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The Acute Effects of Plyometric Exercises on Sprint Performance and Kinematics

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Abstract: Background: Post-activation potentiation refers to the acute and temporary enhancement of performance in explosive movements after performing a conditioning activity, such as plyometrics. The current study aimed to investigate the acute effects of horizontal leg bounding on 30 m acceleration performance, 5 m split times, and sprint kinematics (step frequency and length, flight and contact time). Methods: Fourteen young sprinters, nine females and five males, performed two experimental conditions and one control condition in randomized and crossover orders. The experimental conditions included 3 × 10 repetitions of alternate-leg horizontal bounding or 3 × 5 repetitions of single-leg horizontal bounding for each leg. Active recovery was performed in the control condition. A 30 m sprint test was executed before and 5 min after each condition. Results: Sprint times at 5 m (p = 0.014) and 10 m (p = 0.041) were improved after performing alternate-leg horizontal bounding. Additionally, an increase in running velocity (p = 0.017) and step frequency (p = 0.028) was observed in the 0–5 m segment of the sprint. Sprint performance and kinematics showed no significant differences after performing single-leg horizontal bounding. Conclusions: Alternate-leg horizontal bounding, which is a sprint-specific exercise that emphasizes a horizontal impulse, can be used effectively to improve performance in the initial phase of sprint acceleration.

Keywords: plyometrics; post-activation potentiation; performance; acceleration; sprint kinematics

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1. Introduction

The acceleration phase in sprint events has been shown to be related to performance [1,2]. The ability to accelerate rapidly in a horizontal direction depends on the magnitude and orientation of the propulsive force produced during the toe-off of the stance phase [3]. The magnitude of force that a muscle group is capable of producing has been reported to increase acutely following a post-activation potentiation (PAP) stimulus [4]. PAP refers to the acute and temporary enhancement of performance in explosive movements after performing a maximal or near-maximal muscle activity, referred to as a conditioning activity [5].

Sprint acceleration performance is improved after performing plyometrics, resistance running, and resistance exercises as conditioning activities [6–9]. Previous studies have highlighted that the effectiveness of a PAP protocol depends on the biomechanical similarity of the conditioning stimulus to the subsequent activity [8,9]. Therefore, horizontal-oriented plyometrics that are highly specific to sprinting have a high potential to improve sprinting performance [3].

Plyometric exercises refer to the performance of stretch-shortening cycle (SSC) movements that involve a high-intensity concentric or shortening muscle action immediately after a rapid and powerful eccentric or lengthening muscle action [10]. The SSC allows the utilization of stored elastic energy, which increases the total power output [11]. Previous studies have induced a PAP effect via the use of a variety of plyometric exercise modalities. Byrne et al. [12] found significant improvement in 5 and 10 m sprint performance 4 and

12 min after performing drop jumps. Additionally, depth jumps and weighted squat jumps have been shown to enhance subsequent 20 m performance [13,14]. Turner et al. [9] used, as conditioning activities, weighted and non-weighted alternate-leg horizontal bounding and found improved 10 m and 20 m sprint times. Horizontal leg bounding is considered to be a sprint-specific exercise that improves acceleration performance by producing a greater propulsive impulse while keeping the contact time the same [15,16]. The application of a horizontal impulse has been reported to be significantly related to acceleration performance [17].

The development of running velocity is determined by the kinematic characteristics of sprinting (i.e., step frequency and length, contact and flight time). Running velocity is the product of the interaction between step length and step frequency. These two variables depend on different physiological parameters. Increasing step length requires high strength levels and flexibility in the hip joint, while increasing step frequency requires high neural activation to achieve the fast turnover of the legs [18]. Increasing the step length or frequency while keeping the other variables constant will increase running velocity and improve sprinting performance [19]. Studies examining acute changes in sprinting kinematics after a PAP protocol are limited. Yoshimoto et al. [20] estimated the step frequency by counting steps per second and found an increase in step frequency and 60 m sprint velocity 10 min after performing running over mini-hurdles. Kummel et al. [21] investigated the acute effects of conditioning hops on 30 m sprint time as well as on step length and contact time in the first 10 m of a sprint, and found no significant changes. To our knowledge, the acute effects of plyometrics on sprint kinematics (step frequency and length, flight and contact time) throughout the acceleration phase have not been examined by other studies.

