriented vs. horizontal-oriented training interventions in basketball athletes. Eighteen highly trained U-16 basketball players participated in this study and were randomly assigned to either a combined vertical-oriented training group (CVG, n = 9) or a combined horizontal-oriented training group (CHG, n = 9). Bilateral and unilateral vertical jump height, unilateral horizontal jump distance, 5-m, 10-m, and 20-m sprint times, change-of-direction sprint times, and a limb symmetry index were among the measured performance variables. Combined strength training was performed twice a week for 8 weeks. CVG was compounded by the squat exercise (3 sets of 6–8 R at 30–45% 1 repetition maximum [1RM]), jump squats (2 sets of 6 R, at 5–12.5% body mass [BM]), and vertical jumps (3–4 sets × 6 R). CHG included the hip thrust exercise (3 sets of 6–8 R at 30–45% 1RM), sled towing sprints (2–3 R, at 5–12.5% BM), and sprints (3–4 R of 20-m). Within-group differences showed significant ($p < 0.05$ and statistical power >80%) improvements in unilateral vertical jumping with the right leg after both training interventions. By contrast, only CHG improved 5-m, 10-m, and 20-m sprint times ($p < 0.05$ and statistical power >80%). Significant effects were observed for CHG compared with CVG in 5-m, 10-m, and 20-m sprint times ($p < 0.05$ and statistical power >80%). This study reinforces the importance of oriented-combined training based on force-vector specificity target, mainly in horizontal-oriented actions.

Q2

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Key Words resistance training; force application; jump; sprint; change of direction

Introduction

Basketball is a team sport characterized by high physiological demands (36), with intermittent actions that require both aerobic and anaerobic systems (43). Numerous high-intensity efforts are performed throughout a match, such as jumps, sprints, turns, accelerations, decelerations, or changes of direction (COD) (2,20). For instance, these high-intensity

actions, such as sprints, account for 15% of game time, with a frequency of 52 sprints per game and an average of 1.7 seconds, leading to a sprint every 21–39 seconds (2,30), and jumping actions every minute of play (42). In addition, total accelerations range from 43 to 145, high-intensity accelerations range from 1 to 15, total decelerations range from 24 to 95, and high-intensity decelerations range from 4 to 40 per game (35). While differences in player performance may indeed exist based on their position and competitive level (42), it seems that determining actions are predominantly influenced by anaerobic factors (30), especially after the change in regulations from 2000 with a reduction in possession time (43). Thus, basketball performance could be determined by actions that involve high levels of strength and speed (20).

Evolving into the practical aspect of enhancing these types of actions related to basketball performance, various training methodologies have been explored. Different types of training have been used successfully in team sports modalities such as basketball (27). However, controversy still needs to be made about how to approach training properly. Traditional strength training has been shown to be effective in augmenting sport-specific actions, such as jumps, sprints, and COD, in these sports (6,39). Nevertheless, recent studies suggest that strength training involving exercises such as the squat, when combined with plyometric jumps, can improve functional performance—understood as the ability to execute sport-specific actions such as jumps, sprints, and COD—more effectively than using a single strength exercise alone (14,37) in basketball players (ES = 1.08; $p < 0.05$) (39). Furthermore, enhancements in these types of actions may be attained through the integration of strength exercises with resisted sprints (34). Combined training encompasses a variety of exercises, typically integrating a traditional strength exercise with a sport-specific action (with or without weights) (11). Such training modality might provide a more significant stimulus than a single modality (e.g., plyometric or resistance training) for the improvement of high-intensity actions such as jumping or sprinting (3,13), especially in male athletes after reaching the peak height velocity (PHV) (27).

Depending on the direction in which the force is applied, exercises can be characterized by having a greater vertical component (i.e., vertical vector) or a greater horizontal component (i.e., horizontal vector), with a significant influence on the adaptations produced (6,19). Force application in the specific direction of movement has been previously described (19), suggesting that athletes in training may benefit more from performing exercises if they share the directionality of force application with the specific movement of sports competition (19). Previous studies on trained athletes have observed that, after a training period, those who used exercises with a horizontal vector improved to a greater extent in sport-specific movements with a predominance of that vector and those who trained with exercises with a vertical vector did so in sport-specific movements of that vector (1,10,16). However, despite the above results, studies have yet to analyze the effects of a combined training strategy on specific force-vector adaptations. Thus, there is a need to know whether combined strength training focusing on 1 vector has superior effects than another. Therefore, the main objective of this study was to compare the effects of vertical and horizontal combined strength training, intentionally focused on enhancing specific force vectors, on unilateral and bilateral jumping, COD ability, between-limbs asymmetry, and linear sprinting performance in young, highly trained basketball players. Because several studies support the force vectors theory, in this study, we postulate that strength training strategies tailored to target a particular force vector could improve specific performance in associated actions.

