THE OPTIMAL PLYOMETRIC EXERCISE HORIZONTAL TO VERTICAL FORCE RATIO FOR SPRINTING

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This study determined the horizontal to vertical force ratio (H:V) of two types of sprint starts and a variety of plyometric exercises, for the purpose of determining the exercises which are most biomechanically specific to sprinting. Subjects included 15 men. All subjects' performed the sprinter start, the standing sprint start, the CMJ, 45.72 cm hurdle hop, bounding, power skipping, standing long jump, and multiple hops, starting on a force platform. A repeated measures ANOVA was used to determine differences in H:V between the sprinter start, the standing start, and the plyometric exercises. Results reveal significant main effects for sprint start H:V and standing start H:V, and the plyometric exercises H:V ($p \leq 0.001$). Post-hoc analyses revealed that bounding and standing long jumps are the most biomechanically similar for training athletes for sprint starts.

KEYWORDS: H:V, specificity, speed development, acceleration, running

INTRODUCTION: Sprinting speed is one of the most important variables required for success in many individual and team sports. The role of horizontal and vertical force production and the transfer of strength and power to sport performance has been described (Randell et al., 2010). The specifics of force development is particularly important for sprinting, where horizontal but not vertical force is correlated to increasing sprinting speed and is believed to be important for acceleration (Randell et al., 2010). For young athletes, plyometric exercises with a significant horizontal force production component have been shown to be more effective than other training strategies such as resistance training (Rumpf et al., 2012). Horizontally directed training strategies and high velocity exercise are thought to be the most effective in developing sprinting speed, enhancing the rationale for the inclusion of horizontal plyometric training in performance enhancement programs (Young et al., 2015).

The kinetics of some plyometric exercises have been studied. This research includes the evaluation of the ground reaction forces (GRF) and knee joint reaction forces of a variety of plyometrics (Jensen & Ebben, 2007), and the GRF of the first three steps of the triple jump (Ramey & Williams, 1985). Other research evaluated the kinetics of a variety of horizontally oriented plyometric exercises to compare and describe the exercise intensity of each (Kossow & Ebben, 2018). These studies assessed vertical GRF as well as the less commonly assessed horizontal GRF, but did not include the assessment of propulsive horizontal forces (Ramey & Williams, 1985) or evaluated only landing and not take-off forces of the plyometric exercises (Kossow & Ebben, 2018).

Research examined specific sprinting speed development strategies including the assessment of vertical and horizontal propulsive GRF of weighted sled towing at different loads (Kawamori et al., 2014). Other research focused on the kinematics and kinetics of the first two steps of sprinting and the differences that are present between slow and fast runners (Coh et al., 2017). While not reported, the horizontal to vertical impulse ratio can be calculated for sprinting when starting from blocks (Coh et al., 2017). It is likely that sled towing produces more total horizontal force than is present during sprinting in sports where an additional load is not present. Similarly, most team sports do not include sprint starts from blocks.

To date, the horizontal to vertical force ratio (H:V) when sprinting from a static start has not been determined. Furthermore, these ratios have not been assessed for plyometric exercises. Therefore, the purpose of this study was to assess the H:V ratio of two types of static sprinting starts compared to the H:V ratio of the vertically oriented countermovement jump, as well as a variety of horizontally oriented plyometric exercises, for the purpose of determining which exercises are most biomechanically specific to sprinting.

METHODS: Fifteen men (mean ± SD, age = 20.07 ± 1.10 yr) served as subjects in this study. Additional subject descriptive information is shown in Tables 1 and 2. The subjects were informed of the risks associated with the study and provided written consent. The study was approved by the institution's Internal Review Board.

Test exercises were demonstrated and the subjects practiced using the sprint starting exercises and the plyometric exercises to be assessed in this study. Following the demonstration and practice, the subjects were tested for the following conditions: 1) sprinter start, 2) standing start, 3) standing long jump, 4) bounding, 5) 45.72 cm hurdle hop, 6) skip, 7) double-leg hop, and 8) countermovement jump. Plyometric exercises such as these have been assessed or previously studied and thought to be useful for improving sprinting performance (Kossow & Ebben, 2018; Mero & Komi, 1994; Rumpf et al., 2012). Subjects performed two trials of each condition and rested for approximately one minute between all trials and test exercise, which were randomized using a random number generator.

The test exercises were performed on a force platform, which was countersunk and mounted flush to the floor (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA). The force platform was calibrated prior to the testing session. Data were acquired at 1000 Hz and analyzed in real time with proprietary software (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA). Peak vertical and sagittal plane horizontal GRF data were obtained for the take-off phase of each sprint start and plyometric exercise, based on the analysis of the force-time record. Subject's H:V was calculated from these data.

