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Intraindividual Effects of Take-Off Distance on Hurdling and Interval Running in Sprint Hurdles

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Abstract: Purpose: This study explores the impact of take-off distance on hurdling and interval running kinematics in sprint hurdles, recognizing its potential to improve performance. While beginners often use shorter take-off distances, a deeper understanding could inform coaching strategies aimed at improving hurdle technique. **Methods**: Ten male elite and highly trained hurdlers ran 60 m hurdles under original, short, and long take-off distances (OTD, STD, and LTD, respectively). The sagittal plane kinematics of the fourth hurdle and interval running were obtained using two high-speed cameras at a rate of 120 frames per second. Intraindividual step parameters were compared between conditions. **Results**: Running speed and step frequency were significantly lower in the STD than in the OTD and LTD. Significant interactions were found for step length with a significantly longer recovery step length in the STD than in the LTD. Furthermore, the hurdling distance was significantly longer in the LTD than in the OTD. In addition, the touchdown distance was significantly shorter in the LTD and longer in the STD compared to the OTD. Therefore, an STD is associated with a shorter acceleration distance between hurdles, whereas an LTD is associated with a longer acceleration distance. Therefore, the take-off distance influenced the distance for acceleration between hurdles, and the recovery step was related to the take-off distance. **Conclusions**: STD has negative effects on hurdling and interval running, even among elite and highly trained hurdlers.

Keywords: step length; changing exercise conditions; intraindividual comparison; sports performance

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1. Introduction

Hurdle running is an athletic event that involves covering a specified distance while overcoming obstacles. Its distinctive feature, which is crucial for successful hurdle running [1], is hurdle clearance, as opposed to flat sprinting. Biomechanical studies have evaluated hurdle-clearing techniques in elite athletes from various perspectives. The most important aspect of the hurdling technique is the trajectory of the whole body's center of mass (CoM). A key biomechanical consideration is the take-off distance to the hurdle, which should be extended to maximize vertical velocity while preserving horizontal velocity [2]. The take-off distance in elite men's 110 m hurdlers is 1.91–2.23 m [3–5]. Since the hurdle height is fixed, smaller take-off distances require steeper take-off angles. As vertical velocity

increases, horizontal velocity decreases during take-off [1]. Previous studies [1,6] have indicated that an optimal ratio of the take-off and touchdown distances allows sufficient space to rapidly extend the lead leg anteriorly prior to crossing the hurdle. Some authors have reported an optimal ratio of almost 60–65:35–40 [6–9], which allows the CoM to reach its maximum height before the hurdle [4].

Hurdling and interval running demonstrate interrelations. At a given interval distance and number of steps, the hurdling distance and the ratio of take-off to touchdown distances affect the step length during the interval section. Gonzalez-Frutos et al. [10] compared the take-off and landing distances between elite and high-level hurdlers and found that elite hurdlers exhibited a greater take-off distance and a shorter touchdown distance. Rowley et al. [6] compared seven- and eight-step approaches and found that the seven-step approach increased the take-off distance and reduced the touchdown distance, enhancing the distance covered during interval running. A longer touchdown distance might limit the step strategy during interval running. Similarly, the take-off distance might affect the degree of freedom in step strategy during interval running.

Previous studies have suggested the potential benefits of a long take-off distance (LTD) for improved performance. However, these studies [3–5] primarily focused on world-class athletes and were observational in nature, relying on race analysis rather than randomized controlled trials. While these studies suggest potentially effective techniques, they do not provide sufficient evidence to conclusively demonstrate their efficacy or explain how individuals can develop and enhance hurdling skills. Moreover, although these studies highlight effective techniques, they lack insights into how individuals can systematically acquire and enhance hurdling skills. LTD is a difficult technique for beginners, who often use a shorter take-off distance. An understanding of the effects of take-off distance on hurdling and interval running would be useful for the development of successful coaching methods for hurdles. When considering sports techniques, cross-sectional studies are useful for identifying desirable techniques across a population. However, substantial anatomical, biomechanical, and neuromuscular variability among athletes suggests that optimal techniques may differ on an individual basis. Techniques that are effective for one athlete may not be transferable to others, particularly those at different performance levels. Given the inherent limitations of cross-sectional studies, an intraindividual study seems essential for exploring individual movement and the mechanisms underlying optimal techniques. Group cohort studies also have the potential to provide insights into how athletes acquire better techniques. However, it becomes difficult to evaluate technique acquisition if the intended changes in techniques are not observed. Bartlett et al. [11] emphasized the need for an intraindividual study, rather than an interindividual study, to provide useful information regarding performance optimization in novice and elite athletes. Intraindividual studies allow for a more nuanced exploration of technique plasticity, providing valuable insights into how athletes can learn, adapt, and optimize their performance based on their unique characteristics. Indeed, previous intraindividual studies have enhanced the understanding of exercise mechanics. A study involving running at various inclinations demonstrated that the knee and ankle joints are key factors for running economy [12]. A long jump study comparing different take-off boards suggested a new training tool for long jump techniques [13,14]. These findings suggest that intraindividual studies could also play a crucial role in understanding and refining hurdling techniques. However, the intraindividual effects of take-off distance on hurdling and interval running are unclear. For intraindividual comparisons, this study focused on the take-off distance, an important variable in hurdling technique [15]. Therefore, the purpose of the present study was to investigate the intraindividual effects of take-off distance on hurdling and interval running in sprint hurdles. It was hypothesized that (1) shorter and longer take-off distances would