Q4 Methods

Experimental Approach to the Problem

This study was developed over 10 weeks in the second half of the competitive season between March and May 2021. Each assessment was scheduled 7 days before and after the 8-week training period. The tests were conducted by Sport Sciences researchers (BSc and MSc) with specific ISAK training in the following order: (a) anthropometric measures; (b) countermovement jump (CMJ); (c) unilateral countermovement jump with the left leg (CMJL) and right leg (CMJR); (d) unilateral horizontal jump with the left leg (HJL) and right leg (HJR); (e) 20-m running sprint (T_{20}) with 5-m (T_5) and 10-m (T_{10}) split times; (f) 10-m (5 m + 5 m) COD test with a 180° turned performed with the left leg (COD_L) and right leg (COD_R); (g) 25-m COD test with 45° turned performed each 5 m (V_{CUT}); and (h) limb symmetry index (LSI) (16).

A prospective randomized study design (A-Basis & B-Basis Analysis distribution) was conducted. The randomization process was performed using the software Microsoft Excel for Microsoft 365 MSO (version 2307, build 16.0.16626.20170) with a 32-bit architecture. A pair of independent researchers were responsible for generating the

randomized allocation sequence, enrolling the study subjects, and designating them to one of the following 2 groups: (a) one who performed a combined training with exercises predominantly designed to enhance the vertical force-vector (~~Combined Vertical-oriented Group~~combined vertical-oriented training group: CVG; $n = 9$); (b) another who performed a combined training where exercises were chiefly aimed at improving the horizontal force vector (~~Combined Horizontal-oriented Group~~combined horizontal-oriented training group: CHG; $n = 9$).

A certified strength and conditioning coach with a BSc in sports science and NSCA CSCS certification supervised all training sessions. Subjects were advised to avoid extra strenuous activities outside the study or their usual basketball training and to keep their regular diet. All sessions coincided (between 6 and 7 PM) on the same basketball court, with temperatures maintained at 22–24 °C and humidity between 50 and 60%.

Subjects

Eighteen male basketball players (age: 15.9 ± 0.5 years; height: 180.7 ± 8.4 cm; mass: 73.7 ± 11.4 kg) volunteered to participate in this study. All the players belonged to the same team, competing in the U-16 category of the Spanish Basketball National League. All subjects had a minimum basketball training experience of 3–5 years and 2 years prior strength training experience. During an 8-week training program, all subjects kept their usual training schedule: 4 on-court basketball training sessions (90 minutes/session), 2 strength and conditioning sessions (60 minutes/session), and 1 game (40 minutes/game).

The inclusion criteria were (a) having a minimum of 1 year experience in strength training; (b) lack of previous injuries or pathologies at the beginning of the study; and (c) completing ≥90% of the strength training program. As an exclusion criterion, having any musculoskeletal injury, pain, or discomfort during the study was established. Consequently, no subjects were excluded from the final sample. The *[blinded for peer review]* University of San Jorge Ethics Committee reviewed and approved the study protocol. (ref. #11–20/21). Before recruitment, subjects and their parents were informed of the purpose, testing, procedures, and potential risks and signed an informed written consent form. This study was conducted following the Declaration of Helsinki.

Procedures

Subjects were familiarized with all tests and procedures 1 week before starting data collection. Anthropometric and initial squat and hip thrust loading tests were measured during these sessions (9). The remaining assessments were conducted during a testing session. To minimize the influence of diurnal variations, the testing times were kept consistent with training session times across both initial and final testing periods. Before testing, all subjects completed a 15-minute standardized warm-up consisting of 5 minutes of jogging, dynamic stretches (lunges, diver, lateral squat) (5 minutes), and a specific warm-up for each test, which has been described in each test independently. The rest interval was 3 minutes between different tests. Speed and COD tests follow the same procedures: The front foot was placed 0.5 m before the first timing gate, and timing gates were placed at 0.75 m height and 1.5 m distance.

Countermovement Jump Test

The CMJ was assessed 3 times using an optical detection system comprising a transmitting and receiving bar with associated software (OPTOJUMP, MICROGATE, Bolzano, Italy), with a 45-second rest between repetitions, and the best score was recorded. Subjects were instructed to keep their hands on their hips throughout all jumps, and the depth of each jump was self-selected. Furthermore, they were instructed to jump as high as possible. The specific warm-up consisted of 2 sets of 4 repetitions at progressive intensity. The test-retest's absolute and relative reliability values were calculated using all pretest attempts for each variable. The intraclass correlation coefficient (ICC) was 0.992 (~~CL90%~~confidence limit 90% (CL90%): 0.981–0.996), whereas the coefficient of variation (CV) was 1.87% (CL90%: 1.46–2.63).

Unilateral Countermovement Jump Test

The assessment was conducted twice, allowing for a 45-second rest between attempts, with the top result being recorded. Players were instructed to jump on 1 leg, hands on hips, and flex the other leg to 90° at hip and knee during CMJ_L and CMJ_R (OPTOJUMP, MICROGATE). The jump was considered invalid if an improper technique (i.e., not keeping hands on hips or not landing on the same leg) was used. Players jumped until 2 valid jumps were recorded. The specific warm-up involved 1 set per limb, each with 4 increasingly elevated jumps. Intraclass correlation

coefficient was 0.988 (CL90%: 0.971–0.995) and 0.978 (CL90%: 0.950–0.991) and CV was 4.02% (CL90%: 3.14–5.67) and 3.77% (CL90%: 2.95–5.32) for CMJ_L and CMJ_R, respectively.