This study aimed to investigate whether sprint-specific plyometric exercises could acutely improve 30 m acceleration performance and split times per 5 m. In addition, the possible changes in sprint kinematics per 5 m were examined. It was hypothesized that sprint-acceleration performance would be significantly enhanced after performing alternate- and single-leg horizontal bounding.

2. Materials and Methods

2.1. Experimental Design

A randomized crossover design was performed to investigate the acute effects of plyometric exercises (alternate- and single-leg horizontal bounding) on 30 m sprint performance and on 5 m split times, running velocity, and sprinting kinematics (step frequency and length, flight and contact time). The participants completed a total of 4 sessions (1 familiarization and 3 testing), which were at least 48 h apart. During the first session, familiarization with the experimental and testing procedures was performed. In the following 3 testing sessions, participants completed a standardized warm-up followed in a random order by 3 intervention conditions: 2 experimental conditions and 1 control condition. The experimental conditions included 3 × 10 repetitions of alternate-leg horizontal bounding (ALB) and 3 × 5 repetitions of single-leg horizontal bounding (SLB) for each leg. Active recovery (walking) was performed in the control condition (CON). To investigate the effects of the conditions on the dependent variables, the participants performed a 30 m maximal sprint before and after each condition. All of the sessions took place at the same time of the day and on the same synthetic track surface. In all of the sessions the participants wore similar clothing and their sprinting spikes.

2.2. Participants

Fourteen young sprinters, nine females and five males (age: 15.6 ± 2.3 years; body mass: 57.7 ± 7.3 kg; and stature: 1.66 ± 0.06 m), were recruited for the study. The inclusion criteria were that participants were completely healthy with no recent injury, had training experience of at least 2 years, and were familiar with plyometric exercises. Participants were asked to abstain from vigorous physical activity 48 h before the tests. Participation was voluntary and a signed parental consent document was required for study involvement. Study methods and procedures were conducted in accordance with the Declaration of Helsinki and were approved by the local ethics committee (registration number: 1169, 12 February 2020).

2.3. Procedures

The familiarization session, which preceded the 3 testing sessions, included the recording of participants' anthropometric characteristics (body mass and stature), familiarization with the sprint testing procedures, and instructions on the bounding technique. Specifically, during bounding, participants were instructed to minimize foot contact time, maximize the horizontal impulse, and cover the longest possible distance with each bound [15]. During the 3 testing sessions participants completed the randomly ordered intervention conditions, i.e., ALB/SLB/CON, after performing a standardized warm-up, which included 5 min of jogging, a series of dynamic stretching of the lower-limb muscles, sprint-specific drills, and 3 × 30 m sprints with progressively increasing intensity, with 2 min of recovery (walking) between repetitions. After 5 min of the standardized warm-up, a baseline 30 m sprint test using a 3-point standing position was performed. Following recovery for 5 min, one condition was randomly performed. In ALB, the participants performed 3 × 10 repetitions of alternate-leg horizontal bounding (5 bounds for each leg per set), while in SLB they performed 3 × 5 repetitions of single-leg horizontal bounding for each leg. Two minutes of recovery between sets in both conditions was provided. In CON, participants performed active recovery, which included walking for the same duration as the plyometric exercises (~4.30 min). The 30 m sprint test was repeated 5 min post-interventions. Previous researchers have suggested that the greatest PAP effect appears 5–7 min after the execution of a conditioning activity [22]. Baseline and post-intervention sprints were recorded by three high-speed (300 Hz) panning cameras (Casio EX-F1, Tokyo, Japan) placed in the sagittal plane of motion, 10 m from the middle of the running lane. Cameras were placed at 5, 15, and 25 m, and recorded 10 m intervals [23]. To determine the 5 m split times, marker poles were placed at adjusted locations, correcting video parallax errors [24]. Step length measurement was performed by placing pairs of 5 × 5 cm custom reference markers on both sides of the entire runway at 1 m intervals [25–27].