result in higher and lower amounts of deceleration of horizontal velocity during take-off, respectively. As a result, running speed would be lower with shorter take-off distances and higher with longer take-off distances; and (2) take-off distances would affect step length during interval running.

2. Materials and Methods

2.1. Participants

Participants were recruited from the track and field club of a university. Eligibility criteria included athletes with official records in either the 110-m hurdles or 400-m hurdles and those who were currently training at least five days per week. Among the 14 athletes who met these criteria, 10 agreed to participate in the present study. The sample size was chosen based on the sample sizes used in similar studies [16,17].

The final sample consisted of 10 male student athletes, classified as elite and highly trained hurdlers (age: 20.5 ± 1.0 years, height: 1.79 ± 0.05 m, body mass: 69.8 ± 2.6 kg, personal best 110 m hurdle race time: 15.23 ± 0.76 s). Based on the classification by McKay et al. [18], the participants included two elite (tier 4) and eight highly trained athletes (tier 3).

Prior to their inclusion in the study, the participants provided voluntary informed consent. The study protocol was approved by the Ethics Committee of the College of Humanities and Sciences, Nihon University, Japan (approval No. 04-19). The study was conducted in accordance with the Declaration of Helsinki.

2.2. Procedures

Before the measurements, each participant completed a self-selected warm-up lasting between 10 and 30 min. The warm-up included activities such as jogging, drills, sprinting, hurdle running, and practicing the trial tasks described later. Figure 1 presents the experimental setup and important terms. The participants ran 60 m hurdles from the starting blocks under three take-off distance conditions (original (OTD), short (STD), and LTD). The interval distance was set at 9.14 m in accordance with the men's 110 m hurdles under the World Athletics (WA) regulations. The present study set hurdle heights at 0.914 m to mitigate the risks of hitting hurdles and collisions with the official hurdle height (1.067 m) specified by WA under unnatural take-off distance conditions. The OTD condition represented the natural take-off distance of the participants. The STD and LTD were shorter and longer than the OTD, respectively. Given that previous studies have revealed take-off distances of approximately 2 m [4], it was assumed that the OTD was approximately 2 m, and guide marks were placed at 1.5 m from the hurdle to mark the take-off distance for an STD and at 2.5 m from the hurdle for an LTD. In our pilot study, we tried using the participants' specific guide marks. As a result of that, it was found that it was difficult to adjust the take-off position accurately, but it was possible to distinguish the take-off distance using the same guide mark position. The guide marks were placed for each hurdle except for the first one because it was challenging to adjust the take-off distance with only the first hurdle, as demonstrated by the pilot experiment. In addition, reference points to transform pixels to metrics were set at every 2.0 m on both sides of the runway. During participant recruitment, we provided details of the measurement conditions and asked the participants to familiarize themselves with these conditions. We also offered an opportunity for participants to familiarize themselves with the STD and LTD conditions during warm-up. The participants initially ran in the OTD, followed by the STD and LTD conditions, with the trial order randomized. Ample rest was provided between trials (at least 5 min). All measurements were conducted on the same day. The participants were not provided with specific training or dietary guidelines. The participants wore short tights and their own spike shoes. High-speed cameras (ILCE-6500, Sony Corp., Tokyo, Japan)

were used to record hurdling and interval running at a rate of 120 frames per second. These cameras were positioned laterally at the fourth hurdle and at the mid-point between the fourth and fifth hurdles, as this section typically exhibits the maximal running speed for elite hurdlers [19].