Unilateral Horizontal Jump Test

The HJ_L and HJ_R performance was assessed using a measuring tape through 2 attempts, with a 45-second rest between jumps, and the best result was used for further analysis. Leg swing was permitted during propulsion, and one-leg landings were mandatory. Only jumps where subjects maintained balance and held the final position were recorded. The specific warm-up consisted of 1 set for each leg, comprising 4 jumps of progressive intensity. Intraclass correlation coefficient was 0.993 (CL90%: 0.985–0.997) and 0.996 (CL90%: 0.991–0.998), and CV was 1.87% (CL90%: 1.46–2.62) and 1.12% (CL90%: 0.88–1.57) for HJ_L and HJ_R, respectively.

Speed Test

Subjects performed 2 maximal, 20-m indoor sprints, with a 3-minute rest between attempts, recording the best result for later analysis. Sprint times over 5 m (T_5), 10 m (T_{10}), and 20 m (T_{20}) were recorded using double-beam photocells (WITTY, MICROGATE). Subjects started voluntarily and accelerated to maximum speed until the finish line. Throughout the test, subjects were verbally encouraged to exert their best. A specific warm-up procedure was followed, including 3 sets of 20-m running accelerations that gradually increased speed. Intraclass correlation coefficient was 0.910 (CL90%: 0.801–0.960), and CV was 2.16% (CL90%: 1.69–3.03).

Change of Direction Test

Subjects executed 2 trials of a 10-m sprint test (5 m out and 5 m back) with a 180°COD at the midpoint, separated by a 2-minute rest, and the best time was recorded for subsequent analyses. Subjects began 0.5 m behind the start line, sprinted 5 m, executed a 180° turn (COD_L or COD_R), and returned to the start. Incorrect turns or pivots (players had to pass a marked line) invalidated the attempt, requiring a redo after adequate recovery. The specific warm-up protocol consisted of 1 submaximal trial. Intraclass correlation coefficient was 0.932 (CL90%: 0.848–0.970) and 0.928 (CL90%: 0.840–0.969), and CV was 2.19% (CL90%: 1.71–3.08) and 2.11% (CL90%: 1.65–2.96) for COD_L and COD_R, respectively.

V-Cut Test

Players had to sprint along a 25-m zigzag path, executing a 45°COD every 5 m (17), completing the test 2 times with a 2-minute rest between attempts, and the best time was analyzed. To do this, they placed their front foot 0.5 m behind the start line before beginning. The specific warm-up consisted of 1 submaximal trial. Intraclass correlation coefficient was 0.953 (CL90%: 0.892–0.979), and CV was 1.58% (CL90%: 1.24–2.22).

Limb Symmetry Index

After every unilateral test, the LSI was meticulously computed post hoc for each subject. This calculation was essential to assess and quantify the level of between-legs asymmetry, offering a precise measurement that facilitates the evaluation of limb performance and functional disparities. To compute the LSI, the performance measure of the weaker leg was divided by the stronger leg. This ratio was multiplied by 100 to produce a percentage. An LSI of 100% indicates perfect symmetry between the legs, whereas values less than 100% signify a disparity in limb performance (21).

Initial Loading Test

Predicted back squat and hip thrust 1 repetition maximum [1RMs] were estimated from the method developed by Brzycki (1993) (9). The Brzycki equation estimates a %1RM from the number of repetitions completed and the weight lifted: 1RM = repetition weight/[102.78–2.78 (nº reps)]. To determine the 10 repetition maximum (10RM) for both exercises, subjects first engaged in a standard warm-up, which included dynamic stretches and the test exercises with their body mass (BM). After this, subjects were allowed ample time to acclimatize specifically to different loads for the test exercises. The initial load was selected so that 10 over 12 repetitions could be completed with some fatigue but no muscle failure to avoid excessive fatigue. Both exercises were executed in the full range of motion. Adjustments to the weight were made based on the subject's ability to complete the 10 repetitions. The final weight successfully lifted for

10 repetitions, without breaking form, was documented as the 10RM. Such a test was only developed to plan the loads used during the training program and, thus, it was only performed at pretest.

Training Protocol

The experimental program lasted 8 weeks and was conducted twice weekly on the same days (Tuesday and Thursday). Each session lasted 45–60 minutes and encompassed the following components: 10 minutes of standard warm-up (5-minute submaximal running, 5-minute joint mobilization exercises, and 1 set of 6 repetitions of the specific main exercise against 50% of the heaviest load of each session) and 30 minutes of the main exercises. The CVG used the squat exercise, the jump squat, and the CMJ, whereas the CHG performed the hip thrust exercise, the sled towing, and sprints in such order. In this particular approach, exercises with high loads are performed at the start of the session. These are followed by power exercises involving lighter loads, in addition to sport-specific actions executed using bodyweight. The key aspect of this strategy is completing all sets of each exercise before moving on to the next 1, ensuring a structured transition from high-load to lighter-load exercises within the session (11). A rest period of 3 minutes was implemented between exercise blocks with different loads.

