EFFECTS OF SPRINT AND PLYOMETRICS TRAINING ON FIELD SPORT ACCELERATION TECHNIQUE

ROBERT G. LOCKIE,[1] **ARON J. MURPHY,**[2] **SAMUEL J. CALLAGHAN,**[1] **AND MATTHEW D. JEFFRIESS**[1]

[1]*Department of Exercise and Sport Science, School of Environmental and Life Sciences, University of Newcastle, Ourimbah, Australia; and* [2]*Department of Sports Studies, Exercise and Sports Science, and Clinical Exercise Physiology, School of Science and Technology, University of New England, Armidale, Australia*

ABSTRACT

Lockie, RG, Murphy, AJ, Callaghan, SJ, and Jeffriess, MD. Effects of sprint and plyometrics training on field sport acceleration technique. *J Strength Cond Res* 28(7): 1790–1801, 2014—The mechanisms for speed performance improvement from sprint training and plyometrics training, especially relating to stance kinetics, require investigation in field sport athletes. This study determined the effects of sprint training and plyometrics training on 10-m sprint time (0–5, 5–10, and 0–10 m intervals), step kinematics (step length and frequency, contact and flight time), and stance kinetics (first, second, and last contact relative vertical [VF, VI], horizontal [HF, HI], and resultant [RF, RI] force and impulse; resultant ground reaction force angle [RFθ]; ratio of horizontal to resultant force [RatF]) during a 10-m sprint. Sixteen male field sport athletes were allocated into sprint training (ST) and plyometrics training (PT) groups according to 10-m sprint time; independent samples *t*-tests ($p \leq 0.05$) indicated no between-group differences. Training involved 2 sessions per week for 6 weeks. A repeated measures analysis of variance ($p \leq 0.05$) determined within- and between-subject differences. Both groups decreased 0–5 and 0–10 m time. The ST group increased step length by ~15%, which tended to be greater than step length gains for the PT group (~7%). The ST group reduced first and second contact RFθ and RatF, and second contact HF. Second contact HI decreased for both groups. Results indicated a higher post-training emphasis on VF production. Vertical force changes were more pronounced for the PT group for the last contact, who increased or maintained last contact VI, RF, and RI to a greater extent than the ST group. Sprint and plyometrics training can improve acceleration, primarily through increased step length and a greater emphasis on VF.

KEY WORDS biomechanics, stance kinetics, vertical force, step kinematics, step length

INTRODUCTION

Athletes from field sports (e.g., soccer, rugby union, rugby league, American football, Australian football, field hockey, and lacrosse) require a high running speed, because this allows players to better compete in defining moments such as ball contests during match-play (37). Greater sprint speed can also differentiate between players from higher and lower competition levels (1,2,12). However, the maximal effort sprints completed during field sport competition tend to be relatively short. For example, sprints within soccer (3), rugby union (10), and Australian football (8) often last less than 2 seconds. Sprints this short will not allow for the attainment of maximum speed, particularly if starting from a stationary position. Indeed, after sprinting for 2 seconds from a stationary start, elite rugby union players (11), experienced Australian footballers (30), and recreational field sport athletes (26,27) cover an approximate distance of 10 m. As such, field sport athletes must have proficient sprinting technique to accelerate to a high running velocity as quickly as possible to make full use of their speed. Some of the kinematic variables that affect running speed are step length and frequency, and contact and flight time. The kinetics produced during stance, which is the period when the athlete is in contact with the ground, will also influence speed.

Many training protocols used to develop speed for field sport athletes promote great force production during ground support to enhance step kinematics and stance kinetics. In addition to strength training (9,28), 2 training protocols that may cause changes to acceleration technique are sprint and plyometrics training. Sprint training features maximal runs over varying distances, with acceleration-focused programs featuring shorter sprints (i.e., 20 m or less) (28,39). Properly structured sprint training can improve 10-m (28) and 15-m (39) sprint performance in field sport athletes. Furthermore, this type of training can induce beneficial changes in kinematics such as increases in step length (23,28) or decreases in contact time (39). Plyometric training can provide an even greater emphasis on stance force production (43), with exercises such as hopping and bounding producing far greater ground reaction forces (GRF) when compared with maximal sprinting (32). Plyometrics training can enhance running

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Address correspondence to Dr. Robert G. Lockie, robert.lockie@newcastle.edu.au.

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speed, with improvements shown in 10-m sprint performance for rugby union players (38) and recreational field sport athletes (28). A major kinematic adaptation after a plyometrics intervention is an increase in step length (28). Nevertheless, there is still much to understand about the causes of improvements resulting from sprint and plyometrics training. This is especially the case when considering the importance of stance kinetics to sprinting speed (20,24,27,33,44), and how this may influence step kinematics.

Weyand et al. (44) stated that the ability to generate greater GRF during stance is vital for maximum sprinting speed in physically active men. However, the biomechanics of sprint acceleration, and maximum velocity sprinting, can differ, which may affect the more important technique parameters (25,45). For example, sprints over short distances that emphasize acceleration, such as those featured in field sports, will generally feature a greater trunk lean and posterior foot plant (24,32). In conjunction with vertical force (VF), this type of foot contact can greatly influence horizontal force (HF) development. As a result, the critical facets of sprint acceleration GRF may vary from that of maximum velocity sprinting. Kugler and Janshen (24) stated that there should be a focus on "optimal" force production during sprinting, rather than just trying to generate a GRF as high as possible. Further to this, Morin et al. (33) asserted that the resultant direction of force production (i.e., the relationship between vertical and horizontal forces), was an important consideration for sprinting speed. The importance of both vertical (27,40,44) and horizontal (5,20,33) forces for running speed has been established in the literature. However, there is no research that has analyzed changes to acceleration stance kinetics that could result from sprint and plyometrics training specific to field sport athletes.