2.4. Data Analysis

Quintic Biomechanics software (Quintic Consultancy Ltd. version 31, Birmingham, UK) was used to analyze the video data to calculate 5 m split times and sprint kinematics. The starting point was set as the first propulsive movement of the rear leg, and 5 m split times were the moments at which a participant's hip crossed the marking poles [24]. The intraclass correlation coefficient (ICC) between the 30 m baseline trials was very high (0.994, 95% CI 0.987 to 0.998). The running velocity was computed for 5 m intervals. The kinematic characteristics were calculated by analyzing each sprint step and averaged over 5 m splits. Touchdown was defined as the moment a participant's foot first touched the ground, and toe-off was defined as the moment it detached from the ground. Contact time was calculated as the time a foot was in touch with the ground, while flight time was defined as the time between the toe-off of one foot to the initial contact with the ground of the other foot. Step length was calculated as the distance between the participant's toes of two consecutive steps during contact time according to previous studies [7,26,27]. Step frequency was computed as running velocity/step length.

2.5. Statistical Analysis

All of the data are displayed as the mean ± standard deviation (*SD*). Before the analyses, the normality of the data distribution was checked with the Shapiro-Wilks test. A two-way repeated measures ANOVA (3 conditions: CON, ALB, SLB × 2 times: pre-, post-) was used to determine whether dependent variables differed significantly between the baseline and post-intervention measurements. Testing for sphericity was performed using Mauchly's test, and the Greenhouse-Geisser correction was applied where necessary. Interactions and the main effects of time as well as condition were examined. The significant main effects were further investigated using a Bonferroni post hoc analysis. The magnitude of the within-subjects effect was defined by Cohen's d effect size (ES) as trivial (<0.20), small (0.20 to 0.49), medium (0.50 to 0.79), or large (≥0.80) [28]. The level of statistical significance was set at $p \leq 0.05$. Statistical analyses were conducted using SPSS software (IBM SPSS version 25.0, Chicago, IL, USA).

3. Results

ANOVA demonstrated a significant main effect of time on 5 m (F = 9.600, $p = 0.008$, $\eta^2 = 0.43$, and observed power (OP) = 0.82) and 10 m (F = 5.828, $p = 0.031$, $\eta^2 = 0.0.31$, and OP = 0.61) sprint times. A post hoc analysis showed that, in ALB, the participants ran faster at 5 m (mean difference (MD) = −0.025 ± 0.009 s, $p = 0.014$, and ES = 0.76) and 10 m (MD = −0.023 ± 0.010 s, $p = 0.041$, and ES = 0.61) post-intervention compared to the baseline trial (Table 1). No significant interaction or main effects ($p > 0.05$) were observed in CON and SLB (Table 1).

Table 1. Mean ± SD sprint times of baseline and post-intervention 30 m sprints for the 3 intervention conditions.

		CON	ALB	SLB
5 m	Pre-	1.41 ± 0.07	1.42 ± 0.08	1.40 ± 0.08
	Post-	1.40 ± 0.08	1.40 ± 0.09	139 ± 0.08
	p, ES	0.362, 0.25	0.014, 0.76	0.056, 0.56
	(95% CI)	(−0.29–0.78)	(0.15–1.35)	(−0.02–1.12)
10 m	Pre-	2.20 ± 0.09	2.20 ± 0.11	2.19 ± 0.11
	Post-	2.19 ± 0.10	2.18 ± 0.12	2.18 ± 0.10
	p, ES	0.697, 0.11	0.041, 0.61	0.147, 0.41
	(95% CI)	(−0.42–0.63)	(0.02–1.17)	(−0.14–0.95)
15 m	Pre-	2.89 ± 0.13	2.90 ± 0.14	2.89 ± 0.13
	Post-	2.89 ± 0.13	2.88 ± 0.15	2.88 ± 0.13
	p, ES	0.766, 0.08	0.122, 0.44	0.334, 0.27
	(95% CI)	(−0.45–0.60)	(−0.12–0.98)	(−0.27–0.80)
20 m	Pre-	3.56 ± 0.17	3.57 ± 0.17	3.56 ± 0.16
	Post-	3.57 ± 0.17	3.55 ± 0.19	3.56 ± 0.16
	p, ES	0.197, 0.36	0.177, 0.38	0.748, 0.09
	(95% CI)	(−0.19–0.90)	(−0.17–0.92)	(−0.44–0.61)
25 m	Pre-	4.21 ± 0.21	4.22 ± 0.21	4.22 ± 0.20
	Post-	4.23 ± 0.20	4.20 ± 0.22	4.22 ± 0.20
	p, ES	0.069, 0.53	0.159, 0.40	0.680, 0.11
	(95% CI)	(−0.04–1.08)	(−0.15–0.94)	(−0.64–0.42)
30 m	Pre-	4.86 ± 0.25	4.86 ± 0.25	4.86 ± 0.23
	Post-	4.87 ± 0.25	4.84 ± 0.26	4.87 ± 0.23
	p, ES	0.061, 0.55	0.118, 0.45	0.264, 0.31
	(95% CI)	(−0.03 –1.10)	(−0.11–0.99)	(−0.84–0.23)