Training volume for the main exercises (squat and hip thrust) was the same for both groups, performing 3 sets of 6–8 repetitions (Table 1). The volume measured in sets for both jump and sprint exercises, whether resisted or bodyweight, was comparable for both groups, which performed from 2 to 4 sets per exercise. When measured in repetitions, the volume could not be accurately matched because sprints are gauged in meters covered. However, both groups maintained a similar volume progression ratio, derived from dividing the total meters covered by the number of jumps executed (average 3.3 m per jump performed) (Table 1). The rest time between sets was 3 minutes.

Table 1

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Descriptive characteristics of the training program for each group.*†

Group	Weeks	1	2	3	4	5	6	7	8
CVG	Squat (sets × reps, %1RM)	3 × 6, 30%	3 × 8, 30%	3 × 6, 35%	3 × 8, 35%	3 × 6, 40%	3 × 8, 40%	3 × 6, 45%	3 × 8, 45%
	Jump squat (sets × reps, %BM)	2 × 6, 5%	3 × 6, 5%	2 × 6, 7.5%	3 × 6, 7.5%	2 × 6, 10%	3 × 6, 10%	2 × 6, 12.5%	3 × 6, 12.5%
	CMJ (sets × reps)	3 × 6 R	4 × 6 R	3 × 6 R	4 × 6 R	3 × 6 R	4 × 6 R	3 × 6 R	4 × 6 R
CHG	Hip thrust (sets × reps, %1RM)	3 × 6, 30%	3 × 8, 30%	3 × 6, 35%	3 × 8, 35%	3 × 6, 40%	3 × 8, 40%	3 × 6, 45%	3 × 8, 45%
	Sled towing (sets × meters, %BM)	2 × 20, 5%	3 × 20, 5%	2 × 20, 7.5%	3 × 20, 7.5%	2 × 20, 10%	3 × 20, 10%	2 × 20, 12.5%	3 × 20, 12.5%
	Sprint (sets × meters)	3 × 20 m	4 × 20 m	3 × 20 m	4 × 20 m	3 × 20 m	4 × 20 m	3 × 20 m	4 × 20 m

Table Footnotes

*BM = body mass; CMJ = countermovement jump; 1RM = 1 repetition maximum.

†~~Experimental groups: CVG = combined vertical group (~~Experimental groups: CVG = combined vertical-oriented training group (*n* ~~= 9); CHG = combined horizontal group (~~ = 9); CHG = combined horizontal-oriented training group (*n* = 9).

The loads used in the squat and hip thrust exercises by each subject were assigned according to their 1RM obtained in the initial loading test (9), increasing from 30 to 45% 1RM (Table 1) (12,34). The loads used in the jump squat and resisted sprint exercises by each subject were assigned according to their percentage of BM, as previously recommended (7), based on the initial anthropometric test, increasing from 5 to 12.5% BM (Table 1).

Statistical Analyses

Statistical analysis was performed using SPSS version 28.0 for Windows (SPSS Inc., Chicago, IL). Descriptive statistics (mean ± *SD*) were calculated for all variables. Between-session reliability analysis was computed using a 2-way random ICC with an absolute agreement and 90% confidence intervals and the CV. Interpretation of ICC values were interpreted in line with Koo and Li (25), where values > 0.9 = excellent, >0.75 to 0.9 = good, >0.5 to 0.75 = moderate, and <0.5 = poor; CV values were considered as good (<5%), moderate (5–10%), and poor (>10%) (23). The normality of data sets was checked with the Shapiro-Wilk test, and all variables were normally distributed within each group. Consequently, parametric statistics were used.

A mixed ANOVA with 2 factors (pre and post) and 2 groups (CVG and CHG) was conducted to assess the interaction effect between time and training group. Eta-squared was used as the effect size to evaluate the magnitude of this interaction. Threshold values for eta squared (η^2) statistics were >0.01 (small), >0.06 (medium), and >0.14 (large).

Independent sample *t*-tests assessed whether groups were equal in the pretest. No statistically significant differences were found in the variables' pre-evaluation. Dependent sample *t*-tests assessed whether within-group differences existed between pretest and post-test. Independent sample *t*-tests were performed to evaluate between-group differences between postevaluation results. All *t*-tests were performed with a significance level of $p < 0.05$. Hedges' g was calculated to evaluate within-group and between-group comparisons effect size because of the small sample size. The following criteria were adopted for interpreting the magnitude of effect size (g) between test measures: Trivial $g < 0.2$; Small $0.2 \leq g < 0.5$, Medium $0.5 \leq g < 0.8$, Large $g \geq 0.8$. Confidence intervals of 95% were calculated for those effect sizes represented graphically to facilitate the interpretation of the probability of type I and type II errors.

Statistical power (1-β) was post hoc analyzed with G*Power 3.1.9.7 software to determine the power of the study based on the sample size of each group ($n = 9$) and the calculated effect size. Acceptable values of statistical power were considered 1-β = 0.80.

Results

The "group" × "time" interaction was found to be large, significant, and demonstrated a high level of statistical power for the variables T_5 ($\eta^2 = 0.603$, $p = 0.001$, 1-β = 0.99), T_{10} ($\eta^2 = 0.491$, $p = 0.001$, 1-β = 0.96), and T_{20} ($\eta^2 = 0.469$, $p = 0.002$, 1-β = 0.94), predominantly in the CHG. For the remaining variables, there were no statistically significant differences (Table 2).