Therefore, this study investigated the effects that sprint and plyometrics training programs, designed to enhance acceleration specific to field sports, has on sprint technique in experienced recreational athletes. This research will document changes to step kinematics (step length and frequency, contact and flight time) in the 0–5, 5–10, and 0–10 m intervals of a 10-m sprint. Changes to the stance kinetics (relative VF, HF, and RF; relative VI, HI, and RI; resultant ground reaction force angle [RFθ]; ratio of horizontal to resultant force [RatF]) of early (first 2 contacts) and later (last contact) acceleration in a 10-m sprint will also be determined. It is hypothesized that both protocols will cause adaptations that will enhance 10-m sprint performance. The mechanisms will likely be step length and frequency increases, in conjunction with favorable changes to stance kinetics (i.e., increased vertical and HF and impulse). Because of the greater loading associated with plyometrics training, it is further hypothesized that any changes to stance kinetics will be more pronounced for this modality. A clearer understanding of the technique adaptations induced by field sport–specific sprint and plyometrics training will provide field sport and strength and conditioning coaches with necessary information to develop speed in their athletes, particularly over short distances commonly seen in team sports.

METHODS

Experimental Approach to the Problem

This study analyzed the effects of sprint and plyometrics training in experienced recreational male field sport athletes. A 6-week training program was used for both protocols, and data were analyzed with a repeated-measures analysis of variance (ANOVA) to determine within- (before and after tests) and between-subject (the 2 training groups) changes. In pre- and post-testing, subjects completed 10-m sprints that were filmed and timed for kinematic analysis in 1 session; in a second session, 10-m sprints were completed over a platform with an embedded force plate to record the first, second, and last ground contacts. For the training programs, subjects completed two 60-minute sessions per week for the 6-week intervention period. Dependent variables included: 0–5, 5–10, and 0–10 m sprint time; step length and frequency, and contact and flight time, over the 0–5, 5–10, and 0–10 m intervals; and first, second, and last contact relative VF, VI, HF, HI, RF, and RI; RFθ; and RatF.

Subjects

Sixteen men (age = 21.81 ± 2.59 years; height = 1.81 ± 0.05 m; body mass = 80.53 ± 5.94 kg), including players from Australian football ($n = 5$), rugby union ($n = 4$), soccer ($n = 4$), and rugby league ($n = 3$), volunteered for this study. Subjects were recruited if they were 18 years of age or older; currently played a field sport, had a history of physical activity (≥2 times per week) extending over the previous 6 months, were available for the duration of the study, did not have any existing medical conditions that would compromise study participation, agreed to follow a predetermined training program, and continued with their normal physical activity. The study occurred during the subjects' competition season (14,19,28,39). As a result, each subject's existing physical activity generally consisted of 2 field-based, 2 gym sessions, and 1 game per week. Although subjects would have different training backgrounds, by ensuring they maintained their normal physical activity, the investigators deemed that any changes in athletic performance could be related to the applied training intervention. The methodology and procedures were approved by the University of Technology, Sydney ethics committee. All subjects received an explanation of the study, including risks and benefits, and written informed consent was obtained before study participation.

Sample size was determined by estimating the magnitude of differences between the effect sizes (ES) that would theoretically result from the training intervention. As ES can be measured in relation to the principle assessment, 0–10 m time was used. Based on speed training research (28,39), the ES for this study was assumed to be large (0.80). An 80% confidence level was desired, and power was set at 0.80, with an alpha level of 0.05. Thus, the sample used in this study was considered adequate to determine speed changes with sufficient statistical power (22). This sample size is also similar to other sprint training research (14,34).

Procedures

Both pre- and post-testing consisted of 2 sessions, separated by 48 hours. Session 1 was the step kinematics assessment, which included six 10-m sprints that were timed and filmed. Session 2 was the stance kinetics assessment, which consisted of six 10-m sprints over a platform with an embedded force plate. Laboratory space limitations demanded separate step kinematics and stance kinetics assessment. This approach has been previously used in the literature (26,27), and the reliability of the data collection procedures adopted in this study has been established (26). Subjects were tested in the late morning, afternoon, or early evening, and at the same time of day for all sessions, respectively; did not eat for 2–3 hours before their sessions; and refrained from intensive lower-body exercise (e.g., heavy resistance training) and any form of stimulant (e.g., caffeine) in the 24 hours before testing. Post-testing occurred within a week of the subjects' final training session. Height and body mass were measured in session 1 for both pre- and post-testing. Height was measured barefoot using a portable stadiometer (Seca 213; Ecomed Trading, Seven Hills, Australia). Body mass was recorded using electronic digital scales (BF-522; Tanita Corporation, Tokyo, Japan). A standardized warm-up of 10 minutes jogging at a self-selected pace on a treadmill, 10 minutes dynamic stretching, and progressive speed runs over the 10-m sprint distance (2 repetitions each at 60, 70, 80, and 90% of perceived maximum velocity) was used for all subjects on each testing occasion. Three-minute recovery periods were allocated between sprint trials.

Step Kinematics Assessment

Ten-meter sprint time was measured by a velocimeter (Speed Probe 2001; Onspot, Wollongong, Australia), which consisted of a stopwatch (Seiko, Tokyo, Japan) and nylon line attached to a reel. The line was attached to the back of the subjects' shorts and unwound during the sprint. The velocimeter was placed on a 0.72-m high table, 1.5 m behind the subject. The stopwatch was electronically triggered with the subjects' first movement. If the timer was falsely triggered, the trial was stopped and reattempted. Times were recorded for the 0–5, 5–10, and 0–10 m intervals. Sprints over 5 m (19,26,27,39) and 10 m (20,26,27,36) have previously been used to analyze speed in field sport athletes. The measurement of sprint times in this manner has high reliability, with intraclass correlation coefficients (ICC) of 0.94 for the 0–5 m interval, 0.88 for the 5–10 m interval, and 0.92 for the 0–10 m interval (26).

A high-speed video camera (HSC200RM; Peak Performance Technologies, Englewood, CO, USA), using a sampling rate of 200 Hz, recorded the sprint tests for the later assessment of step kinematics. The camera was positioned 8.75 m lateral (perpendicular to sprint direction) to the subject and calibrated using established methods (13). Before testing, a standard meter rule was carried throughout the observation volume and recorded. This process provided a scale for subsequent video analysis. These data were then exported and analyzed within custom software (UTS Kinematic Data Collection Software, Lindfield, Australia) to ensure that the images were representative of the real-space coordinate system. The 0–5 and 5–10 m intervals were filmed separately; 3 trials each measured kinematics for the 2 intervals, for a total of 6 sprint trials. For the 0–5 and 5–10 m intervals, the camera was positioned at 2.5 and 7.5 m perpendicular to sprint direction, respectively. A television (TC-14S10; Panasonic, Osaka, Japan) and video recorder (Peak Performance Technologies) were connected to the camera to record each trial. Two 500-W lights provided external illumination.