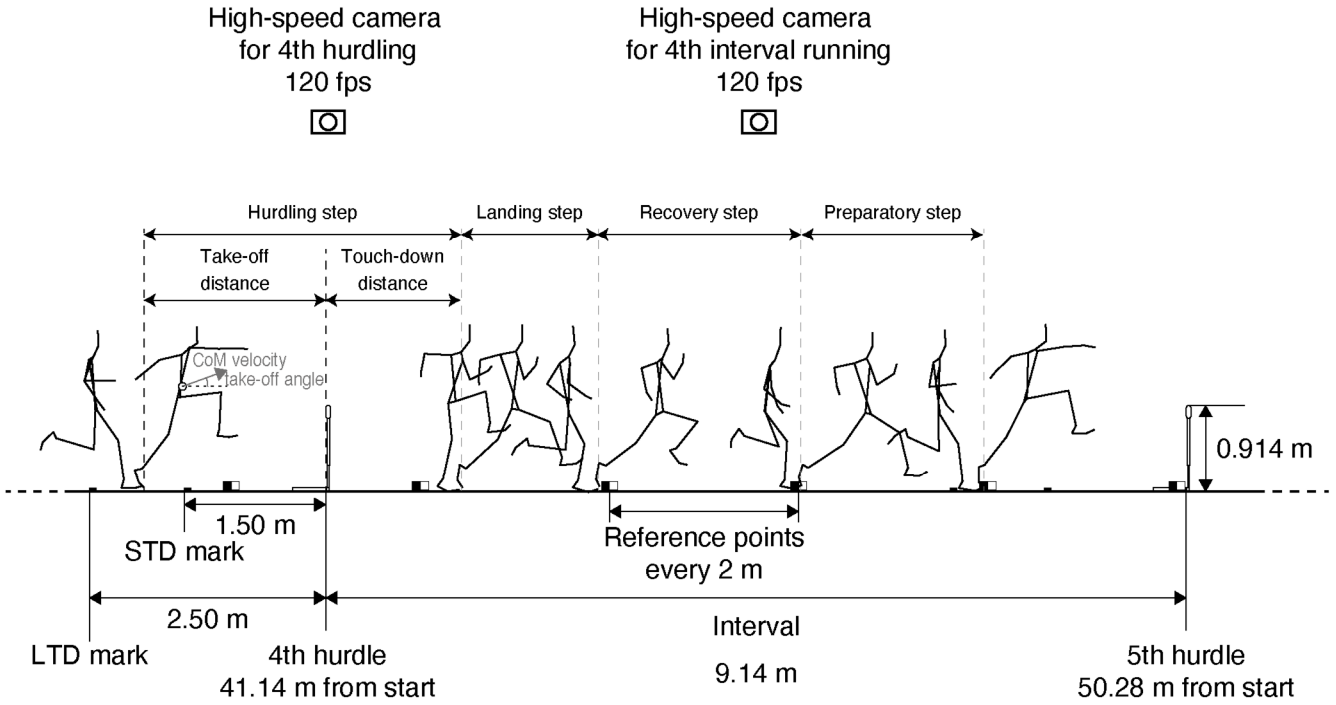


Figure 1. Experimental setup for 60 m hurdles and important terms.

2.3. Analysis

Two-dimensional coordinates were obtained by digitizing anatomical landmarks (toes, head of the fifth metatarsal bone, heels, ankles, knees, hips, hands, wrists, elbows, shoulders, head, ear, and sternum) and the reference points using video analysis software (Frame-DIAS 6, Q's fix, Tokyo, Japan) at a rate of 120 Hz. The coordinates of the landmarks were transformed from the camera coordinate system into the ground coordinate system according to the distance between the reference points. After residual analysis of each point, the coordinate data were smoothed using a Butterworth low-pass digital filter at 3.6–10.8 Hz with a mean cutoff frequency of 9.8 ± 1.3 Hz [20]. The estimated location of the CoM of body segments was obtained [21].