Table 2

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Q7 **Changes in performance after a horizontal (CHG, *n* = 9) and a vertical (CVG, *n* = 9) combined training.*†**

Variables	Group	Pre	Post	Dependent *t*-test			Mixed ANOVA	
		Mean ± *SD*	Mean ± *SD*	Δ Hedges' g	*p*	1 − β	*p* Time effect	*p* Group × time
CMJ (cm)	CHG	32.7 ± 6.5	34.1 ± 6.4	0.64	0.066	0.39	0.009§	0.456
	CVG	32.7 ± 5.5	33.6 ± 5	0.68	0.056	0.43		
CMJ_L (cm)	CHG	15.8 ± 4.9	17.8 ± 4.1	0.99	0.011	0.74	0.001§	0.324
	CVG	17.2 ± 4.1	18.5 ± 4.2	0.72	0.043	0.48		
CMJ_R (cm)	CHG	15.4 ± 4.0	17.1 ± 4.3	**1.11**	**0.006‖**	**0.83**	<0.001§	0.548
	CVG	15.9 ± 3.3	18 ± 3.7	**1.44**	**0.001‖**	**0.96**		
CMJ_{LSI} (%)	CHG	88.0 ± 5.9	90.4 ± 11.3	0.21	0.509	0.08	0.333	0.933
	CVG	87.6 ± 9.4	89.6 ± 4.5	0.22	0.484	0.10		

HJ_L (cm)	CHG	147 ± 29	161 ± 21	0.83	0.025	0.59	0.008§	0.123
	CVG	153 ± 20	157 ± 21	0.41	0.215	0.19		
HJ_R (cm)	CHG	147 ± 29	157 ± 22	0.56	0.101	0.32	0.048	0.422
	CVG	150 ± 20	154 ± 18	0.33	0.305	0.14		
HJ_{LSI} (%)	CHG	92 ± 7	96 ± 4	0.51	0.129	0.27	0.220	0.204
	CVG	94 ± 3	94 ± 4	0.01	0.969	0.05		
T_5 (s)	CHG	1.10 ± 0.10	1.01 ± 0.08	**1.56**	**0.001‖**	**0.98**	0.249	0.001§
	CVG	1.05 ± 0.06	1.11 ± 0.05	–0.70	0.049	0.46		
T_{10} (s)	CHG	1.88 ± 0.13	1.81 ± 0.13	**1.89**	**0.001‖**	**0.99**	0.097	0.001§
	CVG	1.85 ± 0.08	1.87 ± 0.08	–0.37	0.258	0.17		
T_{20} (s)	CHG	3.24 ± 0.26	3.16 ± 0.22	**1.13**	**0.006‖**	**0.84**	0.054	0.002§
	CVG	3.22 ± 0.14	3.24 ± 0.14	–0.41	0.215	0.19		
COD_L (s)	CHG	2.70 ± 0.23	2.73 ± 0.16	–0.14	0.646	0.07	0.718	0.720
	CVG	2.75 ± 0.11	2.75 ± 0.20	0.00	1.000	0.05		
COD_R (s)	CHG	2.73 ± 0.24	2.76 ± 0.21	–0.27	0.402	0.11	0.963	0.179
	CVG	2.81 ± 0.13	2.78 ± 0.12	0.36	0.270	0.16		
COD_{LSI} (%)	CHG	98.04 ± 1.59	96.17 ± 3.59	0.40	0.225	0.19	0.508	0.175
	CVG	95.81 ± 2.61	96.47 ± 1.84	0.18	0.556	0.08		
V_{CUT} (s)	CHG	7.40 ± 0.58	7.32 ± 0.54	0.49	0.141	0.25	0.329	0.317
	CVG	7.39 ± 0.43	7.39 ± 0.41	0.01	0.987	0.05		

[Comment: To PGN: Insert the following as a new general footnote: Bold entries denote a significant difference ($p < 0.05$) and a statistical power > 0.80.]‡~~Intragroup significant differences from Pre to Post: $p < 0.05$ and 1-β > 0.80.~~

Q8

Table Footnotes

*~~CHG = combined horizontal group; CMJ = countermovement jump; COD~~CHG = combined horizontal-oriented training group; CMJ = countermovement jump; COD_L and COD_R = 5 + 5 m sprint with 180° ~~change of direction with left and right leg; CVG = combined vertical group; CMJ~~ change of direction with left and right leg; CVG = combined vertical-oriented training group; CMJ_L and CMJ_R = countermovement jump with left and right leg; HJ_L and HJ_R = horizontal jump with left and right leg; LSI_{CMJ} = limb symmetry index in unilateral CMJ; LSI_{COD} = limb symmetry index in COD; LSI_{HJ} = limb symmetry index in unilateral HJ; T_5 = 5 meter sprinting time; T_{10} = 10 meter sprinting time; T_{20} = 20 meter sprinting time; V_{CUT} = 25 m zigzag path, executing a 45° COD every 5 m.