Reflective tape was placed on the subjects' feet (specific landmarks on the right [head of the fifth metatarsal] and left [head of the first metatarsal]) for the calculation of step kinematics. Recordings were transferred onto a computer (Dell Inc., Round Rock, TX, USA) and exported into the custom software (UTS Kinematic Data Collection Software) for analysis. All trials completed by the subjects were analyzed, with averages calculated. The total number of steps and contacts a subject had within an interval was used to determine mean step kinematics. Start and finish points of the movement phases were visually determined from the actions of each subject in the video footage (4,26). Contact time was the period between touchdown (i.e., the first instance when the foot contacted the ground) and toe-off (i.e., the first instance when the foot broke contact with the ground) of 1 foot during stance. Flight time was the duration

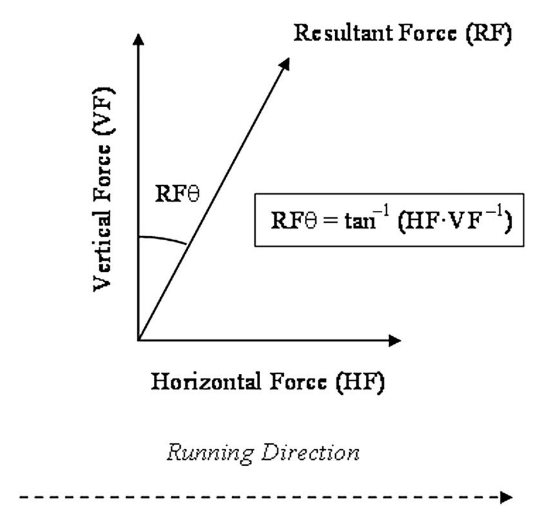


Figure 1. Diagrammatic representation of the resultant ground reaction force angle (RFθ) as a function of vertical and horizontal force (24,33).

between toe-off and touchdown of the opposing foot. Step length was the distance between toe-off of 1 foot and touchdown of the opposing foot. Step frequency was derived from the inverse of step duration ($1 \cdot \text{step duration}^{-1}$) (18).

Stance Kinetics Assessment

The stance kinetics assessment was conducted over one 3-dimensional force plate (Onspot) embedded in a platform. Two dimensions (vertical and horizontal [anteroposterior]) were used. Data were sampled at 1000 Hz and recorded to a laptop (Dell Inc.) through a National Instruments (DAQCard-AI-16E-4) analog-to-digital converter (National Instruments, Austin, TX, USA). The vertical plane was calibrated by placing known loads on the plate, and a regression equation was developed between load and voltage. The horizontal plane was calibrated by initially calibrating a strain gauge in the same manner as the vertical plane. The strain gauge was then used to calibrate both the positive and negative plate directions. The regression equation from the strain gauge was applied to develop equations for both directions; the average of these values provided the final horizontal plane equation. The velocimeter was positioned for the stance kinetics assessment as for the step kinematics analysis. This ensured that there were no time differences between the sessions, such that it could be assumed the subjects' performance was similar on both occasions.

The method used for measuring stance kinetics was adapted from previous research (26,27). Subjects used the same starting stance and front leg from the session 1 sprints. Stance kinetics were measured for the first 2 (early acceleration) and the last contact (later acceleration) within the 10-m sprints. Two trials were used for each contact, providing a total of 6 sprint tests. The first 2 sprints were used to measure the first contact; the second 2 sprints collected data for the second contact; and the last 2 sprints assessed the last contact. Step length measurements for each subject were taken from the video recordings and used to adjust the subjects' start position such that appropriate contact was on the force plate. Subjects were discouraged from "tracking" the

TABLE 1. Training programs for the sprint and plyometrics protocols (28).

	Sprint training			Plyometrics training		
Week	Interval, m	Sets × repetitions	Distance	Exercise	Sets × repetitions	Contacts
1	0–5	2 × 3	30	Box jump	3 × 10	30
	0–10	2 × 3	60	Bounding	4 × 5	20
	0–15	1 × 3	45	Forward hop	2 × 10	20
	0–20	1 × 3	60 (195 m)	Hurdle jump	2 × 10	20
				Drop jump	2 × 5	20 (100)
2	0–5	2 × 4	40	Box jump	3 × 10	30
	0–10	2 × 4	80	Bounding	4 × 6	24
	0–15	1 × 3	45	Forward hop	3 × 8	24
	0–20	1 × 3	60 (225 m)	Hurdle jump	3 × 8	24
				Drop jump	2 × 8	16 (118)
3	0–5	3 × 3	45	Box jump	3 × 10	30
	0–10	2 × 4	80	Bounding	5 × 6	30
	0–15	1 × 4	60	Forward hop	3 × 10	30
	0–20	1 × 3	60 (245 m)	Hurdle jump	3 × 8	24
				Drop jump	2 × 8	16 (130)
4	0–5	3 × 3	45	Box jump	3 × 8	24
	0–10	3 × 3	90	Bounding	6 × 6	36
	0–15	1 × 4	60	Forward hop	3 × 10	30
	0–20	1 × 4	80 (275 m)	Hurdle jump	3 × 10	30
				Drop jump	3 × 8	24 (144)
5	0–5	2 × 5	50	Box jump	3 × 8	24
	0–10	2 × 5	100	Bounding	5 × 9	45
	0–15	1 × 4	60	Forward hop	4 × 8	32
	0–20	1 × 4	80 (290 m)	Hurdle jump	4 × 8	32
				Drop jump	4 × 7	28 (161)
6	0–5	3 × 4	60	Box jump	3 × 8	24
	0–10	3 × 4	120	Bounding	5 × 9	45
	0–15	1 × 4	60	Forward hop	5 × 8	40
	0–20	1 × 4	80 (320 m)	Hurdle jump	5 × 8	40
				Drop jump	4 × 8	32 (181)

