SPATIAL, TEMPORAL, AND KINETIC VARIABLES DURING THE EARLY ACCELERATION PHASE OF SPRINTING

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This study evaluated the relationships between spatial, temporal, and kinetic variables and velocity during the early acceleration phase of sprinting. Ten women and ten men performed sprints across two force platforms. Pearson's and partial correlation coefficients removing the effect of sex were used to assess relationships between step and sprint velocity during the first four steps and a variety of variables. Significant ($p \leq 0.05$) correlations and partial correlations were found between overall sprinting velocity and subject height, countermovement jump, average horizontal force, vertical force, H:V force, stride frequency, foot contact duration and step distance. During the acceleration phase of sprint training, it may be important to liberalize step length after the first two steps. A variety of other recommendations are made.

KEYWORDS: Acceleration, stride length, speed development, running

INTRODUCTION: A variety of biomechanical factors determine sprinting performance (Mero et al., 1992). Sex, experience level, and training specificity may also influence how speed is manifested. In the process of further understanding these issues, research has sought to identify the relationships between a variety of kinetic and kinematic variables and sprinting speed.

Sex-based differences in horizontal plyometric (Kossow & Ebben, 2017) and sprint performance (Devismes et al., 2019; Jimenez-Reyes et al., 2018) have been studied. In some cases, no sex-based differences were found (Kossow & Ebben, 2017), whereas others demonstrated select differences in sprinting biomechanics (Devismes et al., 2019; Jimenez-Reyes et al., 2018).

Some studies included the assessment of the role of subject ability or training status in the analysis (Coh et al., 2017), and showed that there are fewer relationships between variables such as subject power and sprinting ability, and a higher degree of specificity between variables for those with greater ability levels (Jimenez-Reyes et al., 2018). While better athletes demonstrate faster reaction times, these abilities may not always correlate with performance (Mero et al., 1992).

Propulsive, anterior-posterior (A-P) impulse may be more important than vertical impulse in the development of sprint velocity (Hunter et al., 2005). However, studies examining the relationship between variables such as force, impulse, and power, and their relationship to speed have produced equivocal results. For example, in the assessment of sprinter's block starts and its effect on 100 meter sprinting speed, the force produced by the front leg but not the rear leg was correlated to speed (Coh et al., 2017). Some kinetic variables were not correlated with speed (Coh et al., 2017). For shorter duration sprints such as 10 meters, horizontal impulse at eight meters was correlated with sprint time, whereas impulse during the first step was not (Kawamori et al., 2013). Additionally, horizontal impulse but not vertical impulse was correlated with sprint performance (Kawamori et al., 2013), which was particularly true for higher level athletes (Jimenez-Reyes et al., 2018).

Kinematic variables have been compared between faster and slower elite sprinters (Coh et al., 2017). Variables such stride length, frequency, contact time and flight time have been studied, with some of these variables correlated to short distance sprint performance (Lockie et al., 2013). Stride length is correlated with short sprint speed (Lockie et al., 2013). However, it is unknown how short and progressively increasing strides during acceleration, as has been recommended with devices such speed ladders (White, 2007), influence sprint kinetics and kinematics. The purpose of this study was to determine the kinetic and kinematic variables that are related to acceleration speed of men and women subjects who used short strides during the early acceleration phase of sprinting.

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 subjects in this study. 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.

Subjects participated in one research session. During this time, the test exercises were demonstrated and subjects practiced the test exercises, which included sprinting in two conditions, including a sprinter start and a standing start, across two force platforms arranged in series. Prior to performing the test exercises, a dynamic and activity specific warm-up was conducted.

During the research session, subjects were tested in the sprinter start and standing start conditions. The sprinter start and standing starts began with the subject within 2 cm behind the first of two force platforms. 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 10 meter sprint. The countermovement jump was also tested with a manual vertical jump testing device (Vertec, North Easton, MA, USA). Two trials of each sprint condition and the countermovement jump were performed and approximately one-minute of rest was provided between all trials. The order of the sprinter start and standing start conditions was counterbalanced.

The test exercises were performed on two force platforms (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA), oriented in series, countersunk, and mounted flush to the floor. The force platforms were calibrated prior to each 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 A-P plane horizontal GRF data were obtained for each sprint start based on the analysis of the force-time record. Subject’s horizontal to vertical force ratio, time between steps, stride frequency, and duration of vertical ground reaction force were calculated from these data.

Data were analyzed with the SPSS 26.0 statistical package (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. ICC were found to be > .60 and CV less than 10.0; thus, variables were considered reliable and the average values were used for further analyses. Pearson’s correlation coefficients were used to assess the relationship between start condition velocities for the four steps (individually and overall) to years of sport participation, subject weight, subject height, countermovement jump height, horizontal and vertical forces, horizontal to vertical force ratio (H:V), time between steps, average stride frequency, duration of foot contact, and stride distance between steps and for all four steps. Partial correlations were used to remove the effect of sex, as there were significant differences between men and women for height and weight. The alpha level was set at $p \leq 0.05$.

RESULTS: For the two types of sprint starts, significant correlations were found between the overall velocity of the four steps to subject height, countermovement jump, average horizontal force, average vertical force, average H:V, average stride frequency, average foot contact duration, and step distances (see Table 1). No other bivariate and/or partial correlations were found between the overall velocity of the four steps and any other variable, or for individual step velocities to any variable ($p > 0.05$; $r < .44$).