†Data are mean ± *SD*, *n* = 18. All results are presented in the same direction, that is, a positive change is considered as an improvement, while a negative change as an impairment.

§Signifi[Comment: To PGN: Please replace the footnote designators "§" and "‖" with "‡" and "§" both in the footnote and body of Table 2.]cant interaction: $p < 0.05$ and 1-β > 0.80.

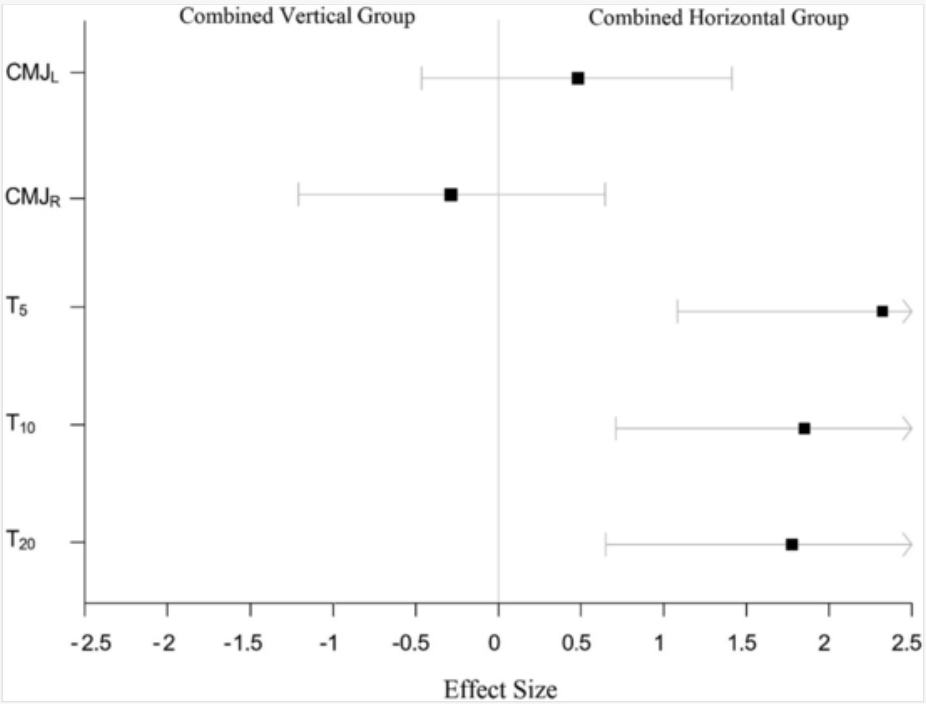
‖Intragroup significant differences from Pre to Post: $p < 0.01$ and 1-β > 0.80.

The time effect interaction was observed to be large and significant and showed an accepted power level for the variables CMJ ($\eta^2 = 0.353$, $p = 0.009$, 1-β = 0.79), CMJ_L ($\eta^2 = 0.509$, $p = 0.001$, 1-β = 0.97), CMJ_R ($\eta^2 = 0.691$, $p < 0.001$, 1-β = 0.99), and HJ_L ($\eta^2 = 0.367$, $p = 0.008$, 1-β = 0.82). For the remaining variables, there were no statistically significant differences (Table 2).

The results from within-group changes are shown in Table 2. Compared with pre-evaluation measures, significant differences ($p < 0.05$), and adequate statistical power (1-β > 0.80) were observed in CMJ_R across both groups. Significant improvements and acceptable statistical power ($p < 0.05$ and 1-β > 0.80) were also found in T_5, T_{10}, and T_{20} in the CHG.

The results from the between-group analysis for pre-post change are illustrated in Figure 1. The CHG showed significantly better outcomes in the T_5 ($g = 2.10$, $p < 0.001$, 1-β = 0.99), T_{10} ($g = 1.67$, $p = 0.001$, 1-β = 0.91), and T_{20} ($g = 1.60$, $p = 0.002$, 1-β = 0.89) in comparison with the CVG at post-test. Conversely, no significant difference was found between groups in CMJ_R ($g = -0.26$, $p = 0.548$, 1-β = 0.08).

Figure 1.



Standardized (Hedges) differences (CL95%) for unilateral vertical jump with right (CMJ_R) and left leg (CMJ_L), 5-m (T_5), 10-m (T_{10}), and 20-m (T_{20}) linear sprint time according to ~~combined vertical-oriented group~~combined vertical-oriented training group (CVG) and ~~combined horizontal-oriented group~~combined horizontal-oriented training group (CHG).

Discussion

This study aimed to compare the effects of 2 combined strength training programs with different emphases on force directionality and application (CVG vs. CHG) on functional variables such as jumping, linear sprinting, and COD ability in young, highly trained basketball players. The main findings of this study were (a) the CHG achieved important enhancements (large ES and statistical power) in sprinting compared with the CVG, and (b) similar unilateral vertical jumping improvements were observed in both groups.