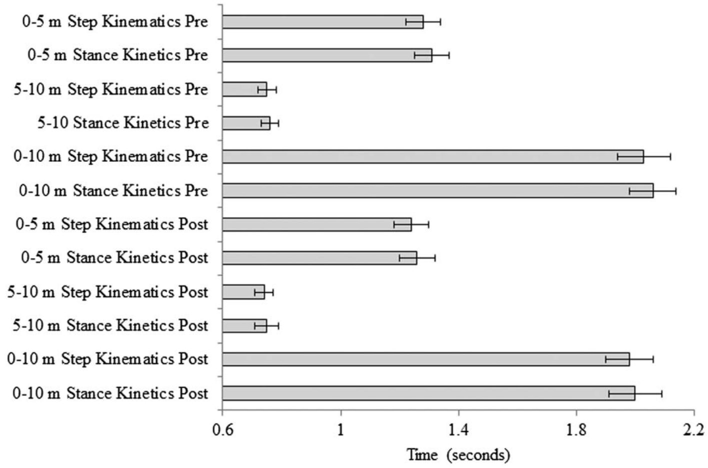


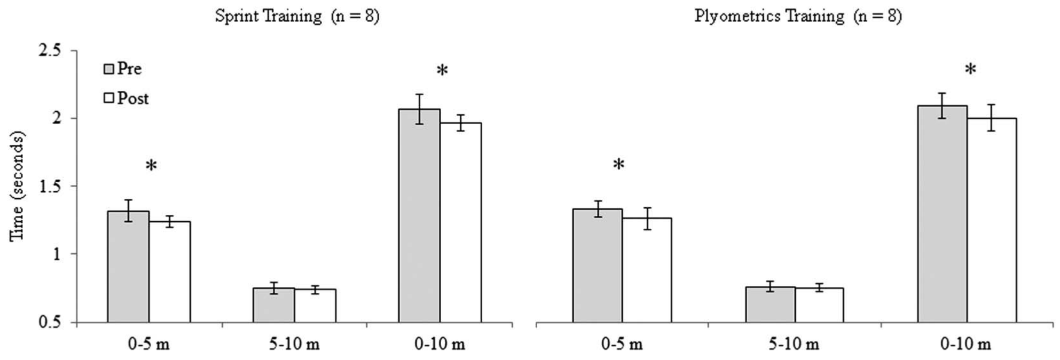
Figure 2. Sprint times (mean ± *SD*) recorded for testing session 1 (step kinematics) and testing session 2 (stance kinetics) during the 10-m sprints (0–5, 5–10, and 0–10 m intervals) for both pre- and post-testing ($n = 16$).

force plate and were instructed to sprint normally. During the warm-up, the researcher observed the subjects' sprints. If the subject did not make full foot contact on the force plate, adjustments were made to the start line to ensure contact in subsequent trials. If the force plate was missed or not struck cleanly, the trial was disregarded and another was completed after the required rest period. Generally, no more than 3 attempts were required before attaining a successful trial.

The data were analyzed using custom software (UTS Kinetic Data Collection Software). The subjects' body weight was calculated from static weight calibration trials, and the kinetic data were normalized against body weight (27,40). The initial contact was defined when the vertical GRF data exceeded 10 N, and toe-off was defined as when the vertical GRF dropped below 10 N (20,40). The kinetic variables investigated were adapted from the literature (24,27,33). The variables included VF, VI, and HF (i.e., anteroposterior) consistent with the direction of forward motion, and HI. The RF and RI were the vector projected to the sagittal plane as a result of the VF and HF, and VI and HI, respectively (24,27). Resultant ground reaction force angle was measured in relation to the vertical axis, with positive angles representing a forward pointing force vector (24,33) (Figure 1). Ratio of horizontal to resultant force was calculated by the formula $\text{RatF} = \text{HF} \cdot \text{RF}^{-1}$ (33).

Training Programs

After pretesting, subjects were ranked according to 0–10 m sprint time and following their ranking, were allocated into the training groups; (1) sprint training group (ST group; $n = 8$) and (2) plyometrics training group (PT group; $n = 8$). Subject allocation was conducted to ensure that groups were evenly balanced in speed capabilities (28,39). Subjects were matched in groups of 4. The subjects ranked 1 and 4 were allocated into 1 training group, whereas 2 and 3 were distributed to the other group. This was performed until all subjects had been allocated. Because the study was designed to analyze the effects of each individual protocol, a nontraining control group was not included (23,28). A 6-week program was used, as this period is sufficient for improving sprint performance



* Significant ($p \leq 0.05$) difference in within-subjects factor (pre- and post-test).

Figure 3. Change in 0–5, 5–10, and 0–10 m time in a 10-m sprint (mean ± *SD*) after 6 weeks of sprint or plyometrics training.

(23,28). During the training period, subjects completed their sessions on 2 nonconsecutive days per week. All sessions were completed at the university and supervised by the investigators. The same dynamic warm-up, involving a low-intensity jog, followed by dynamic stretching, and progressive speed runs, was used before every session by all subjects. A cool-down involving low-intensity jogging and stretching was also used after every session. The training programs were adapted from previous research (28), and progressively overloaded (Table 1). The sprint training program increased the distance run each week, whereas the plyometrics program progressively increased the number of ground contacts per exercise. Training volume between groups was equated by duration, with sessions lasting for approximately 60 minutes. Verbal instructions and encouragement were provided by the researchers during each training session to make sure that the exercises were completed correctly and that the subjects provided a maximum effort.

Statistical Analyses

Descriptive statistics (mean ± *SD*) were calculated for all subjects. Unless stated otherwise, statistics were computed using the Statistical Package for Social Sciences, version 20.0 (IBM, Armonk, NY, USA). Because of the study methodology, paired samples *t*-tests were used to ensure that there were no significant ($p \leq 0.05$) within-subject differences between 0–5, 5–10, and 0–10 m time recorded in testing sessions 1 and 2 for both pre- and post-testing. To further ensure that sprint performance within each subject was similar across pre- and post-testing sessions, trial-to-trial reliability was assessed by ICCs. An ICC equal to or above 0.80 was deemed acceptable (42). In addition to ICCs, the spreadsheet of Hopkins (17) was used to determine the typical error(s), expressed as a coefficient of variation (CV, %). A CV of less than 5% was set as the criterion for reliability and consistency across trials (6). Before the training interventions, independent samples *t*-tests ($p \leq 0.05$) were used to determine whether there were any differences between the groups in pre-test time for the 0–10 m sprint. This between-subject analysis was conducted to ensure that sprint performance for both groups was similar before the training interventions.