CON = control condition, ALB = alternate-leg horizontal bounding, and SLB = single-leg horizontal bounding.

The results of the statistical analysis for the sprinting kinematics are presented in Tables 2–4 for the CON, ALB, and SLB conditions, respectively. A significant main effect of time on running velocity in the 0–5 m distance was found (F = 8.996, $p = 0.010$, $\eta^2 = 0.41$, and OP = 0.79). The post hoc analysis revealed that, in the ALB condition, the participants' running velocity was significantly higher post-intervention at 0–5 m (MD = 0.065 ± 0.024 $m \cdot s^{-1}$, $p = 0.017$, and ES = 0.73). CON and SLB showed no significant differences ($p > 0.05$) in running velocity. A main effect of time at 0–5 m distance indicated a significantly higher step frequency (F = 15.768, $p = 0.002$, $\eta^2 = 0.55$, and OP = 0.96). The post hoc analysis showed that, in the first 5 m of the sprint, step frequency was significantly higher (MD = 0.060 ± 0.024 Hz, p = 0.028, and ES = 0.66) in the ALB condition following the execution of alternate-leg horizontal bounding. No significant interaction or main effects (p > 0.05) were found for step length as well as flight and contact time at any interval distance of the 30 m sprint.

Table 2. Mean ± SD of the kinematic characteristics of baseline and post-intervention 30 m sprints in the control condition.