Several studies suggest the importance of jumping ability in team sports because of its role in explosive actions (29), lower-body muscular power (45), and its relationship to agility and speed (32). No significant enhancements were achieved in CMJ for either CHG ($g = 0.64$) or CVG ($g = 0.68$). Although the current results did not achieve significant effects ($p > 0.05$), although they were very close ($p = 0.06$ and 0.056), the ES reported (0.64–0.68) are in agreement with previous studies that used other combined resistance training methods, which reported significant ES ranging from 0.16 to 0.94 (5,27,40,41). The intrinsic characteristics of the study's population substantially affect the resulting data. In this case, the subjects are extensively trained basketball players accustomed to frequent jumping activities, potentially narrowing the margin for generic enhancements in this capacity. Thus, factors such as training volume may play a crucial role in eliciting further development in their jumping abilities, necessitating a more substantial training load for noticeable improvements. Research has shown that a plyometric training protocol with 60–120 jumps per session is necessary to elicit significant enhancements in vertical jump performance among young basketball players (15,41). By contrast, distinct studies have reported notable improvements in vertical jump through a combined training protocol involving 6 sets of traditional strength exercises and approximately 40 plyometric jumps (27). Therefore, the specific volume used in this study (i.e., 3 sets in traditional strength exercises plus 30–40 plyometric jumps) could be a pivotal factor in the observed lack of significant enhancements in bilateral vertical jump performance.

Compared with pretest scores, significant improvements were observed in both groups for CMJ_L and CMJ_R. Specifically, the CHG demonstrated large ES in CMJ_L ($g = 0.99$) and CMJ_R ($g = 1.11$). Similarly, the CVG showed

medium effect sizes in CMJ_L (g = 0.72) and large effect sizes in CMJ_R (g = 1.44), although the statistical power for CMJ_L was not appropriated. However, no significant difference was found between groups in CMJ_L (g = 0.43) and CMJ_R (g = −0.26). These results could suggest that vertical and horizontal force-vector training methods improved unilateral vertical jumping performance. A recent meta-analysis has supported the previous finding, reporting a trivial between-treatment effect (vertical vs. horizontal) for vertical jumping (24). By contrast, Gonzalo-Skok et al. (16) reported no significant effects on unilateral-vertical jump ability (ES = from 0.18 to 0.33) after unilateral-lateral eccentric training in male basketball players. Apparent differences exist between the research of Gonzalo-Skok et al. (16) and this study, given the variations in training programs and force-vector strategies. Therefore, it could be expected that the outcomes would differ. Several researchers contend that the axial force vector enables athletes to generate increased force during horizontal and vertical jumps (10). In this regard, horizontal force application necessitates significant axial force output to counteract gravity during horizontal movements. As a result, athletes who undergo unilateral horizontal training protocols may see improvements in their unilateral vertical actions. In addition, such findings had been found in single training modalities such as plyometric or resistance training. This study also helps to understand that a horizontal combined training program affects vertical jumping ability similarly to a vertical combined program.

The results indicate significant improvements in horizontal jump performance over time for both HJL and HJR. These improvements, evidenced by the substantial statistical power (1-β = 0.816 for HJL and 0.521 for HJR), are noteworthy. However, these enhancements do not seem to be dependent on the group to which the subjects were assigned because the interactions between group and time did not reach statistical significance for either HJL (p = 0.123, η^2 = 0.142) or HJR (p = 0.422, η^2 = 0.041). It has not been could be in line with the previous results (1,6,10), which found significant increases in horizontal jumping performance for the horizontal training group (ES = from 0.48 to 1.24) compared with the vertical training group (ES = from 0.10 to 0.71). Training protocols that incorporate exercises such as the hip thrust augment the tension in the hip muscles and elevate their electromyographic activity. This adaptation is pivotal for optimizing performance in movements directed along the anteroposterior axis (1). Conversely, several researchers (4,10) also observed enhancements in HJ during a front squat training intervention. The axial force vector of the front squat could assist subjects in generating greater vertical force during a jump, which is essential for both horizontal and vertical jumps. Building on the discussion mentioned above, it is also critical to consider the biomechanical parallels between vertical and horizontal jumping. These actions share a common emphasis on vertical force application and biomechanical patterns (26). Thus, such commonality may explain those improvements found in both unilateral jumping abilities (i.e., vertical and horizontal) through both training groups.

Sprinting ability is a complex skill influenced by several factors, including muscle strength, power, speed, and technique (22). Research in sports science indicates a clear relationship between combined strength training and sprint performance (5,11,27). CHG showed large effect sizes in the T_5 (g = 2.10), T_{10} (g = 1.67), and T_{20} (g = 1.60) in comparison with the CVG. The observed enhancements are in line with previous research suggesting that combined resisted training can have a positive impact on sprinting performance (ES = 0.42 to 0.59) (38), and anteroposterior resisted movements seem to better transfer to horizontal-based activities (ES = from 0.30 to 0.37) (10). This study is consistent with these investigations because both underscore the importance of muscular power in enhancing short-distance sprinting performance. The likely underlying mechanism involves the enhancement of neuromuscular efficiency and force direction output (10), leading to increased stride length and frequency, both of which are key determinants of sprinting speed (28). Nonetheless, contrasting evidence also exists. Aztarain-Cardiel et al. (6) found no effective improvements in sprint performance after a 6-week horizontal plyometric training protocol in basketball athletes. The divergence between their findings and this research may be attributed to several factors. For one, the caliber of athletes could be a contributing factor: Professional adult athletes may already be near their potential performance peak, making improvements harder to achieve. Moreover, the specific nature of the training—whether plyometric or combined—plays a crucial role. Plyometric exercises have proven to be highly effective for pre-PHV children, leading to significant improvements in both sprinting and jumping abilities (27). However, for individuals post-PHV, the use of combined training methods has shown to be more effective in enhancing overall athletic performance, with observed improvements in acceleration, peak running speed, and squat jump height ranging from moderate to substantial (27). This reasoning could potentially explain the differences noted between studies. Although both studies involved post-PHV male basketball players, the key distinction lies in the nature of the intervention (combined vs. plyometric training).