After the interventions, data were analyzed through a repeated-measures ANOVA, including training group as a between-subjects factor (sprint training and plyometrics training) (39). The within-subject factor represented the pre- and post-training measures (sprint times, step kinematics, and stance kinetics). Because only 2 repeated measures were used, the assumption of Mauchly's test of sphericity did not apply. All other repeated measures ANOVA assumptions were

TABLE 2. Change in step length (SL), step frequency (SF), contact time (CT), and flight time (FT) in the 0–5, 5–10, and 0–10 m interval in a 10-m sprint (mean ± *SD* and effect size [ES]) after 6 weeks of sprint or plyometrics training in field sport athletes.

	Sprint training ($n = 8$)				Plyometrics training ($n = 8$)				Between-subjects
	Pre	Post	*p*	ES	Pre	Post	*p*	ES	*p*
0–5 m SL (m)	1.14 ± 0.09	1.31 ± 0.10*	<0.001	1.79	1.19 ± 0.12	1.29 ± 0.12*	0.010	0.83	0.051
5–10 m SL (m)	1.59 ± 0.14	1.83 ± 0.17*	0.002	1.54	1.70 ± 0.13	1.80 ± 0.15*	0.020	0.71	0.051
0–10 m SL (m)	1.37 ± 0.11	1.57 ± 0.12*†	<0.001	1.74	1.45 ± 0.12	1.55 ± 0.13*†	0.005	0.80	0.013
0–5 m SF (Hz)	4.15 ± 0.28	4.07 ± 0.32	0.381	0.27	4.12 ± 0.20	4.18 ± 0.30	0.216	0.24	0.152
5–10 m SF (Hz)	4.22 ± 0.30	4.10 ± 0.36	0.211	0.36	3.98 ± 0.28	4.02 ± 0.40	0.740	0.12	0.264
0–10 m SF (Hz)	4.18 ± 0.28	4.08 ± 0.31	0.283	0.34	4.06 ± 0.21	4.12 ± 0.33	0.340	0.22	0.146
0–5 m CT (s)	0.145 ± 0.009	0.156 ± 0.009*†	0.015	1.22	0.146 ± 0.011	0.148 ± 0.010†	0.685	0.19	0.047
5–10 m CT (s)	0.125 ± 0.008	0.130 ± 0.011	0.227	0.52	0.123 ± 0.007	0.124 ± 0.009	0.598	0.12	0.409
0–10 m CT (s)	0.139 ± 0.008	0.145 ± 0.009	0.095	0.70	0.138 ± 0.009	0.139 ± 0.008	0.598	0.12	0.227
0–5 m FT (s)	0.100 ± 0.016	0.090 ± 0.012*	0.007	0.71	0.100 ± 0.016	0.099 ± 0.020	0.763	0.06	0.089
5–10 m FT (s)	0.119 ± 0.016	0.120 ± 0.013	0.732	0.07	0.135 ± 0.010	0.129 ± 0.021	0.351	0.36	0.313
0–10 m FT (s)	0.110 ± 0.015	0.109 ± 0.011	0.685	0.08	0.119 ± 0.012	0.116 ± 0.020	0.516	0.03	0.794

*Significant ($p \leq 0.05$) difference in within-subjects factor (pre and post-test).
†Significant ($p \leq 0.05$) difference in between-subjects factor (sprint and plyometrics training).

Table 3. Change in first contact stance kinetics (mean ± *SD* and effect size [ES]) in a 10-m sprint after 6 weeks of sprint or plyometrics training in field sport athletes.

Stance kinetics	Sprint training (n = 8)				Plyometrics training (n = 8)				Between-subjects
	Pre	Post	p	ES	Pre	Post	p	ES	p
Vertical force ($N \cdot kg^{-1}$)	1.93 ± 0.09	1.96 ± 0.09	0.196	0.33	1.92 ± 0.16	1.94 ± 0.15	0.735	0.13	0.807
Vertical impulse ($N \cdot s^{-1} \cdot kg^{-1}$)	0.265 ± 0.024	0.270 ± 0.016	0.422	0.25	0.254 ± 0.021	0.258 ± 0.013	0.610	0.23	0.828
Horizontal force ($N \cdot kg^{-1}$)	1.08 ± 0.19	0.99 ± 0.16	0.082	0.51	0.91 ± 0.24	0.99 ± 0.14	0.332	0.41	0.073
Horizontal Impulse ($N \cdot s^{-1} \cdot kg^{-1}$)	0.176 ± 0.040	0.184 ± 0.050	0.531	0.18	0.154 ± 0.036	0.172 ± 0.021	0.152	0.61	0.559
Resultant force ($N \cdot kg^{-1}$)	2.22 ± 0.13	2.20 ± 0.12	0.643	0.16	2.14 ± 0.14	2.18 ± 0.19	0.350	0.24	0.296
Resultant impulse ($N \cdot s^{-1} \cdot kg^{-1}$)	0.319 ± 0.034	0.330 ± 0.033	0.100	0.33	0.299 ± 0.022	0.311 ± 0.014	0.216	0.65	0.923
Resultant force angle (degrees)	29.13 ± 4.14	26.72 ± 3.62	0.056	0.62	25.37 ± 6.93	26.91 ± 2.15	0.499	0.30	0.123
Ratio of forces (%)	56.07 ± 9.66	50.56 ± 7.97*	0.050	0.62	48.09 ± 14.40	50.82 ± 4.77	0.559	0.26	0.124

*Significant ($p \le 0.05$) difference in within subjects factor (pre and post-test).

considered. The criterion for significance was $p \le 0.05$. The Levene statistic established homogeneity of variance of the distribution of data. If a significant *F* ratio was detected, post hoc tests were conducted using the Bonferroni adjustment procedure for multiple comparisons. Effect sizes were calculated for the pre- and post-test results for each group from the difference between the means divided by the pooled *SD*s (7). For the purpose of this research, ≤0.20 was considered a trivial effect, 0.21–0.60 a small effect, 0.61–1.20 a moderate effect, 1.21–2.00 a large effect, 2.01–4.00 a very large effect, and 4.01 and above an extremely large effect (16).