CON Condition		Velocity (m/s)	Step Length (m)	Step Frequency (Hz)	Contact Time (s)	Flight Time (s)
0–5 m	Pre-	3.55 ± 0.17	1.09 ± 0.09	3.30 ± 0.35	0.163 ± 0.013	0.079 ± 0.017
	Post-	3.58 ± 0.20	1.08 ± 0.09	3.35 ± 0.38	0.168 ± 0.010	0.077 ± 0.016
	p, ES	0.310, 0.28	0.503, 0.18	0.238, 0.33	0.117, 0.44	0.351, 0.26
	(95% CI)	(−0.26–0.81)	(−0.35–0.71)	(−0.21–0.86)	(−0.99–0.11)	(−0.28–0.79)
5–10 m	Pre-	6.38 ± 0.35	1.45 ± 0.11	4.42 ± 0.33	0.134 ± 0.008	0.099 ± 0.015
	Post-	6.33 ± 0.34	1.46 ± 0.10	4.35 ± 0.28	0.136 ± 0.008	0.097 ± 0.013
	p, ES	0.063, 0.54	0.151, 0.41	0.062, 0.70	0.109, 0.46	0.216, 0.35
	(95% CI)	(−1.10–0.03)	(−0.95–0.15)	(−0.10–1.27)	(−0.10–1.00)	(−0.20–0.88)
10–15 m	Pre-	7.22 ± 0.45	1.62 ± 0.09	4.47 ± 0.27	0.125 ± 0.008	0.104 ± 0.012
	Post-	7.16 ± 0.41	1.63 ± 0.09	4.41 ± 0.29	0.127 ± 0.009	0.103 ± 0.013
	p, ES	0.150, 0.41	0.431, 0.22	0.156, 0.40	0.062, 0.57	0.835, 0.06
	(95% CI)	(−0.95–0.15)	(−0.31–0.74)	(−0.15–0.94)	(−0.00–1.13)	(−0.47–0.58)
15–20 m	Pre-	7.52 ± 0.52	1.71 ± 0.11	4.39 ± 0.31	0.123 ± 0.007	0.107 ± 0.013
	Post-	7.45 ± 0.47	1.72 ± 0.11	4.35 ± 0.27	0.124 ± 0.008	0.107 ± 0.011
	p, ES	0.084, 0.50	0.827, 0.06	0.124, 0.44	0.057, 0.56	0.892, 0.04
	(95% CI)	(−1.05–0.07)	(−0.47–0.58)	(−0.12–0.98)	(−0.02–1.11)	(−0.49–0.56)
20–25 m	Pre-	7.69 ± 0.57	1.77 ± 0.10	4.35 ± 0.31	0.121 ± 0.008	0.110 ± 0.012
	Post-	7.63 ± 0.54	1.76 ± 0.10	4.33 ± 0.27	0.123 ± 0.008	0.112 ± 0.010
	p, ES	0.073, 0.52	0.478, 0.20	0.597, 0.15	0.072, 0.52	0.362, 0.25
	(95% CI)	(−1.07–0.05)	(−0.72–0.34)	(−0.39–0.67)	(−0.05–1.07)	(−0.29–0.78)
25–30 m	Pre-	7.80 ± 0.60	1.82 ± 0.10	4.29 ± 0.27	0.119 ± 0.007	0.117 ± 0.010
	Post-	7.75 ± 0.59	1.82 ± 0.09	4.27 ± 0.27	0.120 ± 0.009	0.116 ± 0.008
	p, ES	0.258, 0.32	0.723, 0.10	0.561, 0.16	0.113, 0.45	0.502, 0.18
	(95% CI)	(−0.80–0.21)	(−0.62–0.43)	(−0.37–0.68)	(−0.11–1.00)	(−0.71–0.35)

Table 3. Mean ± SD of the kinematic characteristics of baseline and post-intervention 30 m sprints in the ALB (alternate-leg horizontal bounding) condition.

ALB Condition		Velocity (m/s)	Step Length (m)	Step Frequency (Hz)	Contact Time (s)	Flight Time (s)
0–5 m	Pre-	3.53 ± 0.21	1.08 ± 0.09	3.30 ± 0.36	0.163 ± 0.009	0.080 ± 0.013
	Post-	3.60 ± 0.24	1.08 ± 0.08	3.36 ± 0.32	0.165 ± 0.010	0.078 ± 0.014
	p, ES	0.017, 0.73	0.815, 0.06	0.028, 0.66	0.176, 0.38	0.587, 0.15
	(95% CI)	(−0.13–1.31)	(−0.46–0.59)	(0.07–1.23)	(−0.17–0.92)	(−0.38–0.67)
5–10 m	Pre-	6.40 ± 0.35	1.46 ± 0.10	4.38 ± 0.29	0.136 ± 0.009	0.097 ± 0.014
	Post-	6.39 ± 0.35	1.46 ± 0.11	4.39 ± 0.29	0.136 ± 0.009	0.096 ± 0.012
	p, ES	0.758, 0.08	0.676, 0.11	0.737, 0.09	0.774, 0.08	0.572, 0.16
	(95% CI)	(−0.44–0.61)	(−0.41–0.64)	(−0.62–0.44)	(−0.45–0.60)	(−0.38–0.68)
10–15 m	Pre-	7.21 ± 0.40	1.62 ± 0.11	4.47 ± 0.31	0.127 ± 0.009	0.103 ± 0.012
	Post-	7.18 ± 0.41	1.62 ± 0.11	4.45 ± 0.27	0.127 ± 0.008	0.105 ± 0.012
	p, ES	0.432, 0.22	0.912, 0.03	0.670, 0.12	0.593, 0.15	0.155, 0.40
	(95% CI)	(−0.32–0.74)	(−0.49–0.50)	(−0.41–0.64)	(−0.38–0.67)	(−0.15–0.94)