Table 1. Significant bivariate and partial correlation coefficients (bivariate/partial) for sprint and standing start velocities across steps 1-4 (N=20). Partial correlation removed the effect of sex.

	HT (cm)	CMJ (cm)	HF (N)	VF (N)	H:V	SF (steps/sec)	FC (sec)	SD 3-4 (m)	SD 1-4 (m)
SP	-.05/-.54 [a]	.54 [a]/.31	-.09/-.46 [a]	-.26/-.71[b]	.31/46 [a]	-.14/-.01	-.15/-.18	.68 [a]/.65 [a]	.51 [a]/.40
ST	-.01/-.28	.50 [a]/.30	.10/-.28	-.11-.51 [a]	.38/.39	-.93 [b]/-.92 [b]	.48 [a]/-.56 [a]	.08/.04	.28/.30

SP = sprint start four step velocity; ST = standing start four step velocity; HT = subject height; CMJ = counter movement jump height; HF = horizontal force averaged for the four steps; VF = vertical force averaged for the four steps; H:V = ratio of horizontal to vertical force averaged for the four steps; SF = stride frequency for the four steps; FC = average duration of foot contact; SD 3-4 = step distance of steps 3 to 4 for the corresponding start; SD 1-4 = total step distance for the four steps in the corresponding start.

[a] Significantly correlated ($p \le 0.05$).

[b] Significantly correlated ($p \le 0.001$).

DISCUSSION: This study showed that for the sprinter start condition, step distance is positively correlated with sprint velocity. This finding raises questions about the use of acceleration ladders with adjustable and relatively short distances between rungs. Often these distances are shortened for acceleration training (White, 2007), in order to increase stride frequency. Distances of the third to fourth step of the sprint and the total distance from steps one to four were correlated with speed, but not the distance associated with the first two steps. Thus, increasing stride length after the first two steps may be important for short duration sprinting speed. Previous research also showed that step distance is positively correlated with velocity (Lockie, et al., 2013). Thus, there may be some limits to how short steps should be during acceleration training. Somewhat consistent with the findings of the current study, impulse at the start of the sprint was not correlated with sprint time whereas impulse at eight meters was (Kawamori et al., 2013).

Across the four step sprint, subjects in the current study had an average step distance of approximately 0.6 meters, a step frequency of over 5 Hz, and a mean ground contact time of 0.25 seconds per step. These values are different than previous research which found a mean step distance of 1.18 meters, a step frequency of 4.13 Hz, and a mean ground contact time of 0.15 seconds per step (Lockie et al., 2013). To further compare, national team track athletes produced mean step distances of 0.98 to 1.30 meters and ground contact times ranging from 0.15 to 0.17 seconds at the beginning of the sprint (Coh et al., 2017). Thus, subjects in the current study took shorter strides, had a higher stride frequency, and spent more time with the foot in contact with the ground, which may explain why stride frequency and duration of the foot contact were negatively correlated with velocity in some of the analyses. This may also explain why some of the vertical and horizontal force values were negatively correlated with sprint velocity.

The current study demonstrated that average horizontal force was either not related or negatively correlated to sprint velocity. While the role of force production on sprinting velocity is non-conclusive, no other study found force to be negatively correlated with velocity. Previous research demonstrated that front block force was positively correlated with 100 m sprint performance with block starts (Coh et al., 2017). Horizontal impulse during 10 meter sprints was correlated with speed only later in the sprint (Kawamori et al., 2013). Other research demonstrated that horizontal force may be more important for sprint performance especially for higher level athletes (Jimenez-Perez et al., 2018).

Average vertical force was either not correlated, or negatively correlated with velocity in the present study. While some evidence indicates that vertical force is important for lower ability athletes (Jimenez-Perez et al., 2018) others indicated that vertical impulse is not correlated to sprint time (Kawamori et al., 2013). While some evidence suggests vertical force may be important for sprinting, the theoretical concept of the force-velocity curve would indicate that force and velocity are inversely related, which may add to the explanation for why ground reaction force might not be related, or even negatively associated with velocity, as was the case in the current study.

In the current study, the average H:V was either unrelated, or positively related, to sprinting velocity. This ratio is believed to be important for speed development (Duffin et al., 2019), particularly since propulsive force is thought to be more important than vertical force (Hunter et al., 2005; Kawamori et al., 2013), especially for higher level sprinters (Jimenez-Perez et al., 2018).
The current study showed that subject stature was negatively related to velocity, which has not been shown in the literature. This study also showed that countermovement jump ability was related to sprinting velocity. Squat jump performance has been correlated with sprinting times, particularly for lower ability subjects (Jimenez-Reyes et al., 2018). In contrast, some research demonstrated that vertical force production was not related to sprint time (Kawamori et al., 2013). In the current study, subject years of athletic experience was not correlated with any velocity related variable. Others found some kinetic differences in the role of sprint speed development between sprinters of different abilities (Coh et al., 2017; Jimenez-Reyes et al., 2018). While subjects in the present study were athletic, they were not elite and may have been more similar to some of the lower ability subjects in these previous studies.

CONCLUSION: During the acceleration phase of sprint training, it may be important to liberalize step length after the first two steps when sprinting, and if using acceleration ladders. There appears to be no disadvantage to shorter initial steps. Athletes should produce short foot contact durations and achieve foot contact as fast as possible. Lengthy foot contact duration may result in the creation of more force, but at the expense of the sprint velocity. For those who are similar to the subjects employed in the current study, vertical force production abilities may result in better sprint performance. Further investigation into the relationship between subject stature and sprinting velocity may be warranted.

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