One step was defined from the foot strike of one foot to the subsequent foot strike of the other foot. The steps of the interval running following the fourth hurdle were defined as the landing, recovery, and preparatory steps, in that order [3] (Figure 1). Step length indicated the distance between the toe of the supporting leg at foot strike and the toe of the supporting leg at the next foot strike. The hurdling step length was determined as the horizontal distance between the toe of the take-off leg and the toe of the landing leg (i.e., landing step). Step frequency was reciprocal to the duration of a single step (from one foot strike to the next foot strike). Running speed was computed by multiplying step length and frequency. Take-off distance referred to the distance between the toe of the take-off leg and the fourth hurdle. Landing distance indicated the distance between the fourth hurdle and the toe of the landing leg. The maximal CoM height was determined as the maximal height of the body's CoM during the flight phase of the hurdling step. The horizontal position of the CoM at its maximal height was the relative position of the body's CoM to the fourth hurdle. The CoM velocity was determined by differentiation of the body's CoM coordinate. The amount of deceleration of horizontal velocity of the CoM during take-off

was computed as the difference in the horizontal velocity of the body's CoM between the foot strike and the minimal value.

2.4. Statistical Analysis

The data are presented as the means ± standard deviations (SDs). Statistical analysis was performed using SPSS software version 28.0 (IBM Corp., Armonk, NY, USA). The normality of the data distribution was evaluated using the Shapiro–Wilk test. Two-way ANOVA for repeated measures was used to evaluate the effects of step × condition on step parameters (step length, frequency, and speed). The step factor is not a testing variable, but we adopted a two-way ANOVA to avoid an excessive number of repeated one-way ANOVA. One-way ANOVA for repeated measures was used to determine the effects of the condition on hurdling variables. The homogeneity of variance was evaluated using Mauchly's test of sphericity. The lack of sphericity was accounted for by adjusting the degrees of freedom before performing an F-test. Multiple comparisons were conducted using Fisher's least significant difference test in cases where the main effect was significant. The level of statistical significance was set at 5%. In addition, Cohen's d was used to evaluate the effect size for differences between the two conditions, and the effect sizes were categorized as trivial ($d < 0.2$), small ($0.20 \leq d < 0.50$), medium ($0.50 \leq d < 0.80$), or large ($0.8 \leq d$) [22].

3. Results

Table 1 presents the descriptive statistics for hurdling variables and the results of ANOVA. The amount of deceleration of horizontal velocity of the CoM during take-off did not differ between the conditions ($F(2, 18) = 0.03$, $p = 0.975$). The take-off angle was significantly greater in the STD ($d = 0.53$, $p = 0.049$) and LTD ($d = 0.77$, $p = 0.001$) than in the OTD ($F(2, 18) = 6.58$, $p = 0.007$).

Table 1. Descriptive statistics and results of one-way ANOVA of the representative variables.

Variable	STD	OTD	LTD	df	F	*p*
Take-off distance (m)	1.81 ± 0.15 ‡,§	2.09 ± 0.17	2.39 ± 0.12 ‡	2 18	54.21	<0.001
Touchdown distance (m)	1.89 ± 0.24 ‡,§	1.57 ± 0.25	1.42 ± 0.18 ‡	2 18	35.94	<0.001
Take-off angle (deg)	15.2 ± 2.5 ‡,§	14.1 ± 2.0	15.6 ± 2.1 ‡	2 18	6.58	0.007
Maximal CoM height during hurdling (m)	1.33 ± 0.06 ‡	1.28 ± 0.03	1.31 ± 0.04 ‡	2 18	5.85	0.011
Relative horizontal position of the CoM to the hurdle at the maximal CoM height (m)	0.17 ± 0.22 ‡,§	−0.13 ± 0.26	−0.43 ± 0.18 ‡	2 18	30.67	<0.001
Amount of deceleration of horizontal velocity of the CoM during take-off (m/s)	0.47 ± 0.21	0.47 ± 0.24	0.49 ± 0.25	2 18	0.03	0.975

‡: $p < 0.05$, significant difference from the OTD. §: $p < 0.05$, significant difference from the LTD.