Table 3. *Cont.*

ALB Condition		Velocity (m/s)	Step Length (m)	Step Frequency (Hz)	Contact Time (s)	Flight Time (s)
15–20 m	Pre-	7.51 ± 0.45	1.73 ± 0.10	4.35 ± 0.28	0.125 ± 0.009	0.107 ± 0.011
	Post-	7.50 ± 0.47	1.71 ± 0.12	4.41 ± 0.32	0.123 ± 0.008	0.109 ± 0.011
	p, ES	0.926, 0.03	0.126, 0.43	0.104, 0.47	0.117, 0.45	0.331, 0.27
	(95% CI)	(−0.50–0.55)	(−0.12–0.98)	(−1.01–0.09)	(−0.11–0.99)	(−0.27–0.80)
20–25 m	Pre-	7.68 ± 0.51	1.77 ± 0.11	4.35 ± 0.30	0.123 ± 0.008	0.110 ± 0.011
	Post-	7.71 ± 0.52	1.77 ± 0.11	4.35 ± 0.31	0.121 ± 0.008	0.111 ± 0.011
	p, ES	0.417, 0.22	0.698, 0.11	0.824, 0.06	0.145, 0.41	0.153, 0.41
	(95% CI)	(−0.31–0.75)	(−0.63–0.42)	(−0.58–0.47)	(−0.14–0.95)	(−0.15–0.95)
25–30 m	Pre-	7.81 ± 0.56	1.83 ± 0.08	4.26 ± 0.27	0.121 ± 0.009	0.116 ± 0.008
	Post-	7.86 ± 0.59	1.82 ± 0.11	4.32 ± 0.29	0.120 ± 0.008	0.117 ± 0.010
	p, ES	0.177, 0.38	0.579, 0.15	0.108, 0.46	0.252, 0.32	0.558, 0.16
	(95% CI)	(−0.17–0.92)	(−0.38–0.68)	(−1.01–0.10)	(−0.22–0.85)	(−0.37–0.69)

Table 4. Mean ± SD of the kinematic characteristics of baseline and post-intervention 30 m sprints in the SLB (single-leg horizontal bounding) condition.