RESULTS

There were no significant differences in age, height, or mass between the groups before training (ST group: age = 21.25 ± 1.67 years; height = 1.80 ± 0.06 m; mass = 79.74 ± 7.57 kg; PT group: 23.00 ± 3.02 years; height = 1.82 ± 0.05 m; mass = 81.33 ± 4.10 kg), nor did mass change within each group after the interventions (ST group: 80.46 ± 8.60 kg, $p = 0.440$; PT group: 80.88 ± 5.57 kg, $p = 0.525$). The comparisons between sprint times measured in sessions 1 (step kinematics) and 2 (stance kinetics), within the pretesting and post-testing sessions, are shown in Figure 2. There were no significant differences between sprint time over any of the sprint intervals between testing sessions 1 and 2 for either the pre (0–5 m: $p = 0.194$, ES = 0.50; 5–10 m: $p = 0.203$, ES = 0.33; 0–10 m: $p = 0.262$, ES = 0.35) or post-tests (0–5 m: $p = 0.512$, ES = 0.33; 5–10 m: $p = 0.735$, ES = 0.28; 0–10 m: $p = 0.568$, ES = 0.23). Furthermore, the reliability for the sprint test times in pre-testing (0–5 m: ICC = 0.81, CV = 3.01%; 5–10 m: ICC = 0.91, CV = 1.31%; 0–10 m: ICC = 0.90, CV = 1.44%) and post-testing (0–5 m: ICC = 0.93, CV = 1.57%; 5–10 m: ICC = 0.95, CV = 1.34%; 0–10 m: ICC = 0.90, CV = 1.50%) were all deemed acceptable.

Figure 3 displays the sprint times before and after the interventions. The ST group decreased 0–5 m time by 6% ($p = 0.006$; ES = 1.26) and the PT group by 5% ($p = 0.008$; ES = 0.99). The ST group decreased 0–10 m time by 5% ($p = 0.010$; ES = 1.13) and the PT group by 4% ($p < 0.001$; ES = 0.95). Neither group significantly decreased 5–10 m time (ST group: $p = 0.232$, ES = 0.28; PT group: $p = 0.072$, ES = 0.28). There were no between-group differences for the change in sprint times (0–5 m: $p = 0.617$; 5–10 m: $p = 0.923$; 0–10 m: $p = 0.703$).

Table 2 displays the step kinematics data. Mean step length significantly increased across all intervals for both groups. This was by 15% in all intervals for the ST group (all large effects) and 8, 6, and 7% for the PT group in the 0–5, 5–10, and 0–10 m intervals (all moderate effects), respectively. The 0–10 m step length gains by the ST group were significantly ($p = 0.013$) greater than those for the PT group. There were no changes in step frequency for either group. Mean 0–5 m contact time for the ST group increased by 8% after training (large effect), and this was significantly

TABLE 4. Change in second contact stance kinetics (mean ± *SD* and effect size [ES]) in a 10-m sprint after 6 weeks of sprint or plyometrics training in field sport athletes.

	Sprint training ($n = 8$)				Plyometrics training ($n = 8$)				Between-subjects
Stance kinetics	Pre	Post	p	ES	Pre	Post	p	ES	p
Vertical force (N·kg^{-1})	2.03 ± 0.19	2.02 ± 0.09	0.926	0.07	2.02 ± 0.18	2.09 ± 0.26	0.105	0.31	0.392
Vertical impulse (N·s^{-1}·kg^{-1})	0.242 ± 0.019	0.255 ± 0.032	0.168	0.49	0.244 ± 0.010	0.254 ± 0.027	0.248	0.49	0.844
Horizontal force (N·kg^{-1})	1.18 ± 0.15	1.02 ± 0.13*	0.016	1.14	1.15 ± 0.11	1.09 ± 0.11	0.251	0.55	0.225
Horizontal impulse (N·s^{-1}·kg^{-1})	0.269 ± 0.044	0.198 ± 0.027*	<0.001	1.95	0.262 ± 0.030	0.215 ± 0.025*	0.002	1.70	0.104
Resultant force (N·kg^{-1})	2.35 ± 0.20	2.27 ± 0.08	0.318	0.53	2.33 ± 0.18	2.35 ± 0.26	0.581	0.09	0.243
Resultant impulse (N·s^{-1}·kg^{-1})	0.363 ± 0.040	0.324 ± 0.028*	0.003	1.13	0.358 ± 0.026	0.333 ± 0.024*	0.032	1.00	0.290
Resultant force angle (degrees)	30.11 ± 3.13	26.77 ± 3.34*	0.042	1.03	29.75 ± 2.24	27.65 ± 2.92	0.078	0.81	0.472
Ratio of forces (%)	58.20 ± 7.34	50.64 ± 7.21*	0.041	1.04	57.25 ± 5.33	52.55 ± 6.47	0.081	0.79	0.464

*Significant ($p \leq 0.05$) difference in within-subjects factor (pre and post-test).

TABLE 5. Change in last contact stance kinetics (mean ± *SD* and effect size [ES]) in a 10-m sprint after 6 weeks of sprint or plyometrics training in field sport athletes.

	Sprint training ($n = 8$)				Plyometrics training ($n = 8$)				Between-subjects
Stance kinetics	Pre	Post	p	ES	Pre	Post	p	ES	p
Vertical force (N·kg^{-1})	2.56 ± 0.12	2.51 ± 0.10	0.318	0.45	2.53 ± 0.29	2.69 ± 0.20	0.106	0.64	0.051
Vertical impulse (N·s^{-1}·kg^{-1})	0.260 ± 0.019	0.246 ± 0.022†	0.062	0.68	0.253 ± 0.026	0.264 ± 0.020†	0.089	0.47	0.010
Horizontal force (N·kg^{-1})	0.92 ± 0.16	0.88 ± 0.17	0.378	0.24	0.89 ± 0.20	0.76 ± 0.32	0.327	0.49	0.200
Horizontal impulse (N·s^{-1}·kg^{-1})	0.166 ± 0.037	0.139 ± 0.024	0.157	0.87	0.150 ± 0.032	0.132 ± 0.034*	0.041	0.55	0.626
Resultant force (N·kg^{-1})	2.73 ± 0.13	2.67 ± 0.12†	0.225	0.48	2.66 ± 0.25	2.84 ± 0.20†	0.075	0.80	0.027
Resultant impulse (N·s^{-1}·kg^{-1})	0.310 ± 0.023	0.283 ± 0.018*†	0.038	1.31	0.295 ± 0.030	0.296 ± 0.030†	0.943	0.03	0.046
Resultant force angle (degrees)	19.70 ± 3.09	19.28 ± 3.39	0.650	0.13	16.97 ± 7.75	18.20 ± 3.91	0.633	0.20	0.539
Ratio of forces (%)	35.91 ± 6.08	35.11 ± 6.67	0.658	0.13	31.06 ± 15.00	33.03 ± 7.69	0.697	0.17	0.599

*Significant ($p \leq 0.05$) difference in within-subjects factor (pre- and post-test).
†Significant ($p \leq 0.05$) difference in between-subjects factor (sprint and plyometrics training).