Figure 2 presents the step speed, length, and frequency of the three conditions (STD, OTD, and LTD). No significant interaction was found for the step speed ($F(6, 54) = 0.708$, $p = 0.645$), whereas a significant main effect was observed for the condition ($F(2, 18) = 9.45$, $p = 0.002$). The step speed was significantly faster in the OTD ($d = 0.85$, $p = 0.008$) and LTD conditions ($d = 0.65$, $p = 0.008$) compared to the STD. A significant interaction was observed for the step length ($F(6, 54) = 4.41$, $p = 0.002$). The hurdling step length was significantly longer in the LTD than in the OTD ($d = 1.07$, $p = 0.010$). The recovery step length was

significantly shorter in the LTD than in the STD (d = 0.81, $p = 0.024$). The take-off to landing ratios were 49:51, 57:43, and 63:37 in the STD, OTD, and LTD conditions, respectively. No significant interaction was found in the step frequency (F (6, 54) = 2.07, $p = 0.073$), whereas a significant main effect was observed for the condition (F (2, 18) = 8.59, $p = 0.002$). The step frequency was significantly lower in the STD than in the OTD (d = 0.23, $p = 0.028$) and LTD (d = 0.22, $p = 0.001$). Figure 3 presents a summary of the hurdling variables.

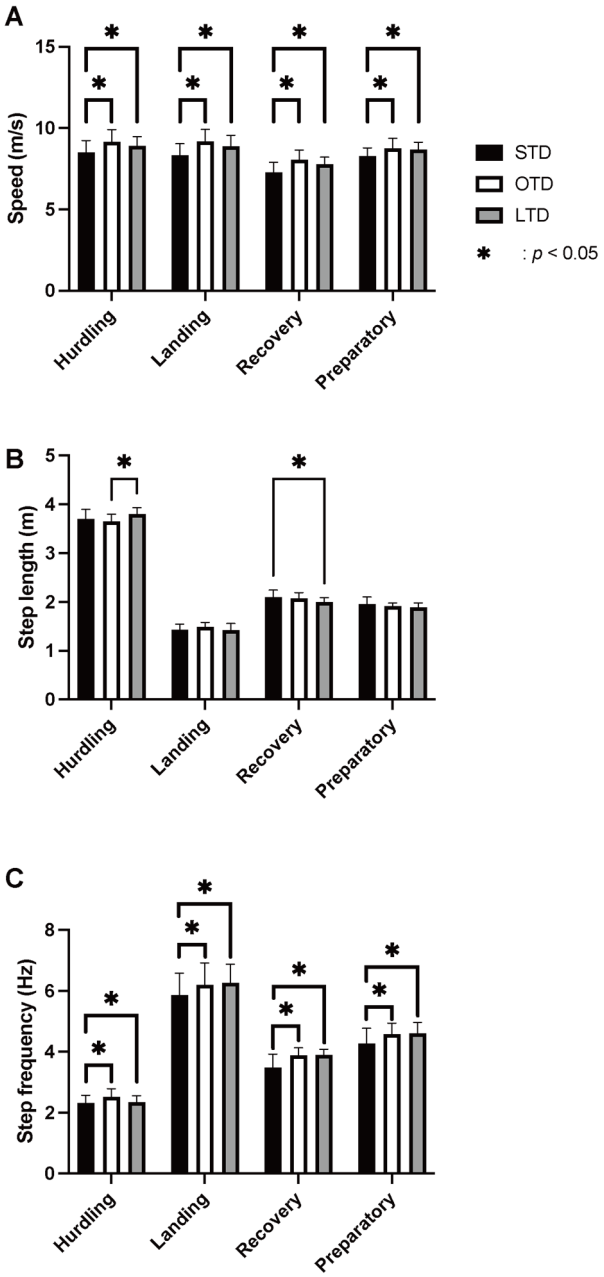


Figure 2. (**A**): running speed, (**B**): step length, and (**C**): step frequency in each experimental condition and multiple comparisons among the conditions. The results of multiple comparisons between the steps follow. Running speed was significantly faster in the hurdling and preparatory steps than in the recovery step ($p < 0.001$). Step lengths were greater in the hurdling step, followed by the recovery, preparatory, and landing steps. Significant differences were observed between all steps in the OTD ($p < 0.001$–0.006), but only between the preparatory and recovery steps in the STD and LTD conditions. Step frequency was higher in the landing step, followed by the preparatory, recovery, and hurdling steps, with significant differences between all steps ($p < 0.001$).

