SEX-BASED ANALYSIS OF SPRINT ACCELERATION

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This study assessed a variety of kinetic, spatial, and temporal variables during the early acceleration phase of sprinting for both men and women (N = 20) during standing and sprinter position starts. Forces, step distance, time, and velocity measured from the first four steps of each start via force platforms were compared across start, step, and sex via ANCOVA while removing the effect of height or weight. Velocity increased from step 1 to steps 2 and 3; while overall velocity was lower for women and the standing start ($p < 0.05$). There were interactions of start * sex for horizontal force, ratio of horizontal to vertical force, overall velocity, and overall time ($p < 0.05$). Men's performance tended to be more negatively affected when using the standing start than women's performance.

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

INTRODUCTION: Sprinting speed is important for many individual and team sports. As a result, several studies have examined biomechanical variables related to sprinting. These studies assessed athlete types, start types, and sprint distances and did so by evaluating a variety of biomechanical variables. However, little is known about sex-based similarities and differences in the development of speed and the forces that contribute to running velocity.
Research assessing the biomechanics of the acceleration phase of sprinting has been conducted with track (Coh et al., 2017; Coyler et al., 2018) or multi-sport athletes (Devismes et al., 2019; Duffin et al., 2019: Kawamori et al., 2013). This includes the assessment of block (Coh et al., 2017; Coyler et al., 2018) and non-block and standing starts (Devismes et al., 2019; Duffin et al., 2019: Kawamori et al., 2013). Research examined the first step (Coh et al., 2017; Duffin et al., 2019; Kawamori, et al., 2013), second step (Coyler et al., 2018; Kawamori et al., 2014) and up to 22 steps (Nagahara et al., 2018) assessing a variety of kinetic variables.
The role of vertical and anterior-posterior (A-P) force has been studied during sprinting (Coh et al., 2017; Duffin et al., 2019; Kawamori et al., 2014; Nagahari, 2018). Some of this work assessed the role of force production, or impulse, on velocity, acceleration, or sprinting times (Coh et al., 2017; Coyler et al., 2018; Kawamori et al., 2014; Nagahara et al., 2018).
Some studies revealed vertical and A-P kinetic data, which could be used to calculate a horizontal to vertical force ratio (Kawamori et al., 2014) or specifically identified these ratios during sprinting starts (Duffin et al., 2019). These ratios describe the relative contribution of force in each direction with horizontal to vertical force ratios (H:V) ranging from 0.26:1 to 0.40:1 being demonstrated (Duffin et al., 2019). Horizontal force is particularly important for maximizing acceleration during the early phase of sprinting (Duffin et al., 2019; Kawamori et al., 2014).
Relatively little speed development research has included women as participants or compared men and women. One study assessed the force-velocity profile of soccer athletes, showing that women have a more force-oriented profile, whereas men developed more horizontal force and power than women, but few other sex-based differences were found (Devismes et al., 2019). The purpose of this study was to assess the magnitude of horizontal and vertical force production, the H:V, and its effect on stride length, distance, frequency, and ground contact time, as well as horizontal velocity during the early acceleration phase of sprinting during standing and sprinter position starts. Similarities and differences between men and women were assessed.

METHODS: Ten women (mean ± SD, age = 19.3 ± 1.06 yr; 166.88 ± 6.86 cm; 60.55 ± 10.25 kg) and ten men (mean ± SD, age = 20.01 ± 0.99 yr; 180.34 ± 9.35 cm; 80.83 ± 11.60 kg) served as participants in this study. Participants were NCAA Division III athletes who played a variety of team sports including basketball, volleyball, baseball, softball, and soccer. The participants provided informed written consent. The study was approved by the institution's Internal Review Board.

Participants were involved in a practice session and a research session. Prior to each, they performed a dynamic and activity specific warm-up. The practice session included instruction, demonstration, and practice of the test exercises, which included sprinting from two conditions, including a sprinter start and a standing start.