($p = 0.047$) different to the PT group, who experienced no changes in contact time. The ST group also decreased mean 0–5 m flight time by 10% (moderate effect); the PT group had no changes in flight time, and there were no between-subject differences.

For the first contact (Table 3), there was a significant 10% decrease in RatF for the ST group, with a moderate effect. There was also a nonsignificant ($p = 0.056$) moderate effect for an 8% decrease in RFθ. The PT group had moderate effects for a 12% increase in HI, and 4% increase in RI, but neither was significant ($p = 0.152$ and 0.216, respectively). There were no significant between-subject differences for first contact stance kinetics. For the second contact (Table 4), there were significant decreases in HF (14%), HI (26%), RI (11%), RFθ (11%), and RatF (13%), for the ST group, all of which had large effects. The PT group had significantly reduced HI (18%) and RI (7%), which both had large effects. Although nonsignificant, the reductions in RFθ ($p = 0.078$) and RatF ($p = 0.081$) had moderate effects for the PT group. There were no significant between-subject differences for second contact stance kinetics.

Table 5 displays the stance kinetics data for the last contact of the 10-m sprint. The ST group had a 5% nonsignificant moderate effect decrease in VI. Correspondingly, the PT group had a 4% nonsignificant small effect increase in VI. As a result, there was a significant ($p = 0.010$) between-subject difference for the change in last contact VI. This also occurred for RF. The ST group had no significant change in RF, whereas the PT group had a 7% nonsignificant moderate effect increase in RF, which resulted in a significant ($p = 0.027$) between-subject difference. The ST group had a 16% decrease in HI with a moderate effect, although the change was nonsignificant ($p = 0.157$). The PT group had a significant 12% decrease in HI, with a small effect. Regarding RI, the ST group had a 9% significant decrease, which had a large effect, whereas the PT group experienced no change to this variable. Consequently, there was a significant ($p = 0.046$) between-subject difference for the ST group's change in RI.

DISCUSSION

The purpose of this study was to define the biomechanical changes to 10-m sprint technique, with a particular focus on stance kinetics, that are induced by sprint or plyometrics training in field sport athletes. The results indicated that an increase in step length was the primary step kinematic adaptation by both training groups, although the gains made by the ST group tended to be greater. Regarding stance kinetics, there was a shift away from HF production tending toward VF production for both groups, which was more pronounced for the PT group in later acceleration. The findings from this research provide strength and conditioning coaches with the knowledge that there will be favorable adaptations acceleration technique after sprint and plyometric training interventions, such that a faster sprint performance will result.

In support of the study hypotheses, both groups reduced time over the 0–5 and 0–10 m intervals, although neither group significantly reduced 5–10 m time (Figure 3). These results further reinforce the importance of speed over the first 5 m in short sprint performance (19,39). Regarding the 5–10 m interval, Lockie et al. (28) suggested that a protocol that provides an even greater force overload, such as that provided by heavy resistance training, may be required to enhance speed in this interval. There were also no significant sprint time differences between the groups, which is not surprising given that both sprint and plyometrics training encourage rapid stretch-shortening cycle actions within the leg muscles (28). Both groups also increased mean step length in all intervals, although the increases in step length for the ST group tended to be greater than those for the PT group (Table 2). The specificity of sprint training would have likely made the ST group more sensitive to changes in step kinematics (28), because step technique was trained within every sprint repetition for this group. Interestingly, as per previous research that has investigated sprint (28,39) and plyometrics (28) training, there were no changes to step frequency (Table 2). This was despite previous research outlining the importance of step frequency to short sprint speed (15,35). If strength and conditioning practitioners wish to increase step frequency in their athletes, they may have to introduce another training protocol (e.g., assisted sprint training) to supplement sprint and plyometrics training. However, this must be confirmed by further research.

Shorter contact times have been linked to faster acceleration in recreational field sport athletes (26). However, the ST group significantly increased 0–5 m contact time, and reduced 0–5 m flight time; the PT group had no significant changes in contact or flight time (Table 2). Additionally, the change in 0–5 m contact time for the ST group was significantly ($p = 0.047$) different to that of the PT group. Longer contact times have been associated with superior acceleration in physical education students, possibly to assist with force development (24). As an initial adaptation to sprint training, field sport athletes may require a longer stance time, to generate the necessary amount of force required to lengthen the step and generate a greater running speed during acceleration (28). As will soon be discussed, these changes to contact time may have been influenced by certain adaptations in early acceleration stance kinetics for the ST group. Furthermore, the flight time decrease would help offset the longer contact times for the ST group, such that sprint time was not negatively affected. In contrast, the load provided from plyometrics exercises was enough to maintain 0–5 m contact time for the PT group after the intervention. Nevertheless, as for step frequency, a modality such as assisted sprinting could be implemented by a strength and conditioning coach if they wished to reduce contact time in their athletes. This is because supramaximal velocities will result in acute increases in step frequency and reductions in contact time (31), although research needs to confirm the permanence of these changes with training. Further investigation is required to determine whether adaptations induced by assisted sprinting can be performed concurrently with the protocols used in this study.

Step kinematics result from the kinetics produced during stance. The changes in stance kinetics from this study were more related to the VF component, which has been linked to effective acceleration in field sport athletes (27), the ability to change direction and accelerate in team sport athletes (40), and maximum velocity sprinting in active individuals (44). This was particularly true for the second and last contact of the 10-m sprint. Nonetheless, for the first contact in the 10-m sprint (Table 3), the ST group significantly reduced RatF and had a nonsignificant moderate effect ($p = 0.056$, ES = 0.62) for a reduced RFθ. These results inferred a greater contribution of the VF component of stance, as the RF was tilted more vertically, and the RatF had a greater percentage contribution from VF. The PT group had no significant changes to first contact stance kinetics, although there were moderate effects for the increases in HI ($p = 0.152$, ES = 0.61) and RI ($p = 0.216$, ES = 0.65). Greater HI has been found to significantly correlate with faster 10-m sprint performance in male team sport athletes (20), demonstrating the importance of this kinetic variable. There were no significant between-subject differences for first contact stance kinetics, suggesting any changes were relatively similar for both groups.