The COD ability, denoting the ability to modify movement trajectory rapidly, is broadly acknowledged in the literature as a crucial performance determinant in team sports (8), including basketball (44). Changes in COD performance were observed to be less pronounced. No significant within-group changes were detected in COD_L, COD_R, and V_{CUT} test for either group. Despite the lack of significant improvements in COD performance, it should be noted that the effects of strength training on COD ability are mixed. Some studies have reported improvements in COD performance after combined strength and power training (11,16,33), while others have found no significant effects (5). Our findings align with the latter studies, suggesting that the training methods used in this study may be less effective for improving COD performance. It could be attributed to the multifactorial nature of COD, which, apart from strength and straight speed, also involves factors such as power, technique, and reactive strength and unilateral-horizontal and lateral force application (8,18). Implementing training protocols that incorporate traditional strength exercises, such as squats or hip thrusts, whose main force-vector application was bilateral-vertical, may not sufficiently enhance some COD determinants, such as unilateral-horizontal and lateral force application, the specific technique, or the reactive strength. Therefore, to improve COD performance, an effective strategy for combined training might include the integration of multidirectional plyometric exercises specifically tailored for COD determinants.

Certain limitations of this study warrant consideration when interpreting our findings. First, the absence of a control group and a limited sample size might affect the outcomes. Nonetheless, the selected statistical analysis should mitigate potential confounding effects. In addition, the study's duration spanned only 8 weeks (16 sessions), which could restrict generalizations concerning long-term adaptations associated with combined strength training emphasizing specific direction. Moreover, it is pertinent to address the specific force-velocity profile needs of basketball players aiming to optimize their vertical jump performance. Individual player profiles may dictate the need to train at lower or higher velocities to garner specific neural adaptations (31). Using a tailored approach that aligns with the force-velocity characteristics of each athlete could potentiate targeted improvements in vertical jumping capabilities, highlighting the importance of velocity-specific training stimuli for enhancing athletic performance in this cohort.

Practical Applications

This study underscores the influence of force-vector specificity in combined strength training, demonstrating its potent role in enhancing diverse performance variables in young basketball players. Our findings suggest that combined training with a horizontal force-vector predominance, using hip thrust with low/moderate loads (30–45% 1RM) and a low training volume (4–8 reps per set) combined with sled towing (5–12.5% BM) and sprints may produce a better effect on running sprint performance than a combined training with a vertical force-vector predominance. These findings suggest that integrating specific force vector training may be essential for targeted performance improvements, highlighting the need for specificity in strength training protocols.

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The corrections made in this section will be reviewed by the production team to ensure they are consistent with the journal’s style. Added or deleted references and corresponding citations, will be reordered by production.

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Queries and Answers

Q1

Query: Please provide the Department/Unit (if any) in affiliations "1 and 2."

Answer: No Department is needed.

Q2

Query: Please note that for “CVG,” definitions "combined vertical-oriented training group, combined vertical-oriented group, and combined vertical group" have been used inconsistently within the article. Please check whether the definition should be made consistent throughout the article.

Answer: It should appear combined vertical-oriented training group.

Q3

Query: Please note that for “CHG,” definitions "combined horizontal-oriented training group, combined horizontal-oriented group, and combined horizontal group" have been used inconsistently within the article. Please check whether the definition should be made consistent throughout the article.

Answer: It should appear combined horizontal-oriented training group.

Q4

Query: Please confirm that this study was approved by an Institutional Review Board. Please also confirm the institution's name if not already stated.

Answer: At the end of subjects's section, you can find all the information. The institution that approved the study was the University of San Jorge.

Q5

Query: Please provide the age ranges for all subjects mentioned in the Subjects section if you have not already. If any subjects were <18 years of age, please confirm that written parental consent was obtained. Please also confirm, if you have not already, that signed informed consent documents were obtained for all subjects.

Answer: Range age: 15 to 17. Written parental consent was obtained in all subjects.

Q6

Query: Please spell out/define abbreviation “CL90%.”

Answer: confidence limit 90% (CL90%).

Q7

Query: Please provide significance for bold entries in Table 2.

Answer: Bold entries denote a significant difference ($p<0.05$) and a statistical power >0.80.

Q8

Query: Please note that the footnote designator “‡” is not cited in the body of Table 2. Please check and provide the missing designator.

Answer: Such designator is the same meaning as the previous bold entries. As such, you can use either (i.e., symbol or bold) to denote intra-group $p<0.05$ and statistical power >0.80.