Following the practice session, participants were tested with a 10 meter sprint from sprinter and standing starts. Each sprint start began within 2 cm from the first of two force platforms oriented in series and mounted flush to the floor. During each sprint, the first and second steps occurred on the first platform and the third and fourth steps struck the second platform. Subjects accelerated throughout the entire sprint. Subjects performed two trials of each sprint condition. The order of start conditions was counterbalanced.

The force platforms (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA) were calibrated prior to testing. Data were acquired at 1000 Hz and analyzed in real time with proprietary software. Peak vertical and A-P ground reaction force (GRF) data were used to calculate horizontal to vertical force ratio, time between steps, stride frequency, and duration of vertical GRF.

Data were analyzed with SPSS 26.0 (International Business Machines Corporation, Armonk, New York). Assumptions for linearity of statistics were tested and met. The trial-to-trial reliability of the dependent variables were assessed using average measures Intraclass correlation coefficients (ICC) and coefficients of variation (CV). The ICC were found to be > .60 and CV less than 10.0; thus, the average values were used for further analyses. Because there were significant differences in the height and mass of the men and women, a 3-Way mixed measures ANCOVA (start * steps * sex) removing the effect of body mass, was used to determine differences for horizontal and vertical forces, as well as the H:V. A 3-Way mixed measures ANCOVA (start * steps * sex) removing the effect of height, was used to determine differences for distance and velocity between steps. A 2-Way Mixed ANCOVA (starts * sex) removing the effect of height, was used to compare time and velocity from steps 1 to 4. The alpha level was set at $p \leq 0.05$ for all comparisons. Bonferroni adjustments were used for pairwise comparisons when significant main effects were found. In the case of sphericity violations, a Greenhouse-Geisser correction was used. All data are expressed as means ± SD. Partial Eta Squared (η_p^2) with thresholds of: small = 0.1, moderate = 0.3, large = 0.5, very large = 0.7, and extremely large = 0.9 were used to interpret effect size (Hopkins, et al., 2009).

RESULTS: The Two-Way ANCOVA revealed main effects for start and sex ($p = 0.037$; $\eta_p^2 = 0.231$ and $p = 0.002$; $\eta_p^2 = 0.440$ respectively) as well as a significant interaction ($p = 0.028$; Figure 1) for velocity from steps 1 to 4. There were no main effects for time from steps 1 to 4 (start $p = 0.072$; $\eta_p^2 = 0.178$ and sex $p = 0.354$; $\eta_p^2 = 0.051$; see Table 1), but there was a significant interaction ($p = 0.041$; see Figure 1).

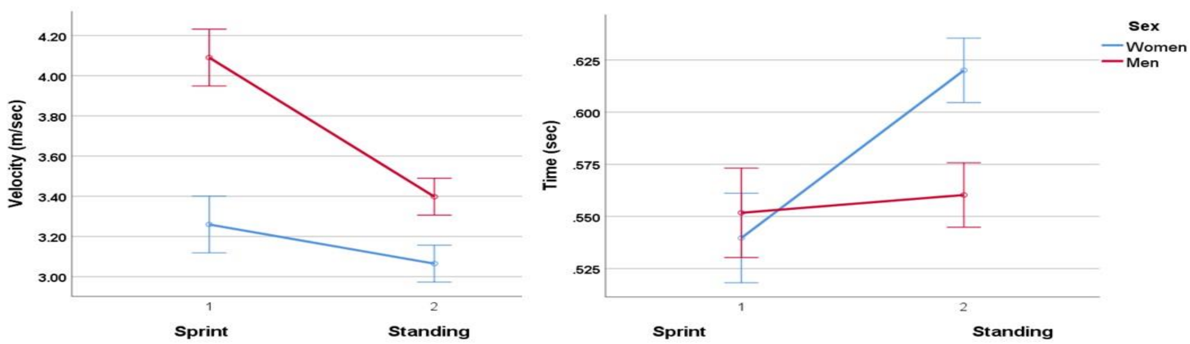

Figure 1. Interaction of start and sex for average velocity and time to move from steps 1-4 during sprint and standing starts for men and women (variability illustrated by Standard Error).