SLB Condition		Velocity (m/s)	Step Length (m)	Step Frequency (Hz)	Contact Time (s)	Flight Time (s)
0–5 m	Pre-	3.58 ± 0.23	1.07 ± 0.09	3.36 ± 0.35	0.165 ± 0.011	0.076 ± 0.013
	Post-	3.61 ± 0.22	1.07 ± 0.08	3.40 ± 0.34	0.168 ± 0.010	0.073 ± 0.013
	p, ES	0.066, 0.53	0.376, 0.25	0.068, 0.53	0.420, 0.22	0.060, 0.55
	(95% CI)	(−0.04–1.09)	(−0.29–0.77)	(−0.04–1.09)	(−0.31–0.75)	(−0.02–1.11)
5–10 m	Pre-	6.35 ± 0.25	1.45 ± 0.09	4.40 ± 0.22	0.133 ± 0.006	0.097 ± 0.010
	Post-	6.33 ± 0.30	1.43 ± 0.10	4.42 ± 0.26	0.136 ± 0.008	0.094 ± 0.012
	p, ES	0.479, 0.20	0.309, 0.28	0.453, 0.21	0.078, 0.51	0.069, 0.53
	(95% CI)	(−0.34–0.72)	(−0.26–0.81)	(−0.33–0.73)	(−0.06–1.06)	(−0.04–1.08)
10–15 m	Pre-	7.18 ± 0.36	1.62 ± 0.09	4.43 ± 0.24	0.125 ± 0.006	0.105 ± 0.008
	Post-	7.16 ± 0.38	1.60 ± 0.11	4.48 ± 0.30	0.128 ± 0.008	0.102 ± 0.013
	p, ES	0.123, 0.44	0.150, 0.41	0.219, 0.35	0.062, 0.55	0.058, 0.56
	(95% CI)	(−0.12–0.98)	(−0.15–0.95)	(−0.20–0.88)	(−0.03–1.10)	(−0.02–1.11)
15–20 m	Pre-	7.48 ± 0.40	1.71 ± 0.09	4.39 ± 0.21	0.122 ± 0.006	0.107 ± 0.008
	Post-	7.44 ±0.41	1.69 ± 0.10	4.41 ± 0.28	0.123 ± 0.008	0.105 ± 0.112
	p, ES	0.057, 0.56	0.112, 0.46	0.505, 0.18	0.306, 0.29	0.233, 0.33
	(95% CI)	(−0.02–1.12)	(−0.10–1.00)	(−0.35–0.71)	(−0.26–0.82)	(−0.21–0.87)
20–25 m	Pre-	7.65 ± 0.43	1.76 ± 0.09	4.35 ± 0.22	0.120 ± 0.007	0.112 ± 0.007
	Post-	7.59 ± 0.42	1.74 ± 0.11	4.37 ± 0.28	0.121 ± 0.007	0.111 ± 0.010
	p, ES	0.074, 0.52	0.175, 0.38	0.787, 0.07	0.534, 0.17	0.501, 0.19
	(95% CI)	(−0.05–1.07)	(−0.17–0.92)	(−0.45–0.60)	(−0.36–0.70)	(−0.35–0.71)
25–30 m	Pre-	7.76 ± 0.46	1.80 ± 0.10	4.32 ± 0.20	0.119 ± 0.007	0.115 ± 0.008
	Post-	7.68 ± 0.44	1.78 ± 0.09	4.31 ± 0.27	0.119 ± 0.007	0.115 ± 0.011
	p, ES	0.076, 0.52	0.178, 0.38	0.770, 0.08	0.682, 0.11	0.830, 0.06
	(95% CI)	(−0.05–1.07)	(−0.17–0.92)	(−0.45–0.60)	(−0.42–0.64)	(−0.58–0.47)

4. Discussion

The purpose of the present study was to investigate the effects of sprint-specific plyometrics on performance and kinematics throughout the sprint acceleration phase. The main findings of this study partially supported our hypothesis, indicating that the execution of alternate-leg horizontal bounding resulted in an improvement in subsequent 5 m and 10 m sprint performance by 1.7% and 1.1%, respectively, compared to the baseline. In addition, the athletes' running velocity increased by 1.9% in the first 0–5 m of the sprint; however, no significant change in the performance occurred following single-leg horizontal bounding.

The results of this study confirm previous findings on the effectiveness of plyometric exercises in inducing a PAP effect. Turner et al. [9] indicated improvements in 10 m and 20 m sprint times 4 and 8 min after performing alternate-leg horizontal bounding with and without a weighted vest (10% of body mass) in trained males. Additionally, an observed 1.6% improvement in running velocity at 10 m was similar to the present study, while weighted exercise resulted in a greater improvement (2.5%). Byrne et al. [12] investigated the acute effects of drop jumps on 5, 10 and 20 m sprint performance in male hurling players. Consistent with the results of this study, a significant improvement in performance was found only in the 5 and 10 m sprint times at 4 and 12 min of recovery, and the greatest decrease in sprint times occurred at 5 m (2.34–3.33%) compared to 10 m (1.42–2.13%); however, other studies have failed to show a significant enhancement in performance in the first 10 m of the acceleration phase via the use of tuck jumps and squat jumps with an external load of 13% body mass as conditioning activities [29,30]. A possible explanation for these findings could be the lack of the biomechanical similarity of these exercises when compared to sprinting. Tuck jumps involve a vertical impulse, whereas sprinting requires large amounts of horizontal impulses to develop running velocity as quickly as possible [17]. Previous studies have reported that horizontal leg bounding has a similar biomechanical pattern to sprinting and exhibits similar ground contact times in the first meters of sprint acceleration [15,16]; therefore, the greatest effect of this plyometric exercise on performance probably occurs in the early phase of acceleration, which includes an athlete's start and first steps during sprinting [25].