For the second contact, the ST group had significantly reduced HF, HI, RI, RFθ, and RatF (Table 4). The PT group had significantly reduced HI and RI, and the reduction in HF had a nonsignificant moderate effect (ES = 0.55). Even without any significant increases to VF or VI, these results imply a greater reliance on VF production for acceleration, in particular, regarding the changes in RFθ and RatF for the ST group. These adaptations occurred despite the expectation that HF could be more affected by the training protocols because of its importance for acceleration (5,20,24,33). During sprint acceleration, there will be an increased reliance on VF as the upper body rises over the progression of a sprint (21). An adaptation for both sprint and plyometrics training seemed to be a reduced reliance on HF and HI, and a relatively greater emphasis on VF production, even though the magnitude of VF may not have significantly changed. In addition, the fact that the ST group had more changes to early acceleration stance kinetics provides an indication why this group increased step length to a greater extent when compared with the PT group. For the ST group, the kinetic adaptations would have assisted with the force generation needed to lengthen the step and contributed to the increases in contact time during the initial stages of the 10-m sprint.

The value of the overload provided during plyometrics training was seen for the stance kinetics of the last contact in the 10-m sprint (Table 5), which was in agreement with the study hypotheses. The increase in VF (ES = 0.64) and RF (ES = 0.80) for the PT group had moderate effects, although both were nonsignificant ($p = 0.106$ and 0.075, respectively). The PT group also had small effect (ES = 0.47) for an increase in VI, which, when combined with a moderate decrease in VI for the ST group (ES = 0.68), led to a significant between-subject difference in this variable. The ST group also had a significant reduction in RI, whereas the PT group had no change in this variable. This also led to a significant between-group difference in the RI changes induced by the training protocols. The GRF overload provided by jumping, hopping, and bounding exercises (32,43) helps illustrate why the PT group was able to maintain relative VF, VI, RF, and RI to a greater extent than the ST group. These later acceleration stance kinetics adaptations for the PT group would have contributed to improvements such as increased step length for this group, which ultimately enhanced 10-m sprint performance.

The PT group also significantly reduced last contact HI, whereas the ST group had a nonsignificant reduction in HI with a moderate effect ($p = 0.157$, ES = 0.87). These kinetic adaptations may be related to theories postulated by Lockie et al. (27), who found no significant relationships between HI and short sprint speed in field sport athletes. Lockie et al. (27) suggested that field sport athletes must be conditioned to complete multiple short sprints during a match, which is supported by time-motion analyses of soccer (41) and Australian football (8). The field sport athletes from this study may already be conditioned for appropriate HI during acceleration. Any reductions in HI suggest a shift toward a greater reliance on VF for generating sprint speed (21). This may have been a necessary adaptation for the field sport athletes in this study to facilitate the step length modifications that resulted after training.

Nonetheless, the value of the horizontal component of stance kinetics should not be discounted (5,20,24,33). Future research should analyze protocols that could enhance the HF component of stance, in addition to the vertical component. This could involve using a plyometrics program with a greater emphasis on horizontal jumps (e.g., standing broad jumps and bounding), or using a sprint training protocol that encourages HF development. Indeed, horizontal power, as measured by bounding, has been linked to faster acceleration (28). A protocol that could achieve this is resisted sprinting, which involves running with an external resistance (e.g., towing a sled), which can improve running speeds (14,28,39), by encouraging a forward lean that could enhance the ability to apply HF (29). Using protocols that emphasize both VF and HF production could potentially lead to more favorable adaptations to acceleration stance kinetics. This must be confirmed through further analysis of the changes to stance kinetics that result from different speed training modalities in field sport athletes.

There are certain limitations for this study. The measurement of sprint kinematics and kinetics separately was not ideal, but occurred because of laboratory space restrictions. Nonetheless, as there were no differences between times recorded between the 2 sessions for both pre- and post-testing (Figure 2), it can be assumed that sprint performances were similar across the sessions. No control group was used, although this is in line with previous research (23,28). Although it seems that both sprint and plyometrics training are effective for improving speed, absolute confirmation of this could be aided by using a control group in a future study. The external workload of subjects was not controlled, although they were told not to start any new training stimulus for the duration of the study. The normal training completed by subjects could have had some influence on the study results. However, the improvement in sprint acceleration for both groups does provide an indication of the effectiveness of the administered programs. In addition, strength or power was not directly measured in this research. Although previous research has already documented that sprint and plyometrics training can improve these faculties in athletes (19,28,38), measurement of strength and power could have added to this research. Nevertheless, this study has revealed important information about the outcomes of sprint and plyometrics training on acceleration and speed over short distances. The results from this research suggest that sprint and plyometrics training can both improve acceleration in field sport athletes. The main technique adaptations are an increase in step length and a greater relative emphasis on VF production during early and later acceleration.

PRACTICAL APPLICATIONS

There are several practical applications from this research for the strength and conditioning professional. Sprint and plyometric training protocols are both effective at improving 10-m sprint performance in field sport athletes. Strength and conditioning coaches should note that this was primarily performed through increased step length and an increased relative reliance on VF production during stance. There were certain technical and mechanical differences in the adaptations caused by each training modality. Sprint training caused somewhat greater changes to step length and relatively more changes to the horizontal component of force during early acceleration. Plyometrics training provides an overload that can maintain or increase components of GRF that would contribute to faster sprint acceleration, which was particularly notable for later acceleration in this study. The practitioner can design speed training programs using these protocols with the expectations that these adaptations can occur in their athletes. However, if strength and conditioning coaches wish to develop step frequency, contact time, or HF production, then other training protocols or exercises should be used to supplement the programs used in this study. This could include assisted sprint training to increase movement speed such that improvements in step frequency and reductions in contact time could result, and resisted sprinting to place a greater emphasis on HF and HI. There should also be further investigations of these training modalities, especially in conjunction with sprint and plyometrics training, to ascertain the effects on sprint acceleration technique. This will demonstrate whether it is a realistic goal for field sport coaches and strength and conditioning practitioners to attempt to improve all facets of step kinematics and stance kinetics simultaneously in their athletes.

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