Results of the 3-Way ANCOVAs revealed significant main effects only between steps 1 and 4 of velocity ($p = 0.029$; $\eta_p^2 = 0.187$); step 1-2 (Mean ± SE = 2.76 ± 0.10 m/sec) was less than steps 2-3 and 3-4, which did not differ (3.52 ± 0.09 and 3.63 ± 0.10 m/sec respectively). There were no other main effects (p > 0.05; η_p^2 < 0.205; see Table 1). There were significant interactions of Sex * Start in the 3-Way ANCOVAs for horizontal force and H:V (p = 0.018 and 0.013 respectively; see Figure 2).

Table 1. Time and average velocity for steps 1-4 of sprint and standing starts (Mean ± SD; n = 10 of each sex).

	Women		Men	
	Sprint	Standing	Sprint	Standing
Time (sec)	0.551 ± 0.060	0.610 ± 0.047	0.540 ± 0.056	0.571 ± 0.038
Velocity (m/sec)[a,b]	3.45 ± 0.46	3.12 ± 0.23	3.90 ± 0.41	3.34 ± 0.27

[a] Sprint significantly faster than Standing start (p = 0.037).
[b] Men significantly faster than women (p = 0.002).

Table 2. Sprint and standing start variables for each step (Mean ± SD; n = 10 of each sex).

	SP1	SP2	SP3	SP4	ST1	ST2	ST3	ST4
Women								
H Force	334.6 ± 49.4	331.2 ± 51.8	308.0 ± 52.5	374.4 ± 58.3	371.5 ± 41.9	307.1 ± 39.3	304.7 ± 48.6	346.0 ± 50.0
V Force	956.6 ± 188.5	1037.2 ± 214.6	1016.7 ± 230.0	1169.9 ± 238.1	1077.5 ± 203.7	1054.5 ± 244.3	1084.5 ± 262.8	1088.7± 206.1
H:V	0.36 ± 0.05	0.33 ± 0.06	0.31 ± 0.04	0.33 ± 0.05	0.35 ± 0.04	0.30 ± 0.07	0.29 ± 0.06	0.33 ± 0.05
Time	0.184 ± 0.009	0.190 ± 0.016	0.193 ± 0.021		0.205 ± 0.016	0.206 ± 0.021	0.189 ± 0.19	
Distance	0.52 ± 0.09	0.69 ± 0.06	0.66 ± 0.09		0.52 ± 0.06	0.71 ± 0.11	0.67 ± 0.10	
Velocity [a]	2.81 ± 0.43	3.58 ± 0.23	3.45 ± 0.46		2.55 ± 0.40	3.48 ± 0.67	3.39 ± 0.60	
Men								
H Force	385.5 ± 66.1	426.3 ± 77.2	375.6 ± 103.4	490.0 ± 158.8	475.6 ± 65.9	398.0 ± 74.5	411.2 ± 74.8	489.2 ± 147.1
V Force	1210.4 ± 184.9	1376.3 ± 198.1	1220.2 ± 179.5	1489.5 ± 294.3	1381.4 ± 145.4	1351.2 ± 184.6	1273.0 ± 167.3	1523.7 ± 315.4
H:V	0.32 ± 0.04	0.31 ± 0.04	0.31 ± 0.07	0.33 ± 0.10	0.34 ± 0.02	0.30 ± 0.03	0.33 ± 0.05	0.32 ± 0.08
Time	0.185 ± 0.020	0.180 ± 0.020	0.182 ± 0.016		0.190 ± 0.017	0.206 ± 0.039	0.183 ± 0.019	
Distance	0.56 ± 0.04	0.66 ± 0.05	0.71 ± 0.09		0.55 ± 0.06	0.67 ± 0.06	0.69 ± 0.09	
Velocity [a]	2.80 ± 0.80	3.68 ± 0.48	3.90 ± 0.41		2.90 ± 0.35	3.33 ± 0.62	3.77 ± 0.52	

SP = sprint condition; ST = standing start condition; Numbers after SP and ST = step in sequence; H Force = horizontal force (N); V Force = vertical force (N); H:V = Ratio of horizontal to vertical force; Time (sec); Distance = length of step (m); Velocity (m-sec^{-1}). Steps are foot contacts 1-2, 2-3, and 3- 4 for Time, Distance, and Velocity variables.
[a] Step 1-2 significantly different than steps 2-3 and 3-4 (p ≤ 0.05).