The improvement in performance only occurred in the first 5 and 10 m of the sprint, while there was no significant change in the overall 30 m performance. The findings in the existing literature on the acute effect of plyometric exercises on the 20 m distance are conflicting. Studies have shown improvements in 20 m sprint performance using hurdle jumps, depth jumps, and weighted squat jumps as conditioning exercises [13,14,31]; however, other studies have failed to induce a PAP effect in 20 m and 30 m distance performance with plyometrics [21,29,30]. The differences in these study findings can be attributed to methodological issues, such as the type of plyometric exercise, the volume and intensity of the conditioning exercise, the recovery duration, and the level of athletes [22,32]. Furthermore, an athlete's response to a PAP protocol seems to be highly individualized, with some athletes enhancing their performance following the conditioning exercise while the performance of others is not affected [22,30]. The phenomenon of a response or non-response to PAP is also found in the present study. Performance improvements were presented in 11 and 10 of the 14 participants at 5 and 10 m, respectively.

The PAP effect that occurred in the present study could be attributed to the increased neural activation and the greater recruitment of higher-order motor units [4,5]. Horizontal leg bounding is an explosive exercise, and the increased recruitment of type II muscle fibers of the muscles involved in sprinting [33] could lead to higher force production and explain the reduction in sprint time that occurred at 5 and 10 m. In addition, the phosphorylation of myosin light chains, which increases the rate of muscle contraction, could contribute to the induction of PAP [5,34]. Muscle fatigue and PAP coexist within the muscle after performing a PAP protocol [35]. Seitz and Haff [22] indicated that the greatest improvement in performance occurs after 5–7 min of recovery; however, the volume of the conditioning activity and the level of the athletes should be considered in order to determine the appropriate rest interval [32]. The 5 min recovery between the alternate-leg horizontal bounding and the subsequent 30 m sprint applied in this study were sufficient to significantly enhance the 5 m and 10 m sprint performance; however, performing single-leg horizontal bounding did not cause significant changes in performance. It is possible that the 5 min of recovery was not sufficient for PAP to prevail in the SLB due to the greater fatigue produced in the lower limbs and the level of the athletes.

In the present study, sprint kinematics were evaluated over the entire 30 m distance. The average step frequency of the athletes at 0–5 m was significantly higher after performing alternate-leg horizontal bounding compared to the baseline sprint. This finding indicates that the increase in velocity presented in the first 5 m of the sprint in the ALB condition was mainly the result of a significant increase in the athletes' step frequency. No significant systematic changes were found for step length as well as flight and ground contact times. The increase in step frequency in the initial phase of acceleration suggests that, after performing alternate-leg horizontal bounding, changes in the function of the motor units could be caused. The higher step frequency requires increased neural activation of the muscles, resulting in a higher firing rate of the cross-bridges cycle [18]. Consequently, high power levels are produced in a short time and achieved a faster turnover of the legs [18]. In addition, Hunter et al. [19] examined the relationship between step length and frequency in repeated 25 m sprints in athletes and found that they tended to perform their fastest sprint with a higher step frequency rather than a longer step length. According to the researchers, achieving a higher running velocity by increasing step length requires long-term improvement in muscle strength and power, while step frequency may affect performance in the short term. A previous study also found an acute increase in step frequency (3.3%) and 60 m sprint performance (3.2%) after running over mini-hurdles [20]; however, there are methodological differences compared to the present study, since Yoshimoto et al. [20] calculated step frequency as the number of steps/s per 10 m intervals. Another study found no acute effect of maximal hops on a sprinter's acceleration performance and on step length as well as contact time in the first 10 m of a sprint [21]. Research data regarding acute alterations in sprint kinematic characteristics are limited; therefore, further research would be needed to verify the findings of the present study.

5. Conclusions

This study demonstrated that sprint-specific plyometrics that emphasize a horizontal impulse are effective conditioning activities to acutely enhance the initial acceleration phase performance. Alternate-leg horizontal bounding can be used to improve performance in the first 10 m of acceleration. This type of exercise also causes an increase in running velocity accompanied by a corresponding increase in step frequency. In conclusion, alternate-leg horizontal bounding can be used effectively to improve performance in the initial phase of sprint acceleration.

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