Data were analyzed with a statistical package (SPSS 25.0, International Business Machines Corporation, Armonk, New York) using a repeated measures ANOVA to determine differences between the sprinter start H:V and the H:V of the plyometric exercises, the standing start H:V, and the H:V of the plyometric exercises, as well as differences in horizontal GRF between all exercises. When significant main effects were found, a Bonferroni adjusted pairwise comparison was used to identify the specific differences. Pearson's correlation coefficients were used to assess the relationship between subject's plyometric training experience and the H:V ratios of the sprint starts and plyometric exercises assessed in this study. The trial-to-trial reliability of each dependent variable was assessed using average measures Intraclass correlation coefficients (ICC) and coefficients of variation were calculated. Assumptions for linearity of statistics were tested and met. Statistical power (*d*) and effect size (η_p^2) are reported and all data are expressed as means ± SD. The *a priori* alpha level was set at $p \leq 0.05$.

Table 1. Subject descriptive information (mean ± SD).

Height measured in centimeters	184.07 ± 8.36
Mass measured in kilograms	83.13 ± 13.51
Speed training experience expressed as days per week	1.20 ± 0.68
Agility training experience expressed as days per week	1.13 ± 0.52
Plyometric training experience expressed as days per week	1.53 ± 0.64
Anaerobic sport participation expressed as days per week	5.33 ± 1.23
Years of high school sport participation	4.00 ± 0.00
Years of collegiate sport participation	2.80 ± 1.08

Table 2. Subject sports background. Number represents the number of subjects in each sport.

High School							College				
BKB	VLB	BSB	FTB	TRK	SCR	XCC	BKB	VLB	SCR	TRK	BSB
13	6	5	4	2	2	1	11	2	1	1	1

BKB=Basketball: VLB=Volleyball: BSB=Baseball: FTB=Football: TRK=Track: SCR=Soccer: XCC=Cross Country

RESULTS: Results reveal significant main effects for sprint start H:V and the plyometric exercises H:V ($p \leq 0.001$, $\eta_p^2 = .79$, $d = 1.00$), standing start H:V and the plyometric exercises H:V ($p \leq 0.001$, $\eta_p^2 = .75$, $d = 1.00$), and horizontal GRF of the sprint starts and the plyometric ($p \leq 0.001$, $\eta_p^2 = .50$, $d = 1.00$). Results of the Bonferroni post-hoc analyses are presented in Tables 3-5. Subject experience with plyometric training was negatively correlated with sprinter start H:V (r = -0.64 p = 0.010), bounding H:V (r = -0.50 p ≤ 0.049), double leg hop H:V(r = -0.53, p = 0.041), hurdle hop H:V (r = -0.70, p ≤ 0.003), and standing long jump H:V (r = -0.47, p = 0.047). The ICC's for the test exercises and all dependent variables ranged from 0.79 to 0.96 for the horizontal GRF data, and 0.90 to 0.97 for the vertical GRF data. Coefficients of variation for all data ranged from 13.4% to 30.5%.

Table 3. Standing start GRF H:V compared to plyometric exercises GRF H:V, all expressed as mean ± standard deviation.

	STS[a]	BND[b]	SLJ[c]	DBH[c]	SKP[c]	HDL[c]	CMJ[b]
H:V	0.36 ± 0.06	0.29 ± 0.06	0.23 ± 0.07	0.22 ± 0.06	0.22 ± 0.07	0.20 ± 0.06	0.11 ± 0.02

GRF= Ground Reaction Force: H= Horizontal Plane: V= Vertical Plane STS= Standing Start: BND= Bounding: SLJ= Standing Long Jump: DBH= Double Hop: SKP= Skip: HDL= 45.72 cm Hurdle Jump CMJ= Counter Movement Jump

[a]Significantly different ($p \leq 0.001$) than all other test exercises.
[b]Significantly different ($p \leq 0.05$) than all other test exercises.
[c]Significantly different ($p \leq 0.05$) than STS, BND, and CMJ.

Table 4. Sprinter start GRF H:V compared to plyometric exercises GRF H:V, all expressed as mean ± standard deviation.