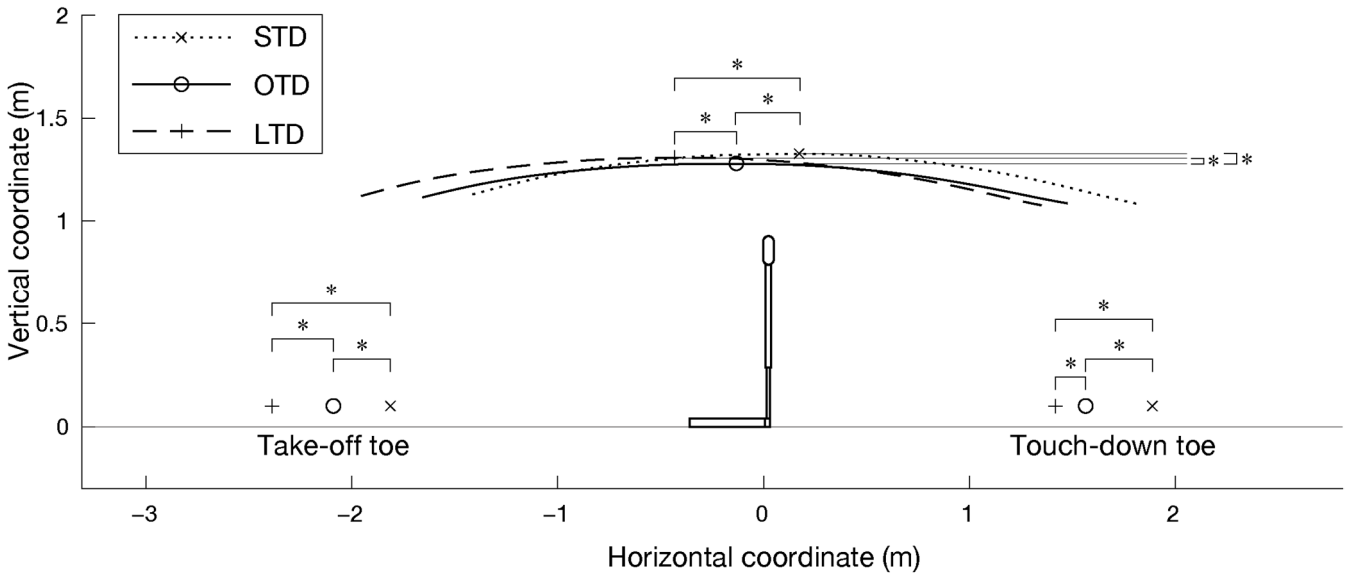


Figure 3. Summary of the hurdling variables. *: $p < 0.05$.

4. Discussion

The aim of the study was to evaluate the intraindividual effects of the take-off distance on hurdling and interval running in sprint hurdles. The main findings follow. First, the amount of deceleration of horizontal velocity of the CoM during take-off was not significantly different between the conditions. Second, the step speed and step frequency were significantly higher in the OTD and LTD than in the STD. Third, the take-off angle was significantly greater in the STD and LTD than in the OTD. Fourth, the hurdling distance was significantly longer in the LTD than in the OTD. Finally, the recovery step length was significantly longer in the STD than in the OTD.

No significant differences were observed between the conditions in the amount of deceleration of horizontal velocity of the CoM during take-off. Previous studies demonstrated that the horizontal velocity decreases with an increase in vertical velocity during take-off [1]. Therefore, it was anticipated that the horizontal velocity during take-off would demonstrate a greater decrease in the STD than in the other conditions [2]. However, the take-off angle was significantly greater in the STD than in the OTD. In the STD, the shorter distance between the take-off toe and the hurdle suggested a need for a more upward take-off compared to the other conditions. Therefore, there was a discrepancy between the expected amount of deceleration of the horizontal velocity and the observed take-off angle. Notably, the STD demonstrated slower running speeds compared to the OTD and LTD conditions, which might contribute to gaining the vertical velocity and preserving the horizontal velocity during take-off in the STD. Consequently, the initial hypothesis was partly rejected. This hypothesis was based on the assumption of similar horizontal velocities among the conditions. However, the fixed interval distance in hurdle running led to differences between the conditions. Thus, a slower running speed in a race might mitigate the advantages of a smaller amount of deceleration during take-off.

Notably, the amount of deceleration of horizontal velocity in the LTD was not significantly different from the other conditions, despite having a steeper take-off angle and similar running speed compared to the OTD. In the LTD, in which the distance between the take-off toe and the hurdle was longer than usual, the participants were expected to cover a greater distance during the flight phase. The study demonstrated a significantly longer hurdling distance in the LTD than in the OTD. Given that the horizontal velocity was not significantly different between the OTD and LTD conditions, the take-off angle directly affects hurdling (flight). Consequently, these results align with the hypothesis,

which posits that an LTD did not increase the amount of deceleration of horizontal velocity during take-off, even at a greater take-off angle.