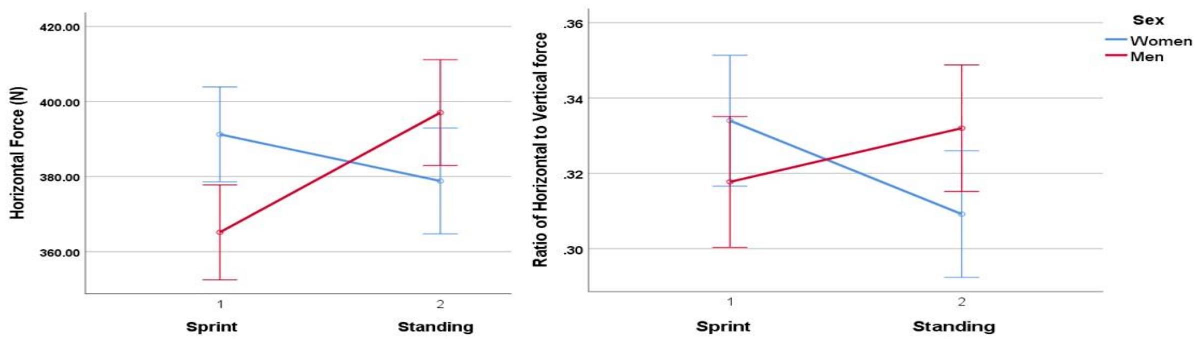

Figure 2. Interaction of start and sex for horizontal force and ratio of H:V force during sprint and standing starts for men and women (variability illustrated by Standard Error).

DISCUSSION: This study represents a comprehensive analysis of how men and women accelerate at the start of a sprint. During the sprinter start, women develop more force normalized to body weight and a higher H:V than men. The opposite is true for the standing start. Others showed that men develop greater force during standing starts (Devismes et al., 2019). While previous research assessed sprint starts, these studies did not compare sexes. In the current study, men developed greater overall force and velocity than women, as previously shown (Devismes et al., 2019).

The current study shows that step distance increased from the first to second step. Others demonstrated a decreased distance from the first to the second step, and a substantially longer first step than found in the current study (Coh, et al., 2017). This difference may be explained by the fact that participants in the current study were trained with acceleration ladders to take relatively short steps at the beginning of a sprint. In the current study, velocity increased after the first step, which is consistent with previous research (Coyler et al., 2018; Nagahara et al., 2018). The current study demonstrated that both men and women developed greater velocity from the sprinter compared to the standing start positon and a greater mean H:V ratio during the sprinter condition. Some evidence suggests greater horizontal, and not vertical force may be most important for sprinting performance (Kawamori et al., 2013). However, in the current study, men generated more mean horizontal ground reaction force in the standing compared to the sprinter condition, yet produced lower velocity.

The H:V in the present study ranged from 0.29 to 0.36:1 for all steps and participants. These values are slightly lower than previously found (Duffin et al., 2019), but lower than the impulse derived H:V of approximately 0.53:1 during block start sprints (Coh et al., 2017), and 3.03:1 during weighted sled towing (Kawamori et al., 2014). Sprinting blocks and weighted vests likely provide a stimulus upon which greater horizontal force can be produced.

Results are most generalizable to those who are most similar to the participants in this study.

CONCLUSION: This study found that while both sexes showed a decrease in velocity and increased time to complete the four steps when using the standing start; men's performance tended to be more negatively affected than that of women. This occurred despite men apparently increasing horizontal force and H:V, while women did not. However, the analyses demonstrated relatively few sex-based differences, suggesting that speed development training need not differ significantly between men and women.

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