	SPS[a]	BND[a]	SLJ[b]	DBH[b]	SKP[b]	HDL[b]	CMJ[a]
H:V	0.40 ± 0.05	0.29 ± 0.06	0.23 ± 0.07	0.22 ± 0.06	0.22 ± 0.07	0.20 ± 0.06	0.11 ± 0.02

GRF= Ground Reaction Force: H= Horizontal Plane: V= Vertical Plane SPS= Sprinter Start: BND= Bounding: SLJ= Standing Long Jump: DBH= Double Hop: SKP= Skip: HDL= 45.72 cm Hurdle Jump CMJ= Counter Movement Jump

[a]Significantly different ($p \leq 0.05$) than all other test exercises.
[b]Significantly different ($p \leq 0.05$) than SPS, BND, and CMJ.

Table 5. Horizontal ground reaction force (N) for all test exercises, all expressed as mean ± standard deviation.

	SPS[a]	STS[a]	BND[a]	HDL[a]	SLJ[a]	DBH[a]	SKP[a]	CMJ[b]
H-GRF	527.42 ± 77.87	507.41 ± 66.52	502.20 ± 104.08	489.38 ± 138.14	462.12 ± 135.61	448.65 ± 104.83	434.35 ± 74.23	273.46 ± 74.23

H-GRF = Horizontal Ground Reaction Force: H= Horizontal Plane: V= Vertical Plane SPS= Sprinter Start: BND= Bounding: SLJ= Standing Long Jump: DBH= Double Hop: SKP= Skip: HDL= 45.72 cm Hurdle Jump CMJ= Counter Movement Jump

[a]Significantly different ($p \leq 0.01$) than the CMJ.
[b]Significantly different ($p \leq 0.05$) than all other test exercises.

DISCUSSION: This is the first study to determine H:V and to compare the application of horizontal and vertical force production of plyometric exercises and match these to sprint starts. Determining exercises that offer a greater horizontal force generation stimulus has been recommended (Rumpf et al., 2012), especially since it is thought to be important for improving the transfer of training to sprinting, since the horizontal force component, but not the vertical force component, has been shown to be correlated with increased sprinting speed and is particularly important for acceleration (Randell, et al., 2010).

Data from the present study show that bounding produces the H:V ratio that is most similar to the standing sprint start and the sprinter start. This finding supports anecdotal recommendations that that high velocity horizontally directed exercises such as bounding may be optimal for sprinting speed development (Young et al., 2015).

In the current study, the H:V ratios of the sprint starts were 0.36 and 0.40:1 for the standing and sprinter start, respectively. These values are lower than the peak GRF H:V of approximately 0.88:1 to 0.95:1 during weight sled towing with 10 and 30 percent of body mass, respectively (Kawamori et al., 2014). Coh et al., 2017 demonstrated a horizontal to vertical impulse ratio of approximately 0.54:1. Thus, sled towing and starting from blocks predictably allows for the production of higher horizontal force compared to the plyometric exercises assessed, and much higher than the standing and sprint start H:V ratios in the current study. While employing these strategies may have value, they likely are less specific to sprint starts. Research shows that adding additional mass to the sled towing increases the H:V, as does assessing impulse as opposed to peak GRF (Kawamori et al. 2014). This explains some of the variability in the H:V between studies.

Other studies which described multi-planar kinetics of plyometrics included the assessment of exercises such as hurdles, skipping, bounding (Rumpf et al., 2012) and the triple jump (Ramey & Williams, 1985). However, these studies examined horizontal braking and not propulsive forces, as was done in the current study.

Though not previously shown in the literature, predictably, the CMJ produced a H:V that was less similar to sprinting than the horizontal plyometric exercise assessed in the current study. This finding adds resolution to the anecdotal observations that sprint training requires the inclusion of exercises that emphasize horizontal and not vertical force development (Randell, et al., 2010; Rumpf et al., 2012).

The sprinter start produced a higher H:V ratio than the standing sprint start. Many team sports are played in a bi-pedal and fairly erect position, with accelerations resulting in displacement of the athlete emanating from this position. Thus, the standing sprint ratio may be the most applicable to use in comparing the H:V ratio of training strategies. Some sports and activities, such as line play in American football, sprinting in track, and speed tests are performed from a beginning position with a hand on the ground. In those circumstances, the sprinter start H:V ratio may be most sport specific.

The finding of a negative correlation between subject experience with plyometric training and sprinter start H:V was likely due to the subject's limited exposure to horizontal plyometric training, potentially evidencing the importance of training specificity.

CONCLUSION: Bounding and standing long jumps are the most biomechanically specific plyometric exercises for training athletes who must sprint from a standing position. Other plyometric exercises with a horizontal emphasis are more biomechanically similar to sprinter starts and standing sprint starts than vertically oriented plyometric exercises such as the CMJ.

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