The take-off distance might influence the touchdown distance. The touchdown distance was significantly longer in the LTD than in the OTD and STD. The take-off to touchdown ratio was closer to the optimal ratio of 65:35 [1] in the LTD than in the other conditions. These results suggest the existence of a range of optimal ratios in hurdling performance. Indeed, some studies have proposed optimal ratios based on analyses of data obtained during world championships [19,23,24]. Tanigawa and Shibayama [24] suggested that the ratio might not be crucial if athletes can clear a hurdle without decreasing the horizontal velocity. Therefore, the optimal take-off distance range is influenced by the amount of deceleration of horizontal velocity during take-off.

Interval running is influenced by the take-off distance. Rowley et al. [6] suggested that an LTD is associated with a shorter touchdown distance and a longer distance from the touchdown of one hurdle to the take-off of the next hurdle. This suggests that a longer distance provides more room for acceleration between hurdles, facilitating easier body acceleration during interval running. In the present study, the recovery step length was significantly longer in the STD than in the LTD, indicating that the recovery step may affect the step length for the subsequent take-off. Adjusting step length is likely more difficult in the landing and preparatory steps than in the recovery step. McDonald and Dapena [3] revealed that the landing step reduces downward velocity. In the preparatory step, a shorter flight time compared with the other steps is important to avoid disruptions during take-off. Conversely, the recovery step allows for a relatively longer step length in the interval section. Although this step can be adjusted based on the remaining distance to the next hurdle, a longer recovery step in the STD compared with other conditions might disrupt interval running and reduce the running speed. Therefore, STD has negative effects on hurdling and interval running, even among elite and highly trained hurdlers.

The present study examined the effects of the take-off distance for elite and highly trained hurdlers. As widely recognized, an STD has no positive effect on hurdling and interval running; instead, it tends to impair performance. Conversely, while an LTD may introduce slight technical inefficiencies, its impact on hurdling is less detrimental compared to an STD. Moreover, an LTD was associated with a longer acceleration distance, which provides a notable advantage for hurdle running performance. However, elite and highly trained athletes are generally aware of their optimal take-off distance and should avoid unnecessarily elongating it beyond what is effective for their technique and overall performance. If adjustments to the take-off distance are necessary, particular attention should be paid to the relationships between the hurdling step and the interval step, especially the recovery step length. In contrast, take-off distance would be a more critical technical issue for athletes with lower performance levels. Future research should explore the effects of the take-off distance in populations at trained and recreationally active levels.

This study has several limitations. First, all the participants were male elite and highly trained hurdlers, which limits the generalizability of our findings to individuals with varying performance levels and females. Second, the interval distance between hurdles and the hurdle height were fixed at 9.14 m and 0.914 m, respectively. While these dimensions were consistent throughout the study, varying interval distances and hurdle heights might influence step strategies. Notably, male 110 m hurdles and female 100 m hurdles have distinct characteristics, particularly in hurdle height. Although the official hurdle height in men's 110 m hurdles is 1.067 m according to the WA regulations, the present study employed a lower hurdle height, which may have influenced the take-off distance effects. Nonetheless, the primary aim of this study was to elucidate the mechanisms of hurdling

and interval running to provide new insights for coaching methods. Third, this study focused solely on the fourth hurdle and its associated interval. It is plausible that hurdling and interval patterns during the acceleration phase exhibit distinct tendencies, which were not captured here. Fourth, repetitive testing in an intraindividual study design could have induced fatigue or, conversely, learning effects in the participants. To mitigate these factors, the trial order was randomized, and the participants were provided with at least 5 min of rest between the trials. Fifth, the warm-up prior to the trials was not standardized. Finally, the small sample size (n = 10) may limit the generalizability of the findings and reduce statistical power to detect small effect sizes. However, recruiting elite and highly trained athletes for a study requiring high-level hurdling techniques is inherently challenging. These limitations should be considered when interpreting the results of this study.

5. Conclusions

The present study compared the intraindividual effects of the take-off distance on hurdling and interval running in sprint hurdles. STD and LTD influenced the hurdling techniques and interval running. In particular, STD reduced running speed, thereby worsening performance. These differences may be attributed to the recovery step length, which is an important factor for body acceleration [3]; a longer recovery step length is associated with reduced acceleration.

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Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: The dataset is unavailable because of an ethics committee decision.

Conflicts of Interest: The authors declare no conflicts